Environmental Science and Policy Committee

Meeting will be held in the Council Chamber, Level 2, Philip Laing House,
144 Rattray Street, Dunedin

This meeting will be livestreamed to the ORC Official YouTube Channel

Members:
Cr Lloyd McCall (Co-Chair)
Mr Edward Ellison (Co-Chair)
Ms Karen Coutts
Cr Alexa Forbes
Cr Gary Kelliher
Cr Michael Laws
Cr Kevin Malcolm
Cr Tim Mepham
Cr Andrew Noone
Cr Gretchen Robertson
Cr Alan Somerville
Cr Elliot Weir
Cr Kate Wilson

Senior Officer: Richard Saunders, Chief Executive

Meeting Support: Kylie Darragh, Governance Support Officer

04 December 2024 09:00 AM

Agenda Topic | Page

1. WELCOME

2. APOLOGIES

No apologies received at time of publication.

3. PUBLIC FORUM

At the time of publishing no requests to speak had been received.

4. CONFIRMATION OF AGENDA

Note: Any additions must be approved by resolution with an explanation as to why they cannot be delayed until a future meeting.

5. DECLARATION OF INTERESTS

Members are reminded of the need to stand aside from decision-making when a conflict arises between their role as an elected representative and any private or other external interest they might have. The Register of Councillors Pecuniary Interests are published on the ORC website.

6. PRESENTATIONS

At the time of printing no requests to present had been received.

[1] This report presents the findings of a recent study by Tidal Research and NIWA into blue carbon habitats within the Otago Region. Blue Carbon is carbon that is stored within marine habitats and ecosystems such as salt marshes, seagrass intertidal sandflats, soft sediment and kelp forests.
[2] The study provides information on the importance of the ecosystem services provided by blue carbon habitats and the potential for restoration opportunities throughout the Otago region around estuaries, both currently, and under potential future sea level rise scenarios.

This paper documents the regional conservation status of selected fungal species (nonlichenised agarics, boletes and russuloid) in the Otago Region.

10. CLOSURE

Environmental Science and Policy Committee
MINUTES

Minutes of an ordinary meeting of the Environmental Policy and Science Committee held in the Council Chamber, Level 2 Philip Laing House, 144 Rattray Street, Dunedin on Thursday 26 September 2024, commencing at 9:00 AM.

PRESENT

Mr Edward Ellison	*(Chair)*
Ms Karen Coutts	*(online)*
Cr Alexa Forbes	
Cr Gary Kelliher	*(online)*
Cr Lloyd McCall	
Cr Tim Mepham	*(online)*
Cr Andrew Noone	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Alan Somerville	
Cr Elliot Weir	
Cr Kate Wilson	

1. WELCOME
Chair Ellison welcomed Councillors, members of the public and staff to the meeting at 10:30 am with a karakia. Staff present included Richard Saunders (Chief Executive), Tom Dyer, (GM Science & Resilience) online, Joanna Gilroy (GM Environmental Delivery), Amanda Vercoe (GM Strategy and Customer, Deputy CE), Kylie Darragh (Governance Support), and Scott Jarvie (Senior Scientist - Biodiversity).

2. APOLOGIES
It was noted that Cr Laws and Cr Malcom were apologies for this meeting.

3. PUBLIC FORUM
No requests to address the Committee under Public Forum were received.

4. CONFIRMATION OF AGENDA
The agenda was confirmed as published.

5. DECLARATIONS OF INTERESTS
No changes to Councillor Declarations of Interests were noted.

6. PRESENTATIONS
No presentations were held.

7. CONFIRMATION OF MINUTES
Resolution: Cr Weir Moved, Cr McCall Seconded
That the minutes of the Environmental Science and Policy Committee meeting held on 27 June 2024 be received and confirmed as a true and accurate record.
MOTION CARRIED

8. OPEN ACTIONS FROM RESOLUTIONS OF THE COMMITTEE
There are no current open actions for this committee.

Cr Mepham left the meeting at 10:33 am.
Cr Mepham returned to the meeting at 10:40 am.
Cr Robertson left the meeting at 10:47 am.

9. MATTERS FOR CONSIDERATION
9.1. Regional Conservation Status of Birds in Otago
[YouTube 4:28] This paper documented the regional conservation status of birds in the Otago Region. Tom Dyer, GM Science and Resilience, online, and Scott Jarvie, Senior Scientist – Biodiversity was available to respond to questions on the report.

Resolution ESP24-111: Cr Weir Moved, Cr Forbes Seconded
That the Environmental Science & Policy Committee:

1) ***Notes** this report.*
2) ***Notes** that regional threat assessment for other species groups will continue as part of the terrestrial ecology work programme.*

MOTION CARRIED

10. CLOSURE

There was no further business and Chair Edward declared the meeting closed at 11:31 am.

________________________ ________________

Chairperson Date

9.1. Regional Pest Management Plan Review Options

Prepared for:	Environmental Implementation Committee
Report No.	GOV2443
Activity:	Governance Report
Author:	Murray Boardman, Performance and Delivery Specialist and Libby Caldwell, Manager Environmental Implementation
Endorsed by:	Joanna Gilroy, General Manager Environmental Delivery
Date:	4 December 2024

PURPOSE

[1] To present options for the potential review of Otago's Regional Pest Management Plan.

EXECUTIVE SUMMARY

[2] The Regional Pest Management Plan (RPMP) is a statutory requirement under the Biosecurity Act 1993 (the Act). Otago Regional Council (ORC) is the 'deemed management agency' to implement Otago's RPMP under the Act. Council's current RPMP was established by Council resolution on 25th September 2019, with a duration of 2019-2029.

[3] The RPMP needs to be reviewed at least once every 10 years. However, a review can be brought forward. Reasons to bring forward a review include if the plan, or part of it, is failing to achieve its objectives or that relevant circumstances have changed since the plan commenced.

[4] To address some inconsistencies within the current RPMP, implementation challenges, along with the prescriptive approach and the time involved to prepare a new RPMP under the Act, it is recommended the Council undertake a full review of the RPMP prior to the current 10-year timeframe of 2029. This paper presents four options to review the RPMP. Given the potentially extensive requirements to issue a revised or new RPMP and resourcing associated with this, it is necessary to consider timeframes now.

[5] To meet the 10-year requirement, funding has been allocated for the consultation and in updating the RPMP in Year 5 of the Long-Term Plan (LTP) (FY28-29). Some funding is allocated each year of the LTP to contribute to the review of the RPMP in advance of Year 5 of the LTP.

RECOMMENDATION

That the Committee:

1) ***Notes*** *this report.*
2) ***Recommends that the Council approves*** *the recommendation of* ***Option 3A*** *to undertake a full review of the Regional Pest Management Plan (RPMP) and* ***provides*** *staff direction as to the year this would be started.*
    a) ***Notes*** *that the timing of the recommended option may be dependent on when the current Biosecurity Act is amended by Parliament.*

b) ***Notes** that staff will make any necessary adjustments to budgets through the 25/26 Annual Plan process.*

BACKGROUND

[6] Regional Councils have a mandate under Part 2 of the Act to provide regional leadership in activities that prevent, reduce or eliminate adverse effects from harmful species that are present in their region. Otago Regional Council (ORC) is the deemed management agency to implement Otago's RPMP under this part of the Act.

[7] The current RPMP was established by Council resolution on 25th September 2019, with a duration of 2019-2029. Section 77 of the Act enables a RPMP to become operative and remain in force for a period of 10 years. Consequently, the RPMP will need to be reviewed by 24th September 2029.

[8] The RPMP may cease at an earlier date than the ten years if Council declares by public notice that the objectives of the RPMP have been achieved. It may also cease at an earlier date if, following a review, it is revoked.

[9] Section 100D of the Act sets out the obligations to review the RPMP. In the context of this paper, the following obligations under this section are relevant:

a) The RPMP needs to be reviewed at least every 10 years [Section 100D(1)(c)].
b) The RPMP may be reviewed, in part or in whole, if the Council (or Minister) has reason to believe that the plan, or part of it, is failing to achieve its objectives or that relevant circumstances have changed since the plan commenced [Section 100D(2)].
c) A review can be initiated by the Minister, Council or any other person [Section 100D(4)].

[10] Minor changes can be made to the RPMP at the discretion of the Council through a resolution [Section 100G(4)] without going through the requirements of Section 100D.

DISCUSSION

[11] The current RPMP will need to be updated by 24th September 2029. This is a statutory requirement of a review needing to be conducted within 10 years of the RPMP coming into force. To meet this requirement, funding has been allocated to review the RPMP in Year 5 of the current LTP FY28-29.

[12] An assessment into the effectiveness of implementing the current RPMP is presently underway. Results of this assessment will be presented to Council in March 2025. The limitations identified with the RPMP (see below) relate more to the content where the effectiveness review has a focus on ORC's delivery of the RPMP. It would be timely to incorporate any recommendations from the assessment of effectiveness into a wider review of the RPMP, to ensure the lessons learnt are formally captured. For each option presented below the findings of the effectiveness review will be able to be incorporated if relevant.

[13] Staff have identified some limitations with the current RPMP, as outlined in the table below, that reduces its effectiveness to manage pests.

Issue	Example
Rule inconsistencies between different plant species	• Some pest plants have a Good Neighbour Rule yet are non-compliant by presence (contradictory) (e.g. Old Man's Beard). • Some pest plants can be present yet compliant (e.g. ragwort).
Implementation challenges	• wilding conifer rules are challenging to interpret (e.g. scale of the issue) and they don't acknowledge wider issues (e.g. erosion control).
Editing errors	• The rule for gorse includes a typographical error that essentially confuses the new Gorse & Broom free areas with the old Gorse & Broom areas.
Inconsistent terminology with National direction.	• Most rules state 'eliminate' yet this is inconsistent with the programme types in national direction. [1]
Inflexible to the progression of compliance and enforcement procedures	• The current RPMP is not flexible enough to incorporate lessons learnt during implementation.
Duplication of pests	• Wallabies are listed as an eradication pest yet are also listed under site-led (the only pest to appear in dual programmes).
Number of declared pests in ambiguous.	• The RPMP states there are 51 declared pests (see forward) yet Table 2 lists 46, other pages have 42.
Inflexible to add new pests	• The inability to add new pests means the RPMP can become out-of-date.[2]
Changed community expectations about what pests should be included	• Community concerns about pests that are not covered in the plan.

[14] Council also has a Biosecurity Strategy and a Biodiversity Strategy. The interaction between the RPMP and the Biosecurity Strategy is not clear and in some place's overlaps. The Biodiversity Strategy is currently being reviewed and intends to cover Biosecurity as well. This review intends to focus on ensuring there is less overlap with the RPMP and clarity is provided. Any review of the RPMP would ensure that there is improved alignment between the RPMP and the Strategy.

[15] Any review (excluding minor changes) will be a significant investment of time and funding due to the need to meet the requirements of the Act. A full, or partial review will require public consultation and a cost benefit analysis for any organism that is currently, or has the potential to be a, declared a pest in Otago.

[1] 'Eliminate' should only apply to exclusion and eradication programmes. For progressive containment, sustained control and site-led programmes, a term related to the 'reduction in pest density' would seem to be more appropriate.

[2] The inflexibility to add new pests is largely a restriction of the Biosecurity Act, which is currently under review.

[16] The Biosecurity Act is currently under review and is presently out for public consultation. To ensure consistency with the amended Act, it would be preferable for any full review of the RPMP to wait until after the amended Act was passed by Parliament. This will have implications on the timings of which option is preferred. Other Councils nationally are currently, or will be reviewing their own RPMP's including Environment Southland and Environment Canterbury.

OPTIONS

Option 1: Minor changes

[17] Section 100G(4) of the Act allows the RPMP to be amended from time to time by Council resolution without a review under section 100D. A minor change is one that does not have a significant effect on any person's rights and obligations and is not inconsistent with the national direction.

[18] As it is likely the addition or removal of a pest, or modifying pest rules, in the current RPMP will have a material effect on someone's rights and obligations, a minor change would, essentially, be limited to correcting typographical/editing errors and improving internal processes to administer the RPMP. The findings of the effectiveness review will be able to be incorporated if relevant and considered to be 'minor'.

[19] This option would not be able add or remove any pests, or correct any inconsistent terminology related to rules. However, it would be able to be completed in 2-3 months and be the lowest cost.

[20] Under this option a full review would still be required prior to 2029 (e.g. Option 3A or 3B). As this is an interim option, it could be completed before the Biosecurity Act was amended.

Option 2: Partial Review

[21] A partial review of the RPMP is permitted under the Act to address to specific issues. It would allow the opportunity to consider adding or removing specific pests and to correct any inconsistent terminology around the rules. A partial review would also include addressing the issues under Option 1.

[22] A partial review would include public consultation and require cost benefit analysis of any pests to be added or removed. The findings of the effectiveness review will be able to be incorporated if relevant.

[23] This option could be completed in approximately 9-12 months and would have moderate costs but would not likely require a dedicated resources to support it. However, there is the risk of duplicated costs because a full review would still be required. A partial review could be completed before the Biosecurity Act was amended.

[24] As with Option 1, a partial review would be an interim step requiring a full review prior to 2029 (e.g. Option 3A or 3B). This would mean two processes would need to be completed between now and 2029.

Option 3A: Full Review – completed by 2027 (recommended option)

[25] The Act does not prescribe when a full review of the RPMP can be done, except that it must be completed within 10-years of commencement. This means Council could decide to undertake a full review of the plan before 2029.

[26] A full review would consider all regulatory[3] aspects of pest management as per the direction of the Act, including the assessment of any organism that had the potential to be a declared a pest in Otago (e.g. marine pests).

[27] This option would cover any issues that were expected to be addressed in Options 1 and 2. A full review would take into consideration any recommendations from the review into the effectiveness of the current RPMP. It would also enable pests, including marine pests that are not currently included in the RPMP to be included.

[28] Under this option work would commence in the second half of 2025 and likely be completed by 2027. This timeline is based on experience with the timelines for the last review which took 18 months, but staff would look to ensure that the process was as efficient as possible. Undertaking a full review would require dedicated resources to deliver this work. It is also more expensive when compared to options 1 and 2, but funding is set aside for year 5 of the LTP and could be brought forward.

[29] This option would enable the review of the RPMP to be undertaken as soon as it is possible, allow for incorporation of the findings of the effectiveness review, address the current issues with the RPMP and not result in a duplication of processes by not taking any interim steps. It would also ensure that the update to the RPMP was happening closer to when the supporting strategies are being updated.

Option 3B: Full Review – completed by 2028

[30] This option is the same as 3A except the completion date would be in 2028. Under this option work would commence in 2026 and be completed by 2028.

[31] This option would enable the financial cost of this review to be pushed out until the 2027/28 financial year, a year later than proposed in Option 2. Currently in the LTP this is budgeted for in year 5 which is the 2028/29 financial year which brings the review forward one year than has been signed off. However, it would mean longer until any issues with the current RPMP are addressed and may result in continued misalignment with supporting strategies.

[32] The findings of the effectiveness review will be able to be incorporated if relevant.

Option 4: Full review – completed by 2029 (status quo)

[33] As the current RPMP commenced in 2019, there is a requirement under the Act for the RPMP to be reviewed by no later than after 10-years of commencement. This option is the same as Option 3A/B except the date for completion would be set for no later than September 2029.

[34] This option is, in effect, the status quo option and is when has been budgeted to complete this in the LTP. The findings of the effectiveness review will be able to be incorporated if relevant.

[3] Non-regulatory actions would be included as part of the ORC Biosecurity Strategy.

[35] Duration and resourcing would be the same as Option 3A/B.

Option Analysis and Recommended Option

[36] Options 1 and 2 are not considered practical as they are both interim reviews and would still require a full review shortly after. Due to this reason these options are not preferred.

[37] Option 4 is the status quo option which means the current RPMP will continue until 2029. Compared to Option 3A/B, this option delays addressing any existing issues in the RPMP and defers the consideration of other potential pests (e.g. marine pests). Consequently, this option is not preferred.

[38] Option 3A is the preferred option. This brings forward addressing the existing issues in the RPMP and the consideration of potential pests as soon as practical. This option would also mean any interim reviews are not required. The decision for Option 3A or 3B relates solely to the completion date as guided by Council.

[39] One challenge with Option 3A is the unknown timeframe of the Biosecurity Act review. However, this can be addressed by pre-planning to ensure the full review commences as quickly as possible after the amended Biosecurity Act comes into operational effect. Some work can start while the Act is being reviewed such as undertaking cost benefit analysis for individual pests.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[40] The ORC Biosecurity Strategy is being revised and will ensure there is better alignment with the RPMP to reduce the overlap between the documents.

Financial Considerations

[41] $1.5 million of funding has been allocated in 2028/29 LTP budget to undertake a full review. Depending on timing[4], this funding may need to be brought forward. Given their interim nature, additional funding may need to be allocated for Options 1 and 2.

Significance and Engagement Considerations

[42] Option 1 would not require any public engagement considerations. Options 2, 3A/B and 4 would require public consultation.

Legislative and Risk Considerations

[43] The main legislative consideration is the planned amendments to the Biosecurity Act. This is likely to influence the timing of the options, especially for Options 3A or 3B.

Climate Change Considerations

[44] No direct considerations related to climate change. Any climate change effects will be addressed in the cost-benefit analysis for individual pest species.

Communications Considerations

[4] The most critical date is when the amended Biosecurity Act comes into force.

[45] As a partial or full review would require public consultation, an appropriate communication plan would need to be developed.

NEXT STEPS

[46] Prepare workplan based on agreed option, including budget re-allocations to be addressed through Annual Plan if needed.

ATTACHMENTS

Nil

9.2. Biodiversity Monitoring Programme Update

Prepared for:	Environmental Science and Policy Committee
Report No.	GOV2467
Activity:	Governance Report
Author:	Matt Salmon Senior Environmental Technician – Biodiversity Eve Bruhns, Environmental Monitoring Manager
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	4 December 2024

PURPOSE

[1] This paper highlights some of the biodiversity work the Environmental Monitoring (EM) team is involved with at the Otago Regional Council (ORC).

EXECUTIVE SUMMARY

[2] The Environmental Monitoring Team has increased capability in biodiversity monitoring over recent years. This is in response to National Policy Statement requirements for regional councils to map and monitor a range of species and ecosystems.

[3] The EM teams work on biodiversity falls under three main realms: terrestrial, freshwater and the coast/marine. Each of these realms of work are further spilt into species components or ecosystem components.

[4] The field work requires a range of methodologies and techniques, including electric fishing, eDNA sampling, audio recording, and vegetation mapping.

[5] The information the EM team collects or collates inform biodiversity management in the Otago Region.

RECOMMENDATION

That the Committee:

1) ***Notes** this report.*
2) **Notes** that EM teams work on biodiversity will continue as part of established work programmes.

BACKGROUND

[6] Traditionally ORC has had little biodiversity monitoring, with a strong focus on water quality and quantity. Recent legislative drivers including the National Policy Statement for Freshwater Management (NPS-FM; 2020), National Policy Statement for Indigenous Biodiversity (NPS-IB; 2023), and New Zealand Coastal Policy Statement (NZCPS; 2010, also see guidance note 2019) have driven the development of science biodiversity programmes which require EM support.

[7] Approximately four years ago ORC recruited a Senior Environmental Technician – Biodiversity. That position along with some help from summer Temporary Assistants provides the EM support for the Science team biodiversity projects.

[8] Biodiversity monitoring programmes cover the terrestrial, freshwater, and coastal areas.

[9] The terrestrial realm focuses on biodiversity that inhabitants the land. Terrestrial work has two distinct parts, ecosystem work which will become part of a State of the Environment (SOE) monitoring regime, and species monitoring.

[10] The freshwater work stream is engaged with Otago's waterways and wetlands. As with the terrestrial realm, the Freshwater work can be spilt into Ecosystem SOE monitoring, currently starting with wetlands. Work in the freshwater realm also involves species monitoring.

[11] The NZCPS (2010) helps shape the Council's coastal (including marine) work stream. Once again, this realm can be split into ecosystem and species monitoring. Currently there is an SOE estuary monitoring network.

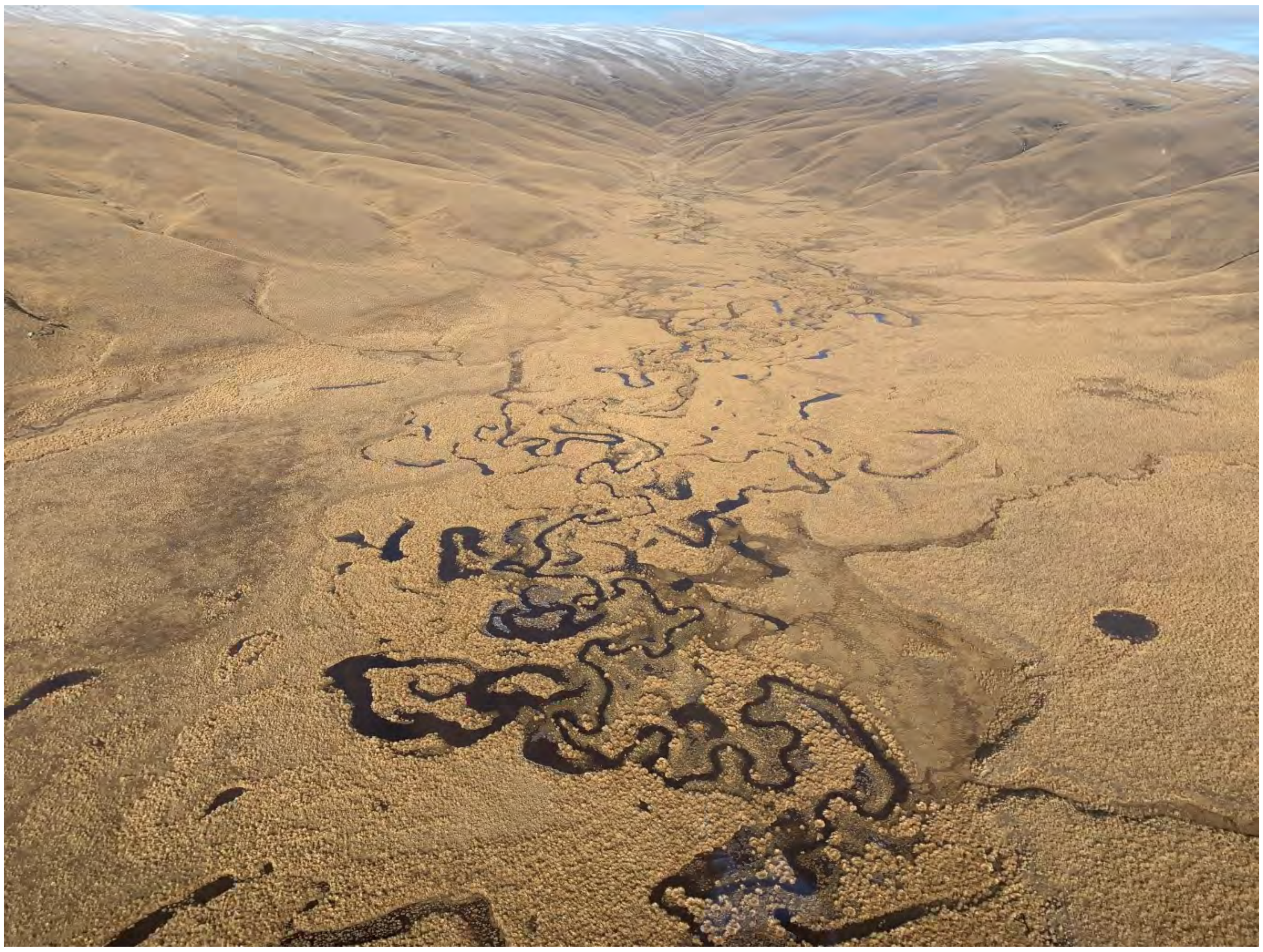


Figure 1: Heading over the Taieri Scroll plain to the Taieri headwater and Beaumont Station - taken during an assessment of fish barriers.

DISCUSSION

[12] The EM team assists the science team with a range of biodiversity surveys, monitoring and mapping programmes. This section highlights some of the work and techniques required to provide field support to the biodiversity programme.

Environmental DNA (eDNA) Surveys

[13] To effectively manage biodiversity, an inventory of organisms found within an area is important. One way of achieving this is to do eDNA surveys. These surveys involve taking

a representative sample of an area of interest (such as a catchment) and analysing any DNA found in that sample to assess what species are present in the environment.

[14] eDNA is becoming a very useful tool for detecting the presence of species and is also a fast-developing technology. Current sampling protocols, developed by the Ministry for the Environment (MfE), for getting the best sampling requires one litre of water to be passed (via a 50ml syringe) through six 4.5-micron filters. If a litre cannot be pushed through, then as much water as possible. The filters are then sent away for analysis.

[15] Using this method two surveys were conducted last summer in Central and Coastal Otago, sites where more biodiversity data was required. The main stem of the Lindis River was divided into 8 sections and each of these sites had a complete eDNA sample taken. 278 species were picked up in this survey; species commonly detected were Upland Bully, Brown Trout and Red Deer. The other survey was carried out in Coastal South Otago streams and rivers. These samples were taken near the mouths of the waterways in 13 different streams/rivers from Brighton to the just north of the Clutha Matau mouth. As in the first survey a full eDNA sample was taken at each site and 458 species were detected, which ranged from New Zealand Sealion - pakake to New Zealand Freshwater Snail.

[16] As an example of the potential for eDNA to help with assessing biodiversity status, the coastal eDNA results revealed a presence of Smeagol Gravel maggot (sub-terranean mollusc). Following the eDNA detection, additional work has been done trying to find a specimen of this little know, uncommon species. This organism lives in a coastal environment, is an air breathing organism, around 2-8mm in length. As gravel maggots have never been recorded in Otago, this could potentially be a new species. This work involves looking through substrate and underneath rocks around rotted kelp close to the high tide mark. ORC has been supported by researchers from Te Papa and DOC while conducting this work.

Terrestrial, Species - Robin Survey

[17] South Island Robins – kakaruai have had many successful years of breeding within the Orokonui Ecosanctuary – Te Korowai O Mihiwaka. The offspring of these birds are now searching for territories outside the ecosanctuary. This August and October, 8 Acoustic Recording Devices (ARD's) were deployed and set to record between 0900-1100 every morning. Acoustic Recording devices (ARD) are used for recording bats and bird song remotely. They are programable microphones that record the sounds it picks up onto an SD card. They are weatherproof and can be attached to an object (stake or tree trunk) and left for 2-3 months. From previous student research 11 Transects were set up around the Orokonui Ecosanctuary. The Transects were monitored once at the end of August and again at the end of October. This involved walking along the transect with a GPS and at every marked point along the transect listening for Robin calls (very distinctive) for two minutes and marking down on a map if any were seen or heard.

Terrestrial Ecosystems - Data Compilation

[18] From the late 1960's through to the mid 1990's Department of Scientific and Industrial Research (DSIR) and Department of Conservation (DOC) produced a significant number of reports called Protected Natural Area Programme (PNAP). These reports contained an

inventory of flora and fauna in areas around Otago. To utilise the data held in these hard copy reports, scanned copies were made, and the data had to be manually extracted and compiled into an Excel spreadsheet. This digital dataset now forms part of a biodiversity inventory in Otago.

Naturally uncommon ecosystems SOE monitoring

[19] Naturally uncommon ecosystems are areas that contain unusual features which create unique ecosystems where organisms have evolved to utilise these niches. There are 72 types of naturally uncommon ecosystems in New Zealand as described by Manaaki Whenua – Landcare Research; 38 are found in Otago. Coastal turf totals about 40 ha throughout New Zealand. This makes them very rare; along with the flora and fauna communities that inhabit them. A local example of a coastal turf ecosystem is the lower slopes of the hills near Tunnel beach (Fig. 2). Manaaki Whenua – Landcare Research consultant Botanist (ORC does not carry a botanist skill set) designed a Coastal turf SOE monitoring program which involves placing transect lines through the areas of turf and recording the Coastal Turf flora species that are encountered while also noting the invasive plants that may be outcompeting the native Coastal Turf Flora. The Coastal Turf monitoring was funded through an Envirolink Advice Grant. The EM biodiversity technician assisted with field work for this project when required.

Figure 2: Coastal Turf at Tunnel Beach

Fish Barrier Assessment:

[20] Fish barrier assessment involves undertaking assessments of existing instream structures (including culverts, weirs, bridges, waterfalls) to better understand fish passage issues in Otago and identify opportunities for remediation. Assessment data is uploaded to the New Zealand Fish Passage Assessment Tool database, which was

developed by National Institute of Water and Atmospheric Research (NIWA) in conjunction with regional councils and others. This works in conjunction with the NIWA citizen science app.

[21] Barriers can have two effects on fish populations. The first effect is to prohibit diadromous fish moving through the catchment, these barriers are typically culverts or weirs. The second form of barrier protects non-migratory galaxiids from being predated by salmonids. These barriers are usually natural barriers, such as waterfalls.

[22] A NIWA desktop exercise showed that there are approximately 13000 potential structural barriers in Otago on public land alone. The app steps the user through what needs to take place to assess the structure. The EM Biodiversity technician with assistance from EM Technical Assistants has conducted several hundred of these surveys. This is ongoing work.

Figure 3: A waterfall barrier in the Upper Waipori Catchment

[23] The Waipori catchment had a barrier survey conducted over the summer to assess the security of populations of Dusky Galaxiid (*Galaxias pullus* – Fig. 4). Brown trout (*Salmo trutta)* have been in the Waipori catchment for around 100 years, which made testing for barriers straight forward - if trout were found there would be no galaxiids and vice versa. Determining the presence of either trout or galaxiids with an Electric Fishing Machine (EFM) was a very efficient method to discover if there was a barrier within the waterway. Electric fishing involves using a specialised machine which is backpack mounted with an anode (+) wand and a cathode (-) tail. This machine pushes electric current through the water with adjustable frequency, pulse width and voltage. The electric current forces fish to swim towards the anode and stuns them, allowing them to be scooped up by a handheld net. A helicopter was used to access the upper streams and look for barriers. Finding the actual barrier was quite difficult as the upper reaches

of this catchment are rugged and difficult to access. So, if an actual barrier wasn't pinpointed the section of river where the barrier was could be located by electric fishing above and below the inaccessible section of river. A gorge in the mainstem of the upper Waipori River was the best example of this (Fig 3).

Figure 4: Dusky Galaxiid (Galaxias pullus)

Beaumont Station non-migratory galaxiid/barrier survey

[24] In late May an EM biodiversity technician assisted ORC's Science Team and consultant with a survey of the upper parts of Beaumont Station inland from Lawrance. Beaumont Station spans the Upper Taieri catchment and Beaumont River of the Clutha catchment. This survey comprised of eDNA, EFM, fin clips samples and required the use of a helicopter to assess barriers and fish species (Fig 5 and Fig 7).

Figure 5: Winter in the Upper Taieri catchment

Pisgah Creek Galaxiid restoration

[25] EM staff are continuing the galaxiid restoration project in Pisgah Creek. This small tributary of the Kye Burn contains a stunted population of Brook Trout (*Salvelinus*

fontinalis) and the endangered Central Otago Roundhead (*Galaxias anomalus* – Fig. 6)). Brook trout are removed using and EFM, with currently 31 trips being completed and approximately 2700 fish removed. This work is undertaken with a permit from both DOC and Fish&Game. Monitoring of the galaxiid population will commence at the end of summer as it is predicted that trout numbers will be low. It is hoped the densities and range expansion will both increase as the fewer remaining trout will have less of an impact.

Figure 6: Central Otago Roundhead (Galaxias anomalus) The fish in this image is 105 mm long.

Natural Wetlands SOE monitoring

[26] A further workstream required by the NPS-FM (2020) is regional wetland monitoring programme. Manaaki Whenua – Landcare Research developed a wetland condition monitoring framework for ORC last year, which will be implemented this summer. This program is starting in the Catlins FMU. The wetland monitoring work involves placing transects through the wetland and recording vegetation types encountered. The biodiversity technician has deployed ARD's in November; these will be listening for Australasian Bittern, Crakes, and South Island Fernbird. The transect monitoring will take place in the new year.

Figure 7: Te Papanui (Upper Taieri) eDNA sample site

OPTIONS

[27] This report is for noting and therefore does not present options.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[28] The EM team biodiversity programme contributes towards the Healthy water, soil and coast, and Healthy diverse ecosystems strategic priorities. The work outlined in this paper aligns with visions in ORC's Biodiversity Strategy Plan 2018: Our Living Treasure | Tō tatou Koiora Taoka and with visions and outcomes in the Biodiversity Action Plan Te Mahi hei Tiaki i te Koiora 2019 –2024.

Financial Considerations

[29] This is planned and budgeted work programme under the council's Long-Term Plan (LTP).

Significance and Engagement

[30] Not Applicable

Legislative and Risk Considerations

[31] With the Current Governments intention to reform the RMA in 2025 there is some uncertainty about how this will affect the focus of the Regional Councils Biodiversity programs.

Climate Change Considerations

[32] The biodiversity monitoring will provide valuable baseline data to assess the effect of future climate changes on species and ecosystems in Otago.

Communications Considerations

[33] Not Applicable.

NEXT STEPS

[34] Continue monitoring programmes.

ATTACHMENTS

Nil

9.3. Lake Programme update

Prepared for: Environmental Science and Policy Committee

Report No. GOV2462

Activity: Governance Report

Author: Hugo Borges, Senior Scientist - Lakes

Endorsed by: Tom Dyer, General Manager Science and Resilience

Date: 04 December 2024

PURPOSE

[1] The purpose of this report is to provide the council with an update on the lakes programme as a supplement to regular State of the Environment (SOE) reporting. This includes presenting the latest data and performance update from lake buoys currently installed in Lake Hayes, Lake Wānaka, and Lake Whakatipu/Wakatipu. Additionally, this report covers recent lake snow monitoring results from Otago lakes and assesses the ecological condition of three key lakes in the Otago region—Hāwea, Whakatipu, and Wānaka—using the Lake Submerged Plant Indicator (LakeSPI) developed by NIWA.

EXECUTIVE SUMMARY

[2] The lake buoys improve the Otago Regional Council (ORC) lakes monitoring programme and measure parameters required by the National Policy Statement for Freshwater Management 2020 (NPS-FM) in near real-time.

[3] The Lake Whakatipu, Wānaka, and Hayes buoy data is presented in this paper, and the benefits and challenges are discussed. Additionally, monthly profile data is presented in Appendix A.

[4] Since the deployment of buoys, profiling has shown that deeper data collection (over 100 m) is necessary to capture critical stratification zones. Notably, analysis reveals standing waves due to wind effects, further emphasizing the importance of full-depth profiles for understanding lake hydrodynamics.

[5] In Lake Hayes, strong summer stratification results in anoxic conditions in deeper layers, which causes phosphorus release from sediments on the lakebed, fuelling algal blooms when the lake remixes in cooler months.

[6] ORC's Lake snow monitoring data are reported and show the prevalence of lake snow in four Otago Lakes (Wānaka, Wakatipu (Whakatipu Waimāori), Hāwea, and Dunstan) from 2016 to date.

[7] Results show that lake snow abundance peaked mostly in summer and autumn, with additional peaks in spring and winter. Lake Wānaka displayed the most consistent seasonal trend, peaking in summer and showing lower levels in winter. Lake Hāwea recorded the lowest levels of lake snow since 2021, and no lake snow was detected in Lake Hayes, likely due to its eutrophic (nutrient enriched) status. Generally, Lake Wānaka exhibited the highest concentrations of lake snow across the study period.

[8] Otago Regional Council has contracted NIWA to assess and report on the LakeSPI for lakes Wānaka, Whakatipu, and Hāwea in Otago (Appendix B). Lake Hāwea continues to rank in excellent condition. In contrast, Lakes Wānaka and Whakatipu experienced slight declines, dropping from the excellent to high ecological category for the first time. The invasive aquatic weed *Elodea* was noted to be more prominent in Lake Whakatipu, though the cause is uncertain.

[9] Efforts are ongoing to manage invasive Lagarosiphon in Lakes Wānaka and Whakatipu, with containment efforts preventing it from spreading to baseline sites. All three lakes remain above the national standards set by the National Policy Statement for Freshwater Management 2020.

RECOMMENDATION

That the Committee:

1) ***Receives** this report.*

BACKGROUND

[10] This section summarizes the lake buoy, lake snow, and LakeSPI programs and current results and observations are detailed in the following section.

[11] The State and Trends of Rivers, Lakes, and Groundwater in Otago 2017–2022 report (published in May 2023) provides a comprehensive assessment of the eight monitored lakes in Otago—Lakes Hayes, Whakatipu, Wānaka, Hāwea, Dunstan, Onslow, Waihola, and Tuakitoto. It evaluates each site against the attribute tables of the National Policy Statement for Freshwater Management (NPS-FM) (Ministry for the Environment, 2020) and includes detailed analyses of the general state and long-term trends, conducted every five years. The report and annual lake state updates are available on the Otago Regional Council website.

Lake Buoys

[12] The Otago region has a set of unique deep lakes and it can be complex to understand their dynamics and ecology. Continuous monitoring throughout the water column is essential to understand their dynamics, helping to understand lake health and detect changes quickly. High-frequency monitoring buoys give a better understanding of the processes affecting lake health, including temperature stratification patterns, oxygen depletion from bottom waters, algal species succession, sediment re-suspension and water clarity. In 2019, ORC deployed its first high-frequency monitoring buoy to Lake Hayes, and later added 2 more buoys in 2022 – one in Lake Whakatipu, and one in Wānaka (Figure 1).

Figure 1 – Buoy location of Lake Whakatipu (1), Hayes (2), and Wānaka (3).

[13] The lake monitoring buoys currently perform 8 profiles a day (Figure 2). A profile is the collection of measurements taken across the depth of the lake. This is obtained by lowering and raising a set of probes through the water column. Profile timing and the depth resolution can be programmed by ORC. The profiles measure water temperature, chlorophyll and phycocyanin (cyanobacteria proxy; Lake Hayes only) fluorescence, dissolved oxygen (DO), turbidity, pH/ORP, conductivity, and meteorological variables (e.g., sun, air temperature, humidity).

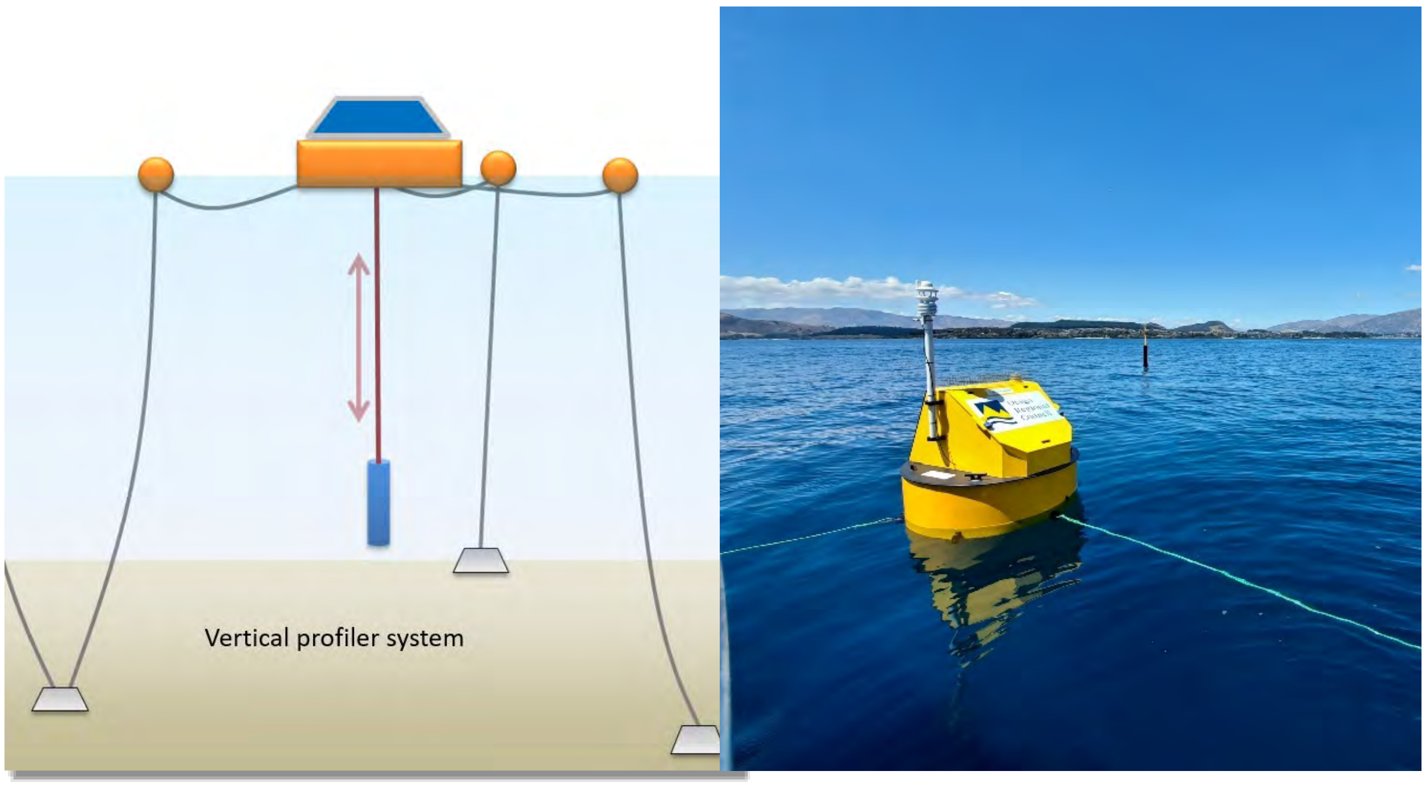


Figure 2 – Representative diagram of Lake Hayes, Wānaka, and Whakatipu vertical buoy profiler and picture of Wanaka's buoy.

[14] Currently we can only profile full water column depth at Lake Hayes, which is up to 33 m deep. At Whakatipu and Wānaka we are only currently able to profile to 70 m due to the constraints of the current winch design. The aim with future developments is to get to 120 m. Even then at Wakatipu we are only reaching the top 3rd of the lake depth but this depth will be sufficient to reach below the thermocline layer. To compensate for the inability of lake buoys to reach the bottom of the deep lakes, we are also running

standalone sensors at greater depths, including near the bed. Additionally, we also perform monthly profiles using a RBRmaestro[3] multi-channel logger (Conductivity, Temperature, Chlorophyll a, Dissolved oxygen (DO), Phycocyanin, PAR, and Turbidity), to full depth of all Otago monitored deep lakes.

Lake Snow

[15] Lake snow is the name given to material formed by clumping together of microscopic bacteria and algae with a sticky, mucus-like polysaccharide material excreted by the microalgae diatom *Lindavia intermedia*. It has been known to be present in our Otago lakes since 2004, and in more recent years it has been reported in other lakes across the South Island.

[16] Lake snow has been prevalent in Lake Wānaka since 2004, where it has caused numerous problems. These include fouling fishing gear, abandonment of commercial trout fishing operations, and blocking hot water systems, washing machines and garden irrigation systems.

[17] As the phenomenon has spread to other oligo- and mesotrophic lakes, more issues have been seen. Lake snow has caused problems in hydroelectricity generation infrastructure and necessitated expensive upgrades to numerous municipal water supplies to remove mucilage from their raw lake water intakes. In the Queenstown Lakes District, aquatic mucilage has also been reported to attach to boat hulls and to swimmers' bodies. While causing obvious problems for water users, the recent phenomenon of mucilage in these lakes will also have repercussions for lake food webs and lake functioning.

[18] ORC has been monitoring Lake Snow in Otago since 2016. We monitor five lakes monthly (Wānaka, Whakatipu, Hāwea, Hayes (Waiwhakaata), and Dunstan) for lake snow abundance. The lakes have presented consistent levels of the algae throughout the years, and it seems to have a well-established population.

LakeSPI

[19] LakeSPI (pronounced "lake spy") is a management tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and to analyse trends in the ecological and biological condition of lakes.

[20] Aquatic plants can be divided into distinct depth-related community types ranging from the lake margin down to the deepest plant growth where light penetration becomes limiting for plant growth. This is shown in the depth profile drawing (Figure 3), of the general vegetation structure of many New Zealand lakes.

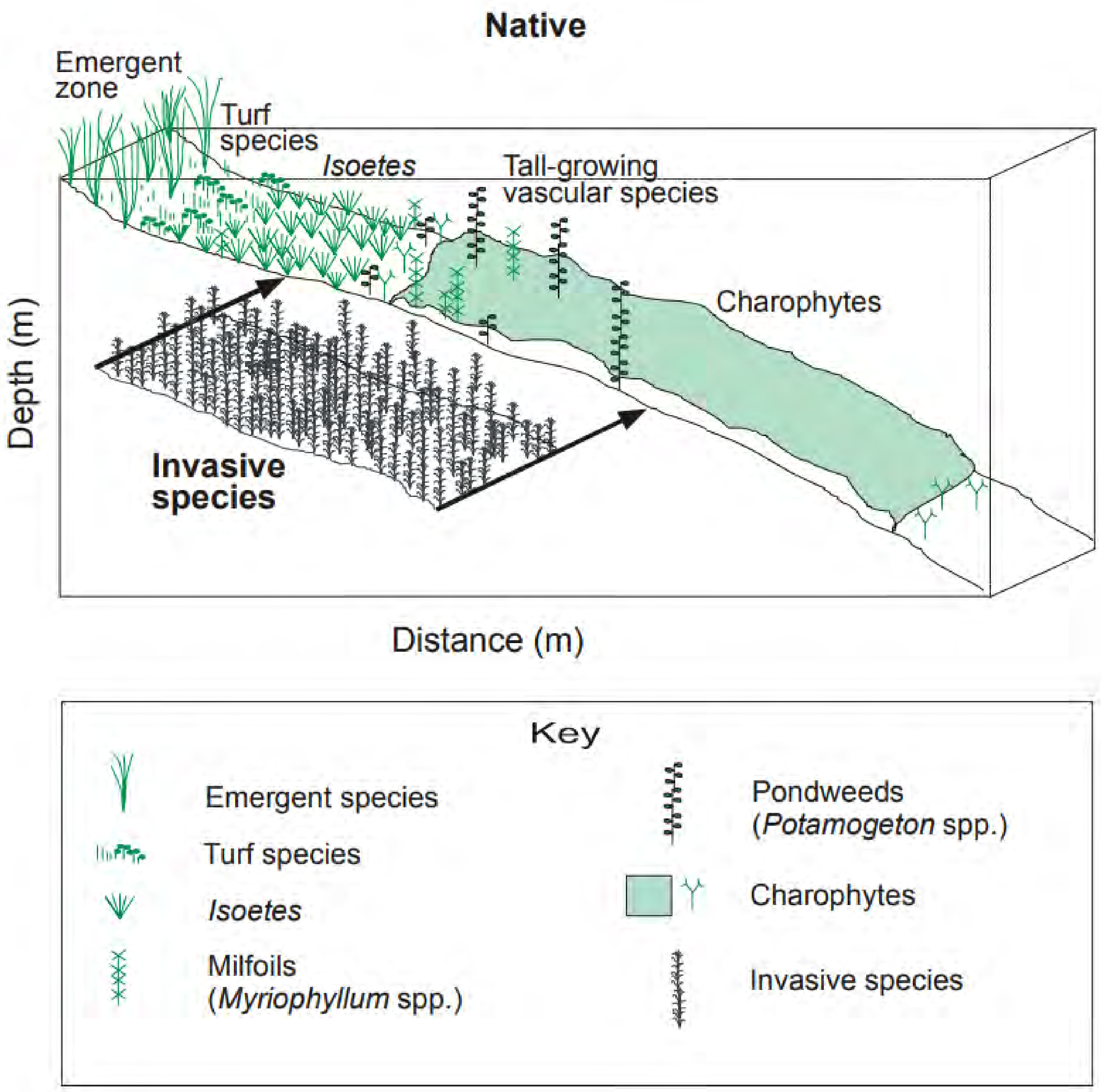


Figure 3 - Depth profile illustrating the main components of native lake vegetation and the region of substitution by invasive species[1].

[21] The 'typical vegetation profile' shown in Figure 3 describes native community types found widely throughout New Zealand lakes irrespective of lake size. However, this changes whenever invasive submerged species become established in a lake. All the main invasive weed species which affect lake vegetation structure are tall-growing angiosperms, with a distinctive difference in growth from the native milfoils and pondweeds. These invasive species, such as Lagarosiphon and Elodea, can form extremely dense growths that exclude all other vegetation. They typically occupy the mid-depth range of lakes and are most common between two to eight metres in depth. Although they can grow at a depth of ten metres, their greatest impact tends to be between two to five metres where they are able to exclude most native species. There are several different invasive species present throughout New Zealand, each with their own characteristics.

[22] Key features of aquatic macrophyte structure and composition are used to generate three LakeSPI indices (Figure 3):

[1] Extracted from Clayton, J., Edwards, T. (2006) LakeSPI – A Method for Monitoring Ecological Condition in New Zealand Lakes. Technical Report, Version Two. June 2006: 67

- 'Native Condition Index' – This describes the native character of vegetation in a lake based on the diversity and quality of the indigenous plant communities.
- 'Invasive Condition Index' – This describes the invasive character of vegetation in a lake based on the degree of impact from invasive weed species.
- 'LakeSPI Index' – This is a combination of components from both the native condition and the invasive condition of a lake and provides an overall indication of the lake ecological condition.

[23] LakeSPI can be used in many ways depending on the needs of individual lakes or a group of lakes. The LakeSPI indices will allow ORC to:
- To monitor Otago lakes against the NPS-FM 2020.
- Assess and compare the ecological condition of different lakes within and between regions.
- Rank the state of lakes in the region and prioritise those most in need of protection, surveillance, or management.
- Monitor trends occurring in lakes over time.
- Compare current lake condition with indices generated from historical vegetation records.
- Make comparisons between dissimilar lakes with different depths and from different regions.
- Provide relevant information for regional and national reporting requirements, including operational monitoring and state of the environment reporting.
- Help assess the effectiveness of catchment and lake management initiatives.

RESULTS AND DISCUSSION

Lake buoys data, performance, and monthly profiles data

[24] Increasing water temperature is a widespread global concern, significantly impacting lake hydrodynamics and ecology. From late spring through early autumn, Lakes Whakatipu, Wānaka, and Hayes experience thermal stratification (Figures 4, 5, 6, Appendix A - Temperature), a phenomenon where lakes separate into three distinct thermal layers. Cooler, denser water settles at the bottom, forming the hypolimnion. A layer of warmer water, called the epilimnion, floats on top, while a thin middle layer, the metalimnion (or thermocline), separates the top and bottom layers and is characterized by rapid changes in water temperature. This separation is often strong enough to prevent wind-driven mixing of the layers. In nutrient-rich environments like Lake Hayes, prolonged stratification can lead to increased algal blooms, fish die-offs, and elevated methane emissions.

[25] The buoys in Lakes Whakatipu and Wānaka have been operational for just over a year. Initially, the profiling depth was set to 50 m but was adjusted to 70 m a few months later. Data from monthly profiles (Appendix A) and initial continuous data from the buoys indicate that profiling to over 100 m depth will be necessary to capture both the thermocline and hypolimnion of these lakes. Limnotrack, the company that designed the buoys, is working on improving the technology to allow deeper profiles. We are currently trialling fixed-depth sensors in the hypolimnion to capture full-depth data. Analysis of this data reveals seiches (standing waves that oscillate back and forth within a lake) that tilt the thermocline due to strong winds (Figures 4 and 5 – temperature), underscoring the importance of capturing full-depth profiles to better understand the hydrodynamics of both lakes.

[26] Lake Hayes, however, is profiled to its full depth (~33 m). The buoy, operational since its deployment in 2019, experienced technical issues in 2021 that were resolved in the same year. Early data was presented to the council in report SPS2131, showing lake buoy data from 2019 to 2021. Stratification in Lake Hayes is strong and prevalent throughout the summers (Figure 6, Temperature), which enhances internal nutrient loads within the lake. During stratification, the hypolimnion (bottom water) becomes anoxic (very low or no dissolved oxygen) (Figure 6 – Dissolved Oxygen). This low oxygen condition triggers chemical changes in the sediments, releasing phosphorus (stored in the lakebed sediment) back into the water. As a key nutrient for algae, phosphorus release can lead to algal blooms when temperature is ideal for their growth. Excess phosphorus from anoxic conditions can fuel significant algae blooms, harming water quality, producing toxins, and further depleting oxygen when the algae die and decompose, creating a harmful cycle for aquatic life.

[27] The dissolved oxygen (DO) sensor on the Lake Whakatipu buoy is currently not operational, and data for this parameter is therefore unavailable. Limnotrack is sourcing a replacement sensor. Although DO data is not currently available from the buoy, we conduct a full monthly profile, as presented in Appendix A, for the full depth of the lake. Dissolved oxygen levels in both Lakes Whakatipu and Wanaka remain high (>90%), which is beneficial for the environment.

[28] Higher pH levels in the epilimnion (surface water above the thermocline) are seen in all three datasets over summer (Figures 4, 5, and 6 – pH). This is expected due to higher temperatures and increased algal growth during this period (Figures 4, 5, and 6 – Chlorophyll a). Algal growth leads to more carbon dioxide uptake which raises the pH in the water, making it more alkaline.

[29] In Lakes Wānaka and Whakatipu, short term increases in particles due to storms can be seen in the turbidity data (Figure 4 and 5, Turbidity). The higher turbidity levels over summer align with rainfall data (data not shown), when the large rivers entering the lakes have a high suspended sediment load which then disperses through the lake.

[30] In Lake Hayes, high peaks in algae concentration (chlorophyll a) are observed over the three summers presented (Figure 6, Chlorophyll a), primarily in the top 10 m of the mixed layer (epilimnion). This information is important for establishing suitable sampling protocol for phytoplankton in Lake Hayes and for understanding phytoplankton dynamics. Higher algae levels associated with elevated water temperatures also correspond with increased pH levels (Figure 6, pH). These associated conditions can harm aquatic life, disrupt ecosystem balance, reduce biodiversity, and worsen water quality.

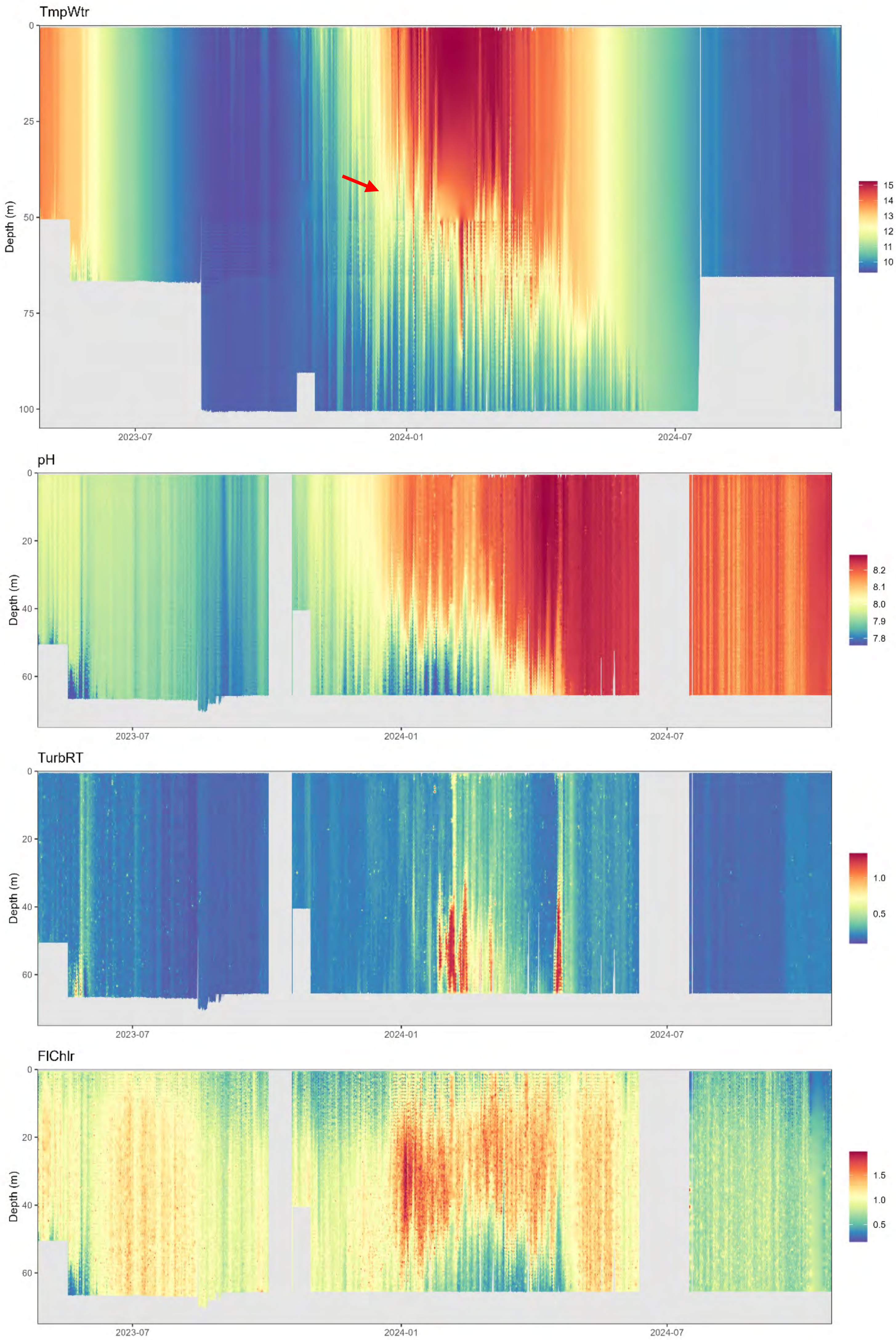


Figure 4 – Water temperature (◦C), pH, Turbidity, and Chlorophyll a vertical profile from Lake Whakatipu high-frequency monitoring buoy, May 2023 to Sep 2024. *Gray areas = buoy was not operational. 0 m is the surface of the lake and 75 m the deepest point measured in the water column. Red arrow indicates the thermocline.

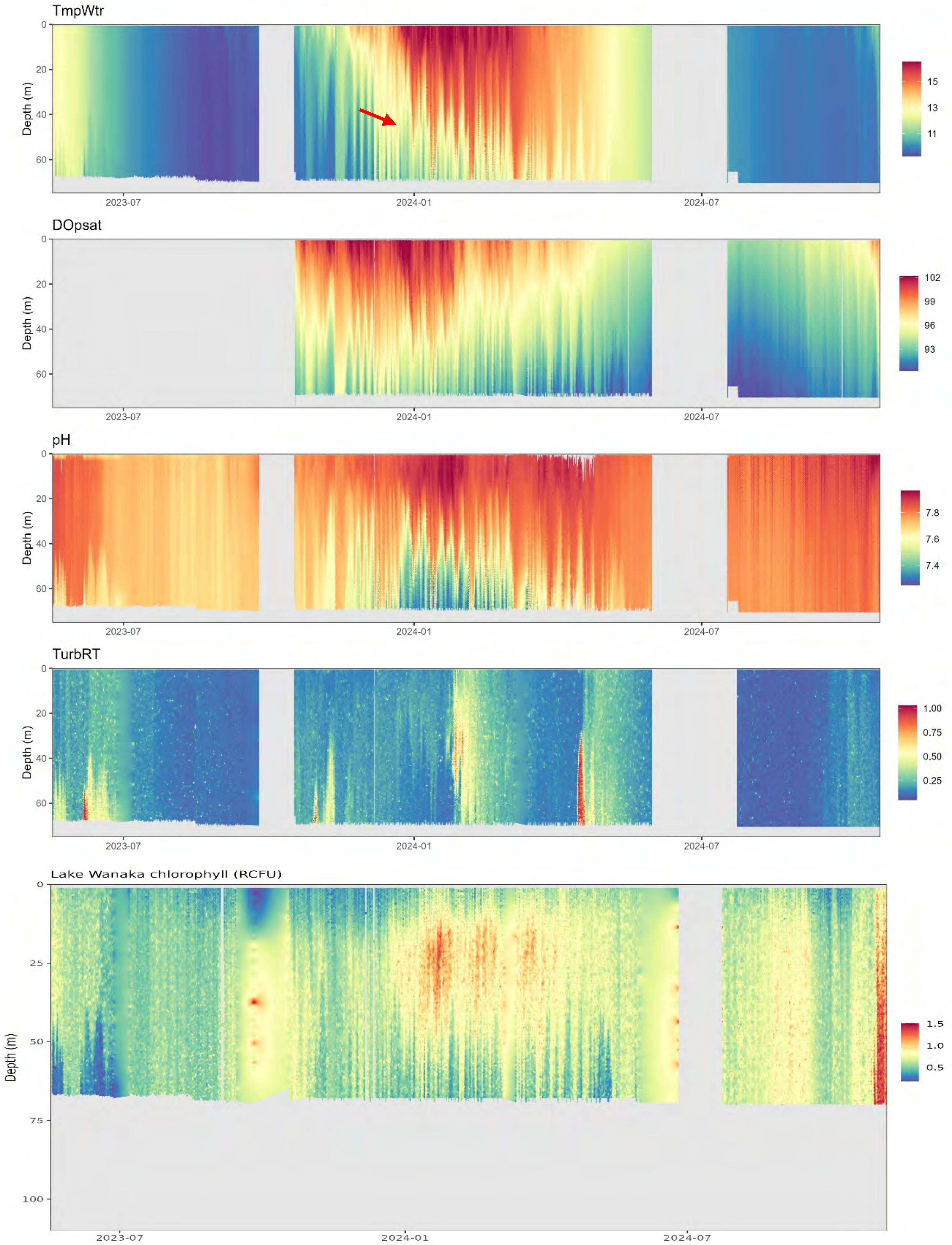


Figure 5 – Water temperature (◦C), Dissolved oxygen (%), pH, Turbidity, and Chlorophyll a vertical profile from Lake Wānaka high-frequency monitoring buoy, May 2023 to Sep 2024. *Gray areas = buoy/sensor was not operational. 0 m is the surface of the lake and 75 m the deepest point measured in the water column. Red arrow indicates the thermocline.

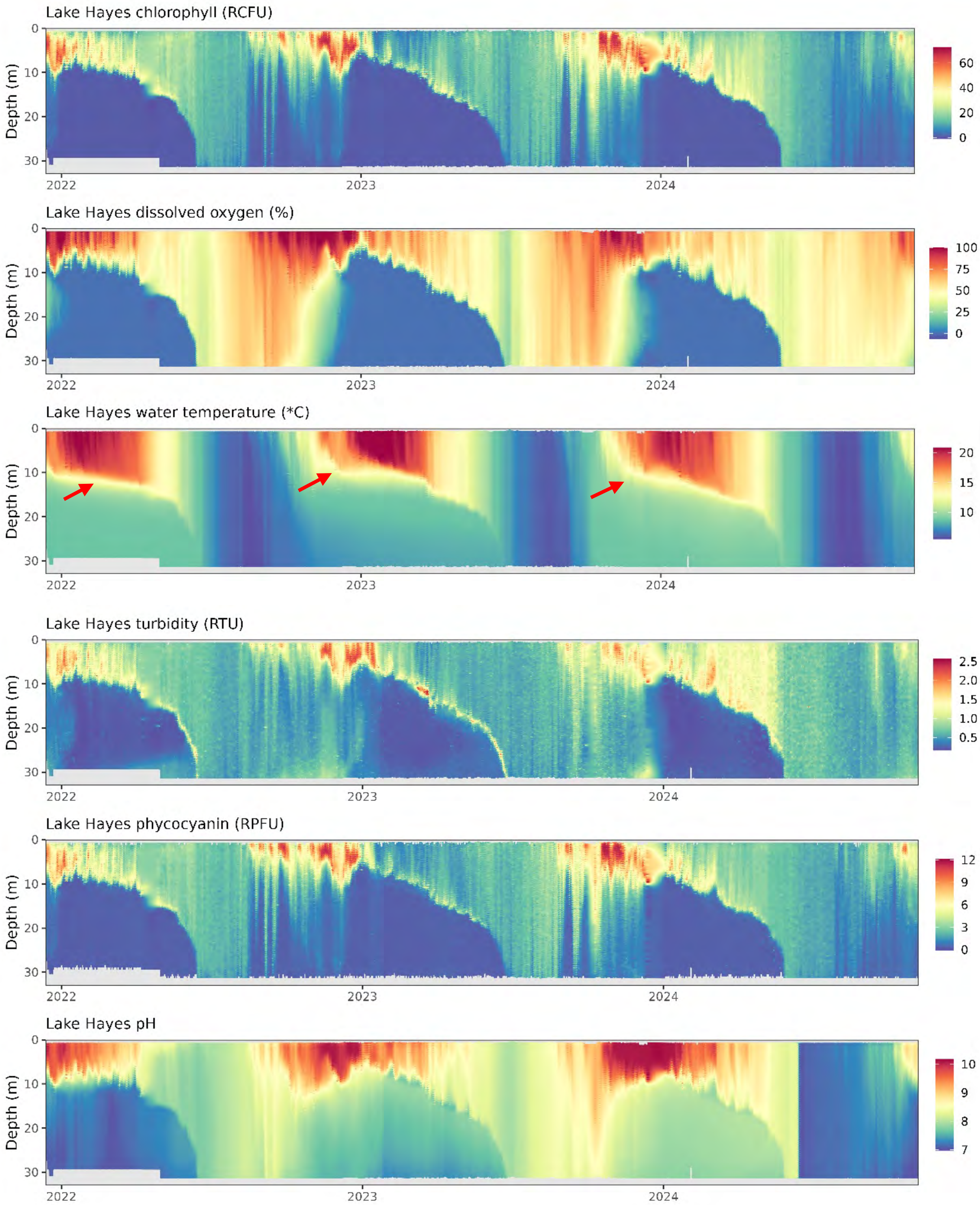


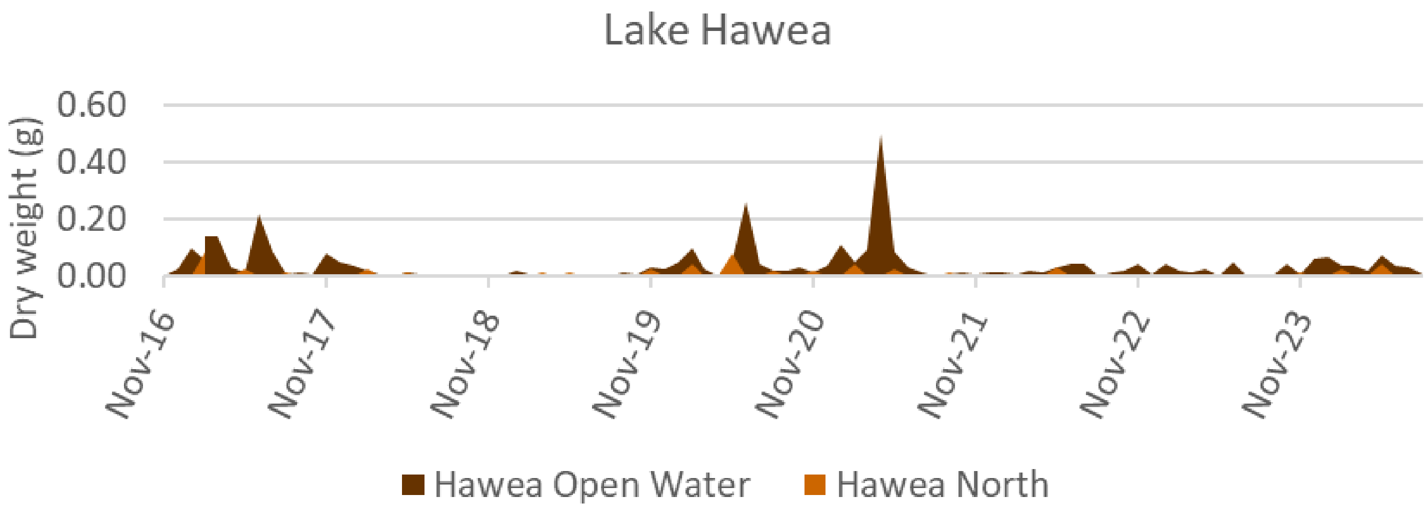
Figure 6 – Chlorophyll a, Dissolved oxygen (%), Water temperature, Turbidity, Phycocyanin, and pH vertical profile from Lake Hayes high-frequency monitoring buoy, Nov 2021 to Nov 2024. *Gray areas = buoy was not operational. 0m is the surface of the lake and 30 m is the lakebed. Red arrows indicate the thermocline.

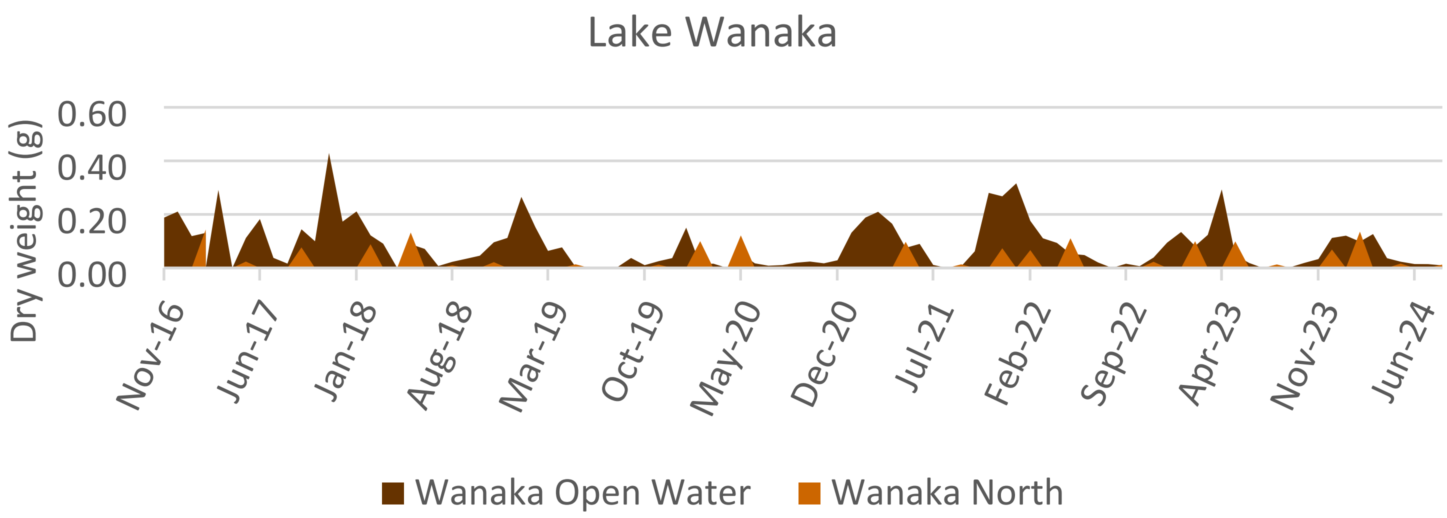
Lake Snow

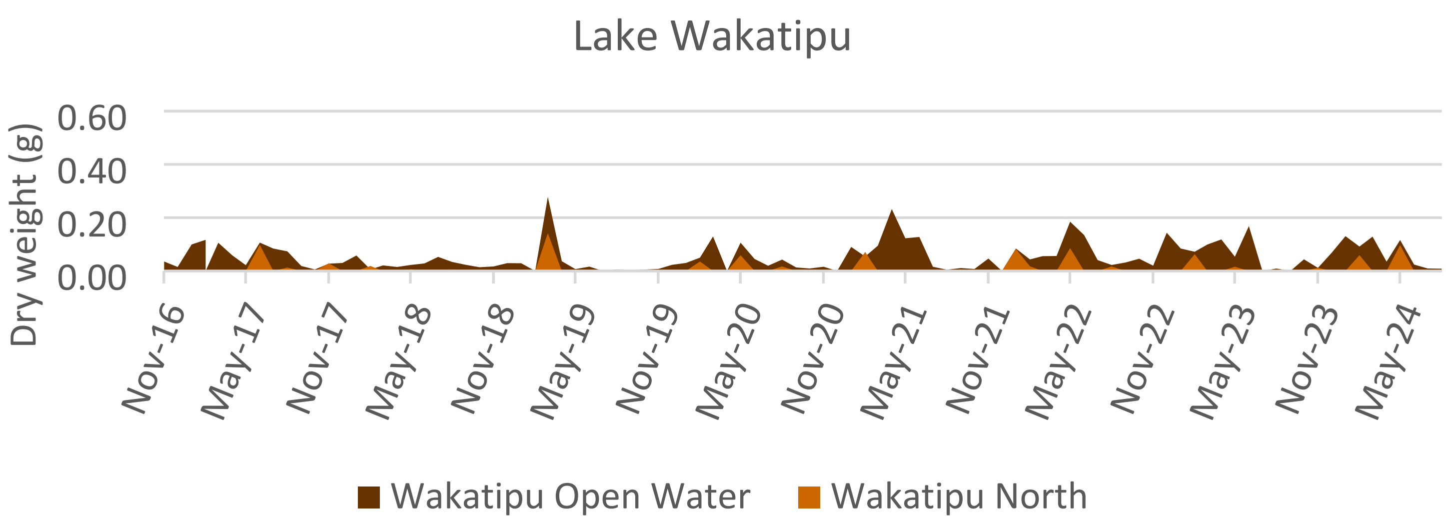
[31] Snow tows were collected monthly on Otago Lakes from November 2016 to July 2024 on the open water sites and quarterly on the north sites. Sites sampled on the northern part of the lake used for comparison of in-lake variation on the parameters measured. The samples were collected by dragging a weighted fishing line approximately 90 m long through Lakes Wānaka, Whakatipu, Hāwea, and 15 m through Hayes and Dunstan (May 2019 to July 2024), at around 4 km per hour for approximately 1 km. The amount of lake snow is calculated by its dry weight.

[32] Peaks of lake snow were most common in summer and autumn, but lake snow abundance also peaked in spring and in winter (Figure 7). Only Lake Wānaka showed some consistency seasonally, peaking in or around summer with low abundances over winter. Since winter 2021, Lake Hāwea presented the lowest abundance of lake snow among the lakes. Lake Hayes had no lake snow during the studied period, and this has been related to the trophic level of the lake as Lake Hayes is classified as eutrophic (nutrient enriched). Lake snow is thought not to be able to establish in nutrient enriched water.

[33] Lake Wānaka generally exhibited the highest concentrations of lake snow throughout the study period. In Lakes Hāwea, Wānaka, and Whakatipu, higher concentrations were observed at the open-water sites compared to the northern sites. However, this difference may be due to the sampling frequency, as northern sites are sampled quarterly, whereas open-water sites are sampled monthly. Another explanation is that these sites receive a larger amount of sediment from major inflow rivers. In Canterbury lakes, it has been reported that after "glacial flour" events, lake snow has been completely cleared from the water.


Lake Hawea
Dry weight (g)
0.60
0.40
0.20
0.00
Nov-16
Nov-17
Nov-18
Nov-19
Nov-20
Nov-21
Nov-22
Nov-23
Hawea Open Water
Hawea North


Lake Wanaka
Dry weight (g)
0.60
0.40
0.20
0.00
Nov-16
Jun-17
Jan-18
Aug-18
Mar-19
Oct-19
May-20
Dec-20
Jul-21
Feb-22
Sep-22
Apr-23
Nov-23
Jun-24
Wanaka Open Water
Wanaka North


Lake Wakatipu
Dry weight (g)
0.60
0.40
0.20
0.00
Nov-16
May-17
Nov-17
May-18
Nov-18
May-19
Nov-19
May-20
Nov-20
May-21
Nov-21
May-22
Nov-22
May-23
Nov-23
May-24
Wakatipu Open Water
Wakatipu North

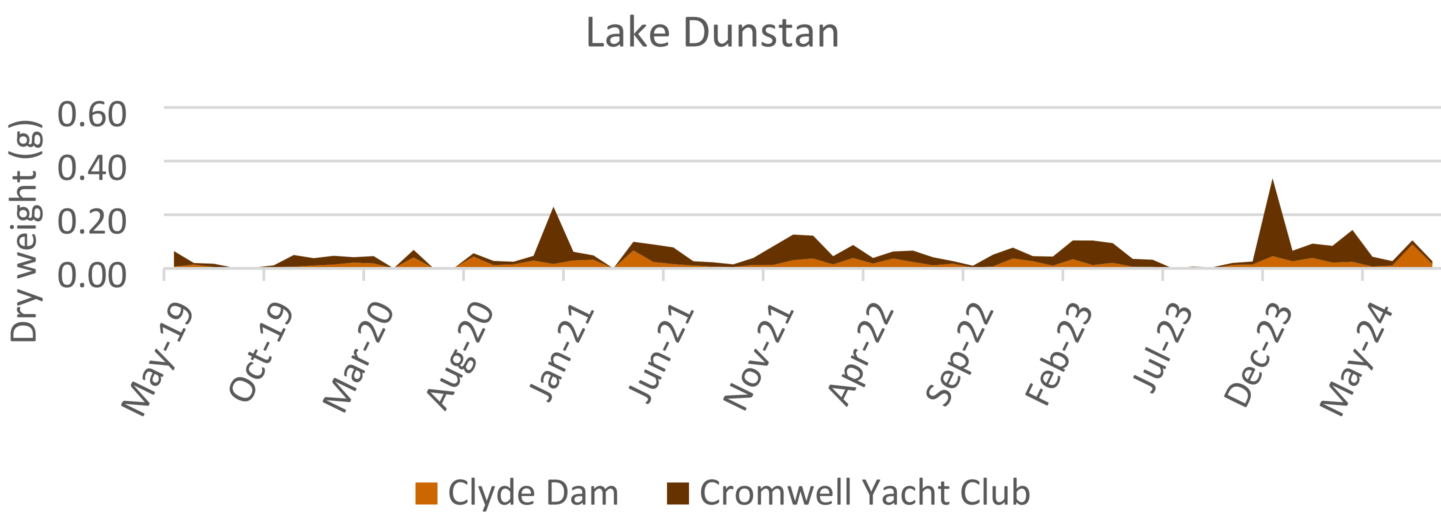

Lake Dunstan
Dry weight (g)
0.60
0.40
0.20
0.00
May-19
Oct-19
Mar-20
Aug-20
Jan-21
Jun-21
Nov-21
Apr-22
Sep-22
Feb-23
Jul-23
Dec-23
May-24
Clyde Dam
Cromwell Yacht Club

Figure 7 – Interannual and seasonal variation in mucilage abundance (lake snow) of Lakes Hāwea, Wānaka, Wakatipu from Nov 2016 to July 2024, and Dunstan from May 2019 to July 2024.

LakeSPI

[34] Three alpine lakes in the Otago Region were reassessed in 2024 (Appendix B). The current LakeSPI status for these lakes indicates that Lake Hāwea remains in excellent condition, while Lakes Wānaka and Whakatipu have slightly dropped below the excellent ecological category (LakeSPI Index <75%), placing them in the high category (Table 1) for the first time.

[35] Lake Hāwea maintained its excellent condition due to substantial native vegetation (Native Condition Index 82%). Although water level fluctuations limit some shallow plant community types, they also provide some protection against the development of dense weed beds and the incursion of new weeds, such as Lagarosiphon. Consequently, this lake has low levels of impact from invasive weed species (Invasive Impact Index 8.1%).

[36] Lake Whakatipu and Lake Wānaka showed a slight decrease in ecological condition based on the 2024 LakeSPI results. However, the change since 2020 is minor, with an 8% decrease for Lake Whakatipu and a 3.2% decrease for Lake Wānaka. For Lake Whakatipu, the aquatic weed elodea appeared to be more prominent in this year's survey, though the reasons are unclear, as elodea has been present in the lake for decades. Both lakes may have experienced a long-term reduction in the depth extent of plant development, a trend seen since the 1980s and 1990s.

[37] Lagarosiphon (*Lagarosiphon major*) is known to be present in Lakes Wānaka and Whakatipu; however, efforts are underway to manage the weed for progressive containment or eradication along most shorelines (program supported by LINZ, ORC, QLDC, NIWA, and Contact Energy). No Lagarosiphon was recorded at any LakeSPI baseline sites.

Table 1 – A summary of the current and previous LakeSPI Indices for Lakes Hāwea, Whakatipu, and Wānaka in order of their overall lake condition and NPS-FM 2020 attribute band.

Lake	Most Recent LakeSPI Survey	LakeSPI Index (%)	Native Condition Index (%)	NPS-FM 2020 Atribute band (native)	Invasive Impact Index (%)	NPS-FM 2020 Atribute band (invasive)	Overall Condition (LakeSPI status)
Hāwea	26/02/2020	82	80	A	12.6	B	Excellent
Whakatipu	2/11/2020	81	77.3	A	11.9	B	
Wānaka	4/11/2020	78	78.7	A	20.7	B	
Hāwea*	19/03/2024	85	82	A	8	B	
Whakatipu*	17/03/2024	73	77	A	29	C	High
Wānaka*	20/03/2024	74	74	B	22	B	
*New survey 2024							

[38] All three Otago lakes remain above the national bottom line set under the National Policy Statement for Freshwater Management 2020 (MFE 2022). Attribute bands for the component indices of LakeSPI, including the Native Condition Index and Invasive Impact Index, are presented in Table 1.

[39] Lake Hāwea remains in the same bands for submerged plant attributes as documented in 2020 (Table 1). Since 2020, Lake Wānaka has shifted from an A band to a B band for

the Native Condition Index (>50 and ≤75%), although the index score changed by less than 5%. Lake Whakatipu moved from a B band to a C band for the Invasive Impact Index (>25 and ≤90%).

CONSIDERATIONS

Strategic Framework and Policy Considerations

[40] LakeSPI surveys and high-frequency monitoring buoys align with ORC's Strategic Directions to monitor and investigate water quality and ecosystem health (NPS-FM 2020).

[41] Understanding the factors that contribute to lake snow will enable us to monitor and develop strategies to minimise the incidence of its occurrence and enable development of interventions to better manage it.

Financial Considerations

[42] No further lake snow research is specifically funded in Long Term Plan budget. However, the current Otago Deepwater Lakes Technical Advisory Group may support future lake snow research.

Significance and Engagement

[43] NA

Legislative and Risk Considerations

[44] NA

Climate Change Considerations

[45] Lake buoys will provide an important source of data and information for future predictive climate change models and support research in this area.

[46] Understanding contributing factors to lake snow will enable us to understand what impact climate change may have on lake snow in Otago lakes.

[47] LakeSPI results will provide an important source of data and information for future predictive climate change models and will support research in this area. Submerged plants are highly affected by temperature increases and the indirect impacts of water clarity.

Communications Considerations

[48] Lake buoy data is available in near-real time on the Otago Regional Council’s website via Limnotrack’s interface.

NEXT STEPS

[49] Another lake buoy is currently being designed for installation in Lake Hāwea this financial year.

[50] A LakeSPI survey will be conducted this coming summer (2024/2025) for Lakes Dunstan, Hayes, and Onslow.

ATTACHMENTS

1. Appendix A_ Monthly CTD profiles final [**9.3.1** - 22 pages]

2. Appendix B_ NIWA Otago Lake SPI report 2024 FINAL [**9.3.2** - 30 pages]

Appendix A

Monthly data from Lakes Wānaka, Whakatipu, Hāwea and Hayes (July 2018 to Feb 2024) have been collected using a RBRmaestro³ multi-channel logger and results are displayed below for Temperature, Dissolved Oxygen (DO), Chlorophyll a, Phycocyanin and Turbidity.

Acquiring profile data on temperature, dissolved oxygen (DO), chlorophyll-a, and turbidity in deep lakes is essential for monitoring lake health and ecosystem dynamics. Temperature profiles help track stratification and mixing patterns, which influence nutrient distribution, habitat suitability, and overall lake stability. Dissolved oxygen levels indicate where aquatic life can thrive and help identify "dead zones" or hypoxic conditions, particularly in deeper layers. Monitoring DO is also critical for understanding nutrient cycling, as low oxygen can release nutrients like phosphorus from sediments, potentially fueling harmful algal blooms.

Chlorophyll-a is a key indicator of algal biomass, providing insights into the lake's productivity and warning of potential eutrophication when elevated. Turbidity measures water clarity, which affects light penetration, photosynthesis, and the habitat quality for various aquatic species. Together, these parameters create a comprehensive picture of the lake's physical, chemical, and biological conditions, essential for tracking seasonal changes, responding to climate impacts, and managing water quality. This information helps guide conservation and management strategies, ensuring deep lakes remain healthy and productive for both ecosystem services and human uses.

Results

Temperature profiles indicate that all four lakes experience persistent stratification from late spring through autumn, with complete mixing occurring in autumn. Lake Hayes shows the most stable stratification, typically mixing fully only in early winter. For Lakes Hāwea, Wānaka, and Whakatipu, the thermocline generally forms between 50 and 120 meters. While in Lake Hayes it sits between 10 and 15m during its most stable periods.

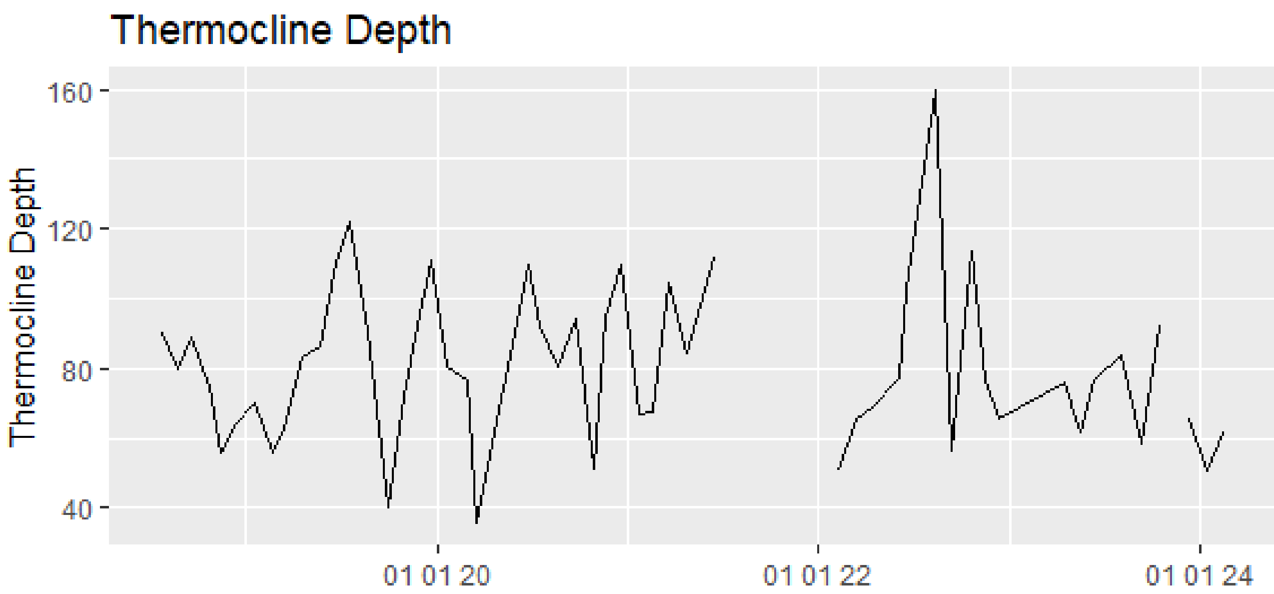
Dissolved oxygen (DO) levels in Lakes Hāwea, Wānaka, and Whakatipu consistently remain above 8 mg/L, indicating low risk for nutrient release from lakebed sediments and no oxygen-related stress for fish species. In contrast, Lake Hayes experiences persistent anoxic (low oxygen) conditions in the hypolimnion (the lake's bottom layer) during summer. At times, only the top third of the water column in Lake Hayes has sufficient oxygen to support aquatic life, creating challenging conditions for species survival.

Chlorophyll-a concentrations, a proxy for algal levels, remain consistently low in the larger lakes (Hāwea, Wānaka, and Whakatipu). However, slight increases in algae have been observed in recent years across all three lakes. In contrast, Lake Hayes, which is eutrophic, exhibits high algal levels year-round, particularly during summer. Elevated chlorophyll-a concentrations are typically found in the top 10 meters of Lake Hayes, with peak levels observed in 2018, 2019, and 2020 (over the study period). Phycocyanin, an indicator of cyanobacteria presence, was also measured, with elevated levels noted only in Lake Hayes during the summers of 2019 and 2020.

Turbidity levels remained consistently low in Lakes Hāwea, Wānaka, and Whakatipu over the five-year monitoring period. However, sharp increases in turbidity were observed in all three lakes following high rainfall events. In contrast, Lake Hayes consistently showed much higher turbidity levels, with significant peaks recorded in 2018, 2020, and 2022.

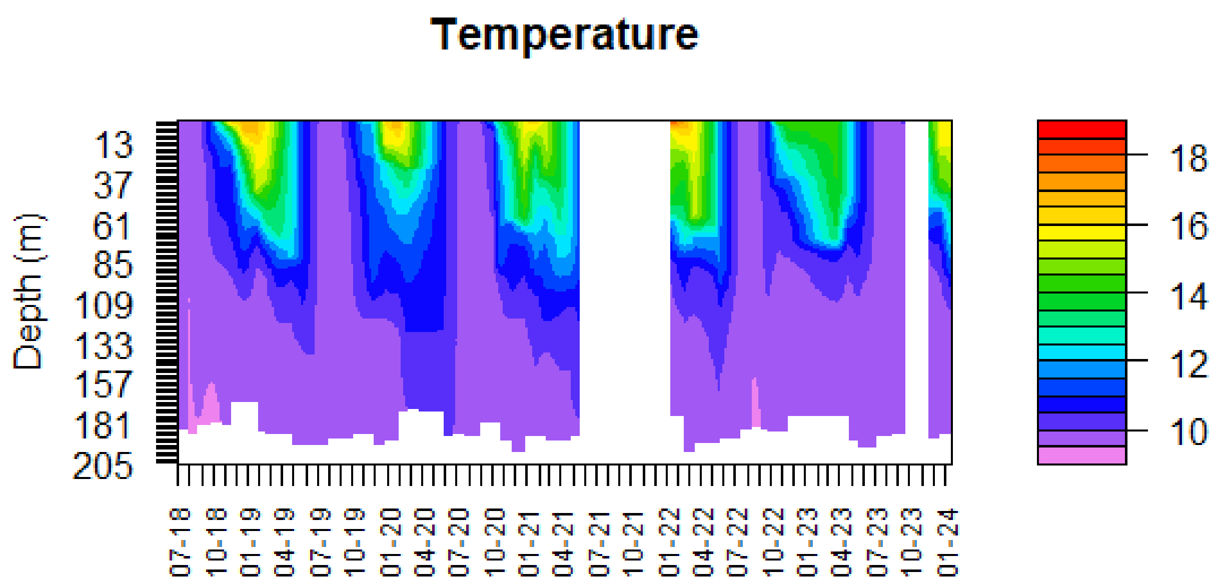
Lake Wanaka Open Water 2018-07-25 to 2024-02-13

Thermocline depth



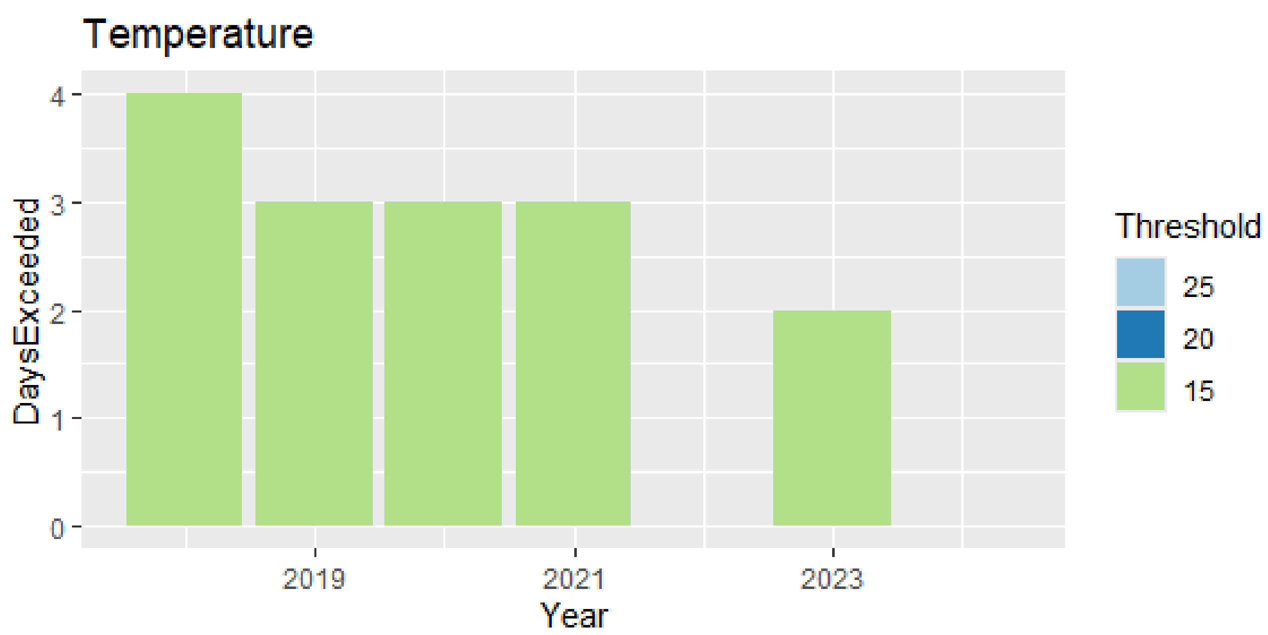
Temperature

Time Series Plots



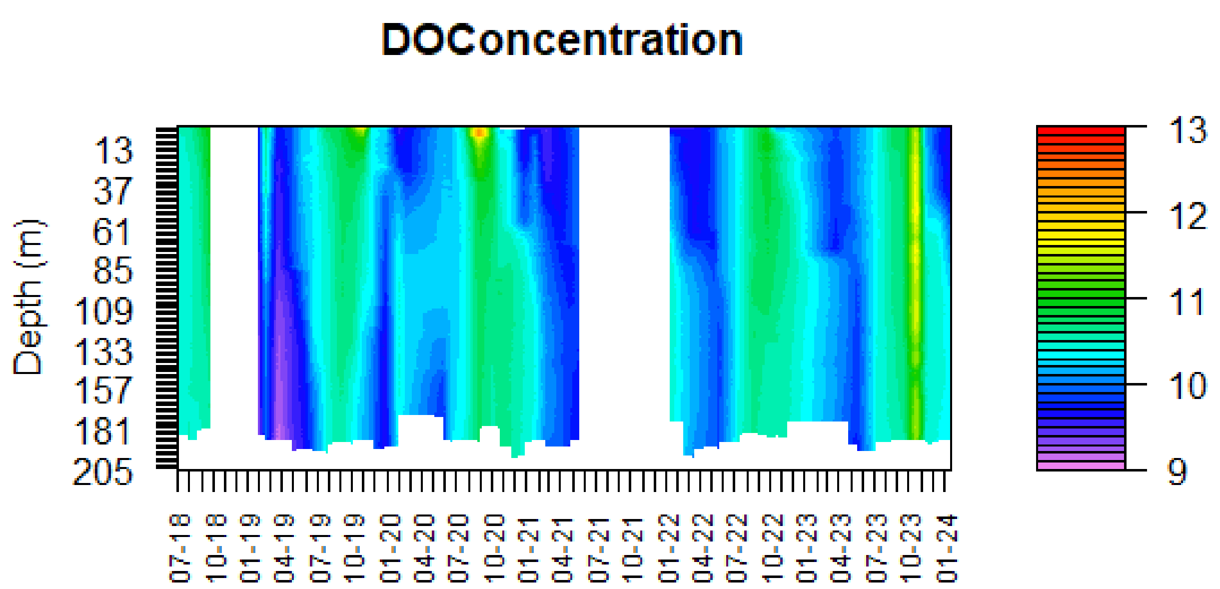
Thresholds - Days Exceeded

Year	15	20	25
2018	4	0	0
2019	3	0	0
2020	3	0	0
2021	3	0	0
2022	0	0	0
2023	2	0	0
2024	0	0	0



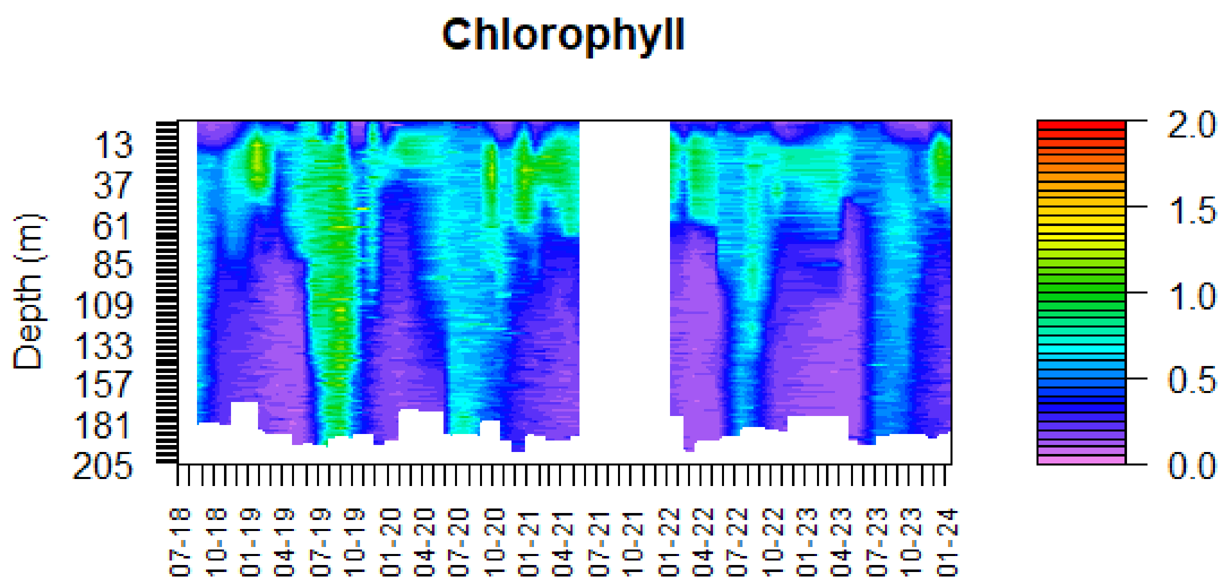
Dissolved Oxygen

Time Series Plots



Chlorophyll a

Time Series Plots

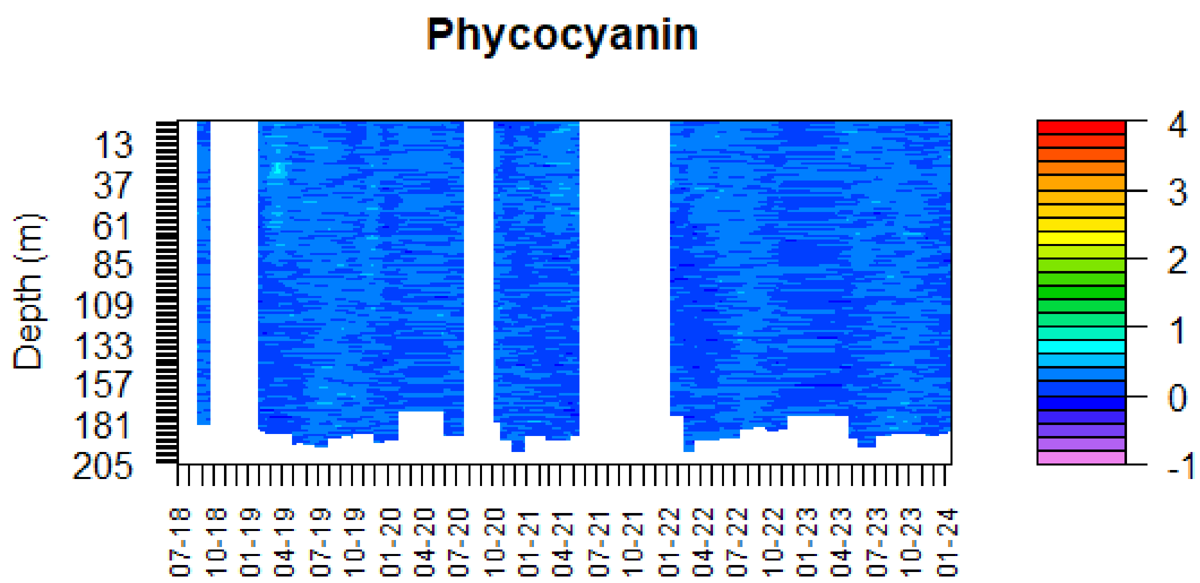


Metrics

Year	Annual Maximum Chla in Mixed Layer	Annual Median Chla in Mixed Layer	Annual Maximum Chla in Water Column	Annual Median Chla in Water Column
2018	1.468	0.483	1.468	0.389
2019	1.042	0.518	1.579	0.568
2020	1.639	0.623	7.853	0.552
2021	1.065	0.716	1.125	0.184
2022	1.298	0.654	1.298	0.370
2023	1.294	0.545	1.294	0.458

Phycocyanin

Time Series Plots

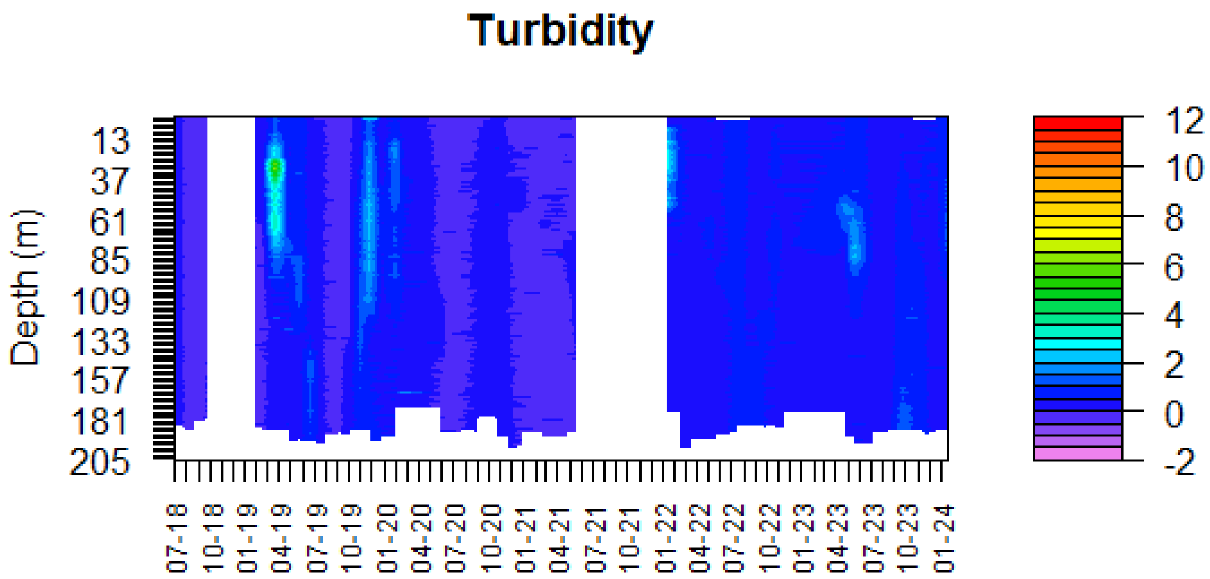


Metrics

Year	80th percentile mixed layer median (across year)
2018	0.3397213
2019	0.2731445
2020	0.2313625
2021	0.2650322
2022	0.2359809
2023	0.2380666

Turbidity

Time Series Plots



Thresholds (Schedule 15) - Dates Exceeded

Year	5
2018	1
2019	3
2020	7
2021	3
2022	4
2023	7
2024	0

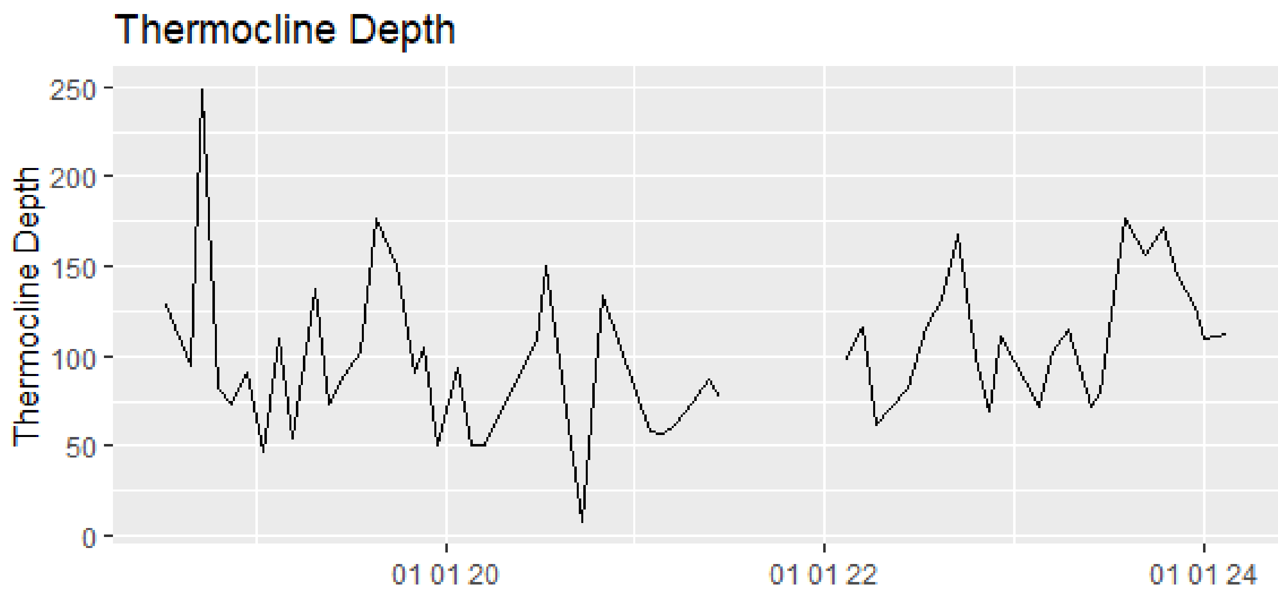
Metrics

Year	Annual Maximum Turbidity in Water Column	Annual Median Turbidity in Water Column
2018	6.424	0
2019	13.116	0.329
2020	245.185	0
2021	77.281	0.322
2022	208.652	0.481
2023	55.705	0.435

ORC CTD Summary Report

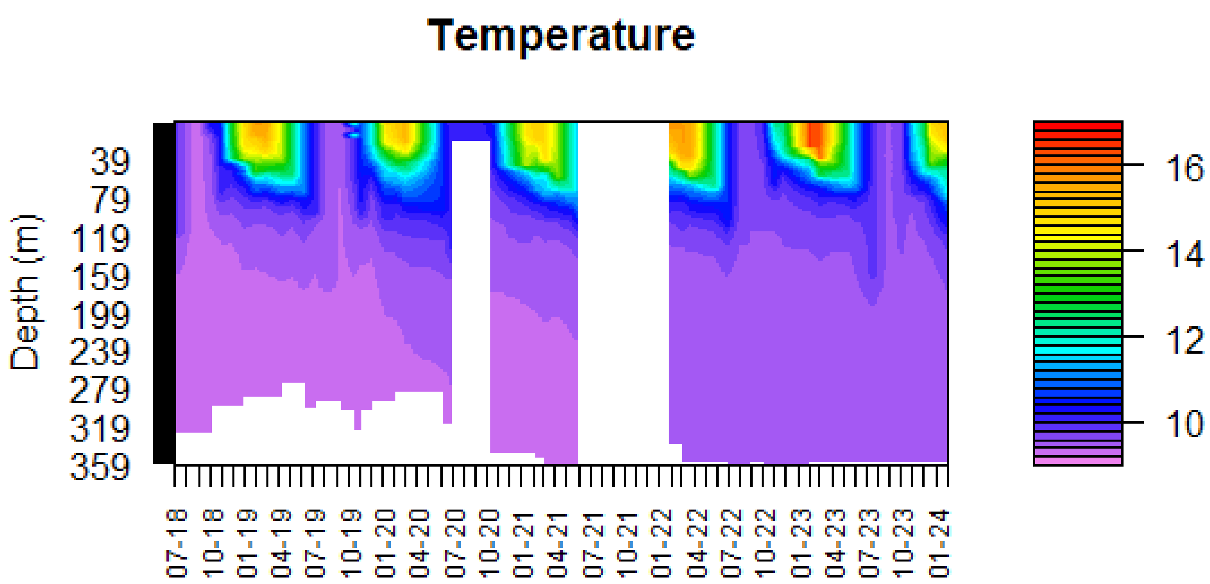
Lake Wakatipu Open Water 2018-07-13 to 2024-02-14

Thermocline depth



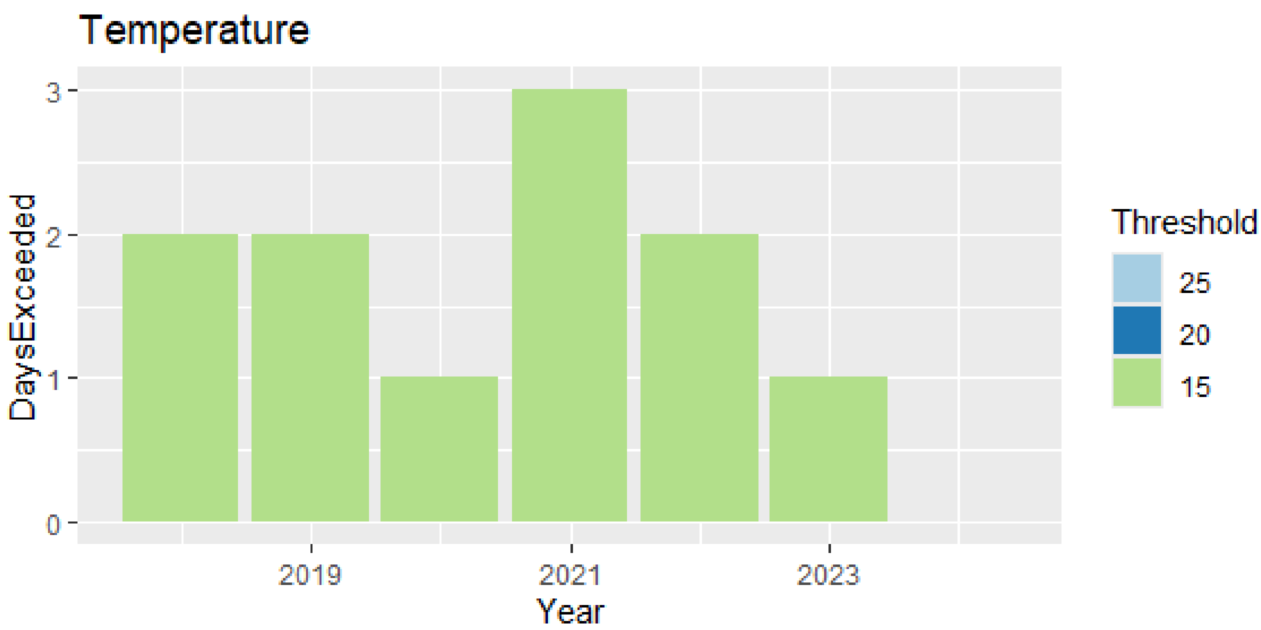
Temperature

Time Series Plots



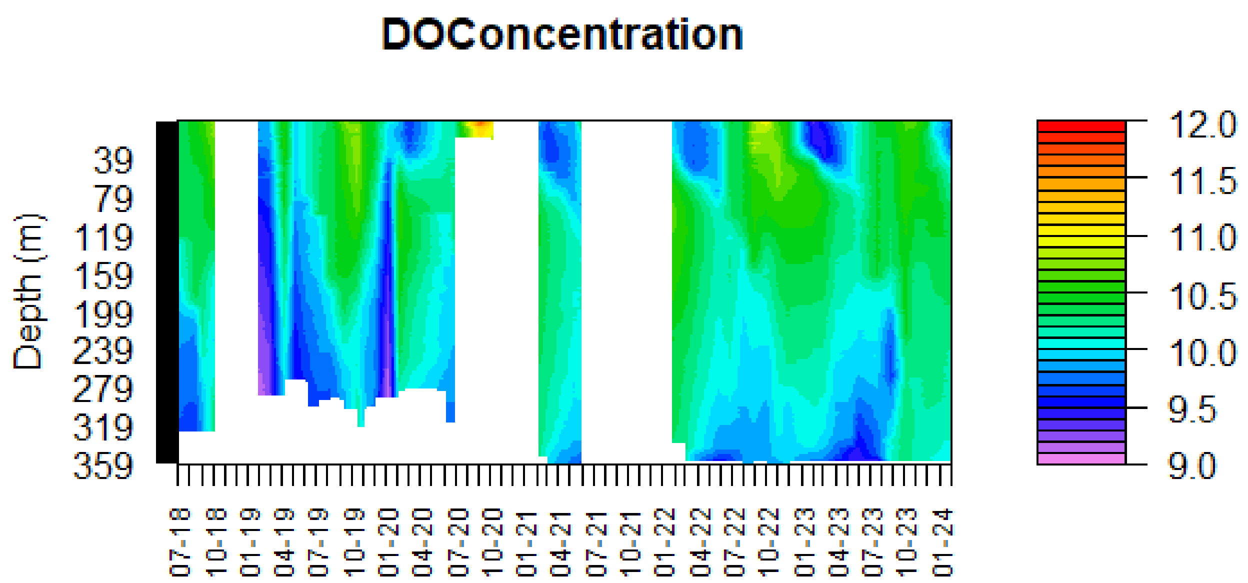
Thresholds - Days Exceeded

Year	15	20	25
2018	2	0	0
2019	2	0	0
2020	1	0	0
2021	3	0	0
2022	2	0	0
2023	1	0	0
2024	0	0	0



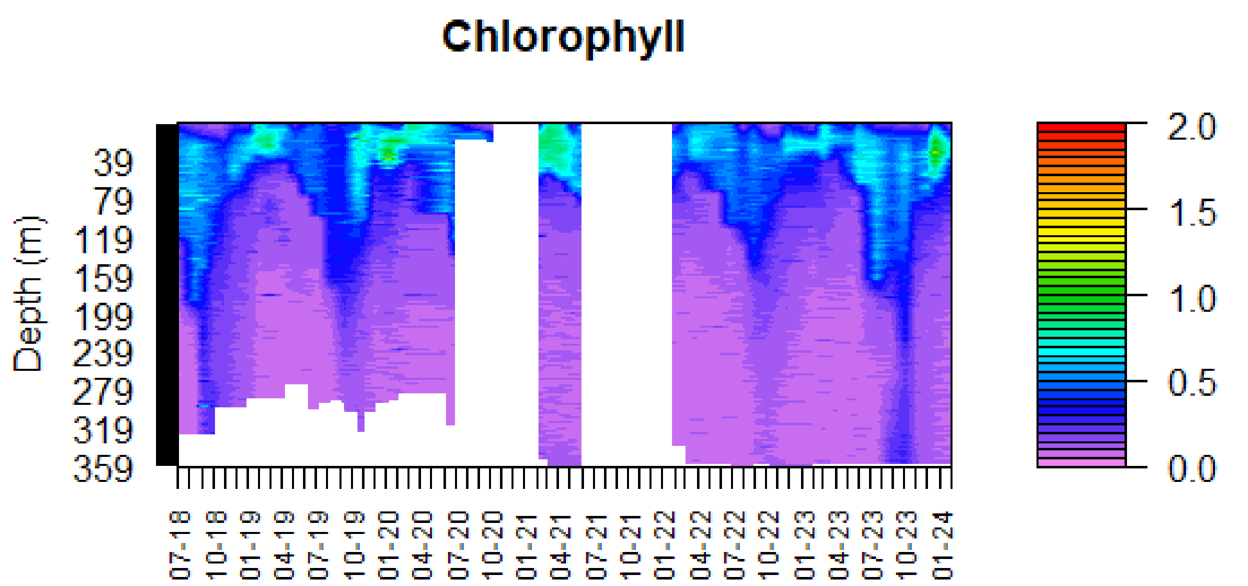
Dissolved Oxygen

Time Series Plots



Chlorophyll a

Time Series Plots

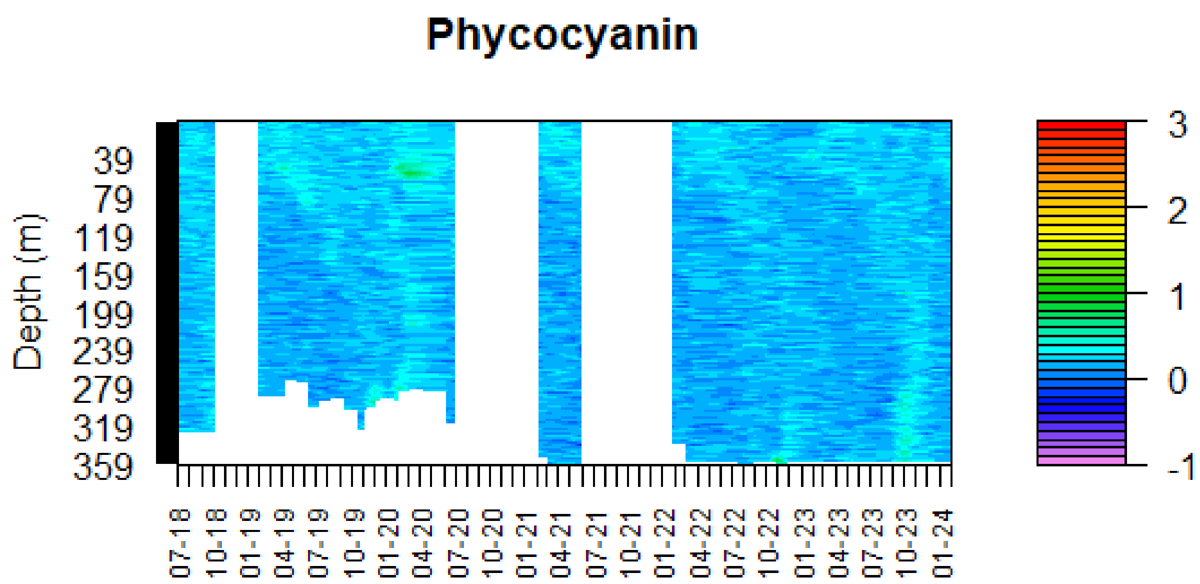


Metrics

Year	Annual Maximum Chla in Mixed Layer	Annual Median Chla in Mixed Layer	Annual Maximum Chla in Water Column	Annual Median Chla in Water Column
2018	1.019	0.459	1.019	0.202
2019	1.471	0.690	2.293	0.175
2020	1.177	0.793	1.177	0.145
2021	0.773	0.473	0.773	0.097
2022	0.893	0.321	21.243	0.118
2023	1.253	0.499	20.254	0.175

Phycocyanin

Time Series Plots

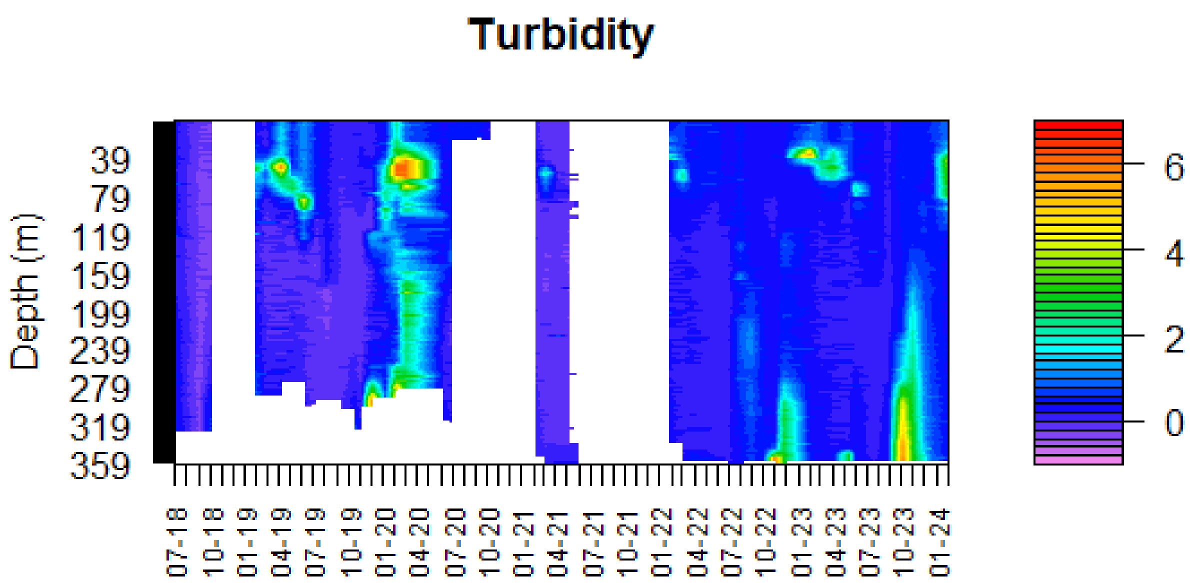


Metrics

Year	80th percentile mixed layer median (across year)
2018	0.2540526
2019	0.2808350
2020	0.2576240
2021	0.2297206
2022	0.2311142
2023	0.2428774

Turbidity

Time Series Plots



Thresholds (Schedule 15) - Dates Exceeded

Year	5
2018	1
2019	4
2020	5
2021	0
2022	4
2023	4
2024	0

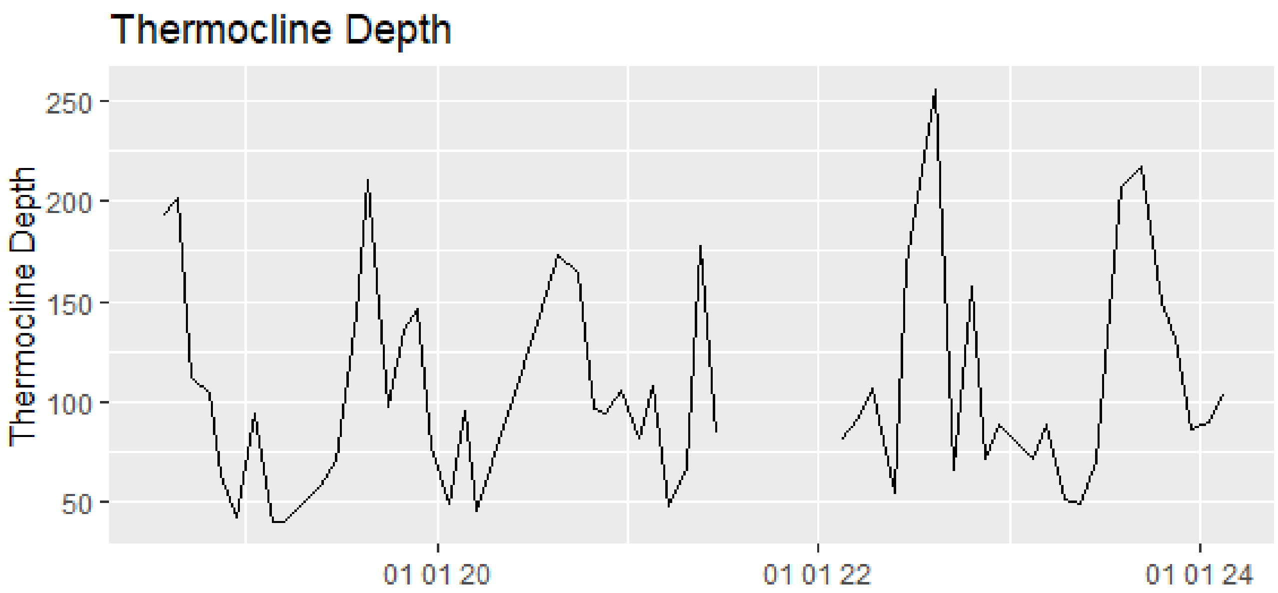
Metrics

Year	Annual Maximum Turbidity in Water Column	Annual Median Turbidity in Water Column
2018	6.371	0.0
2019	132.194	0.263
2020	80.025	0.00
2021	3.180	0.205
2022	41.202	0.314
2023	88.960	0.477

ORC CTD Summary Report

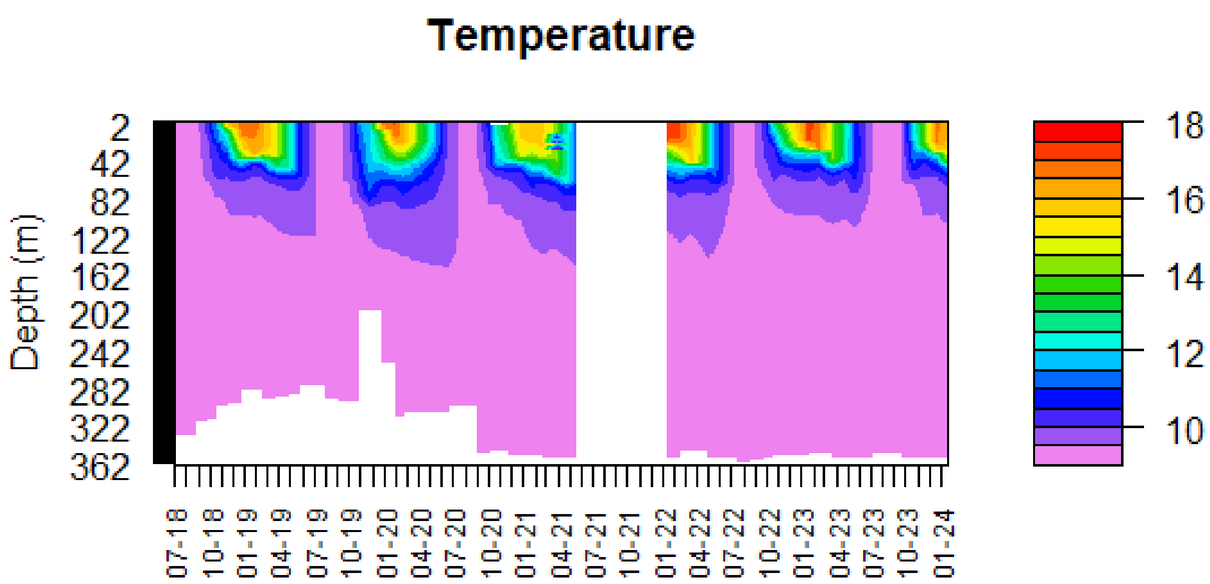
Lake Hawea South Open 2018-07-25 to 2024-02-12

Thermocline depth



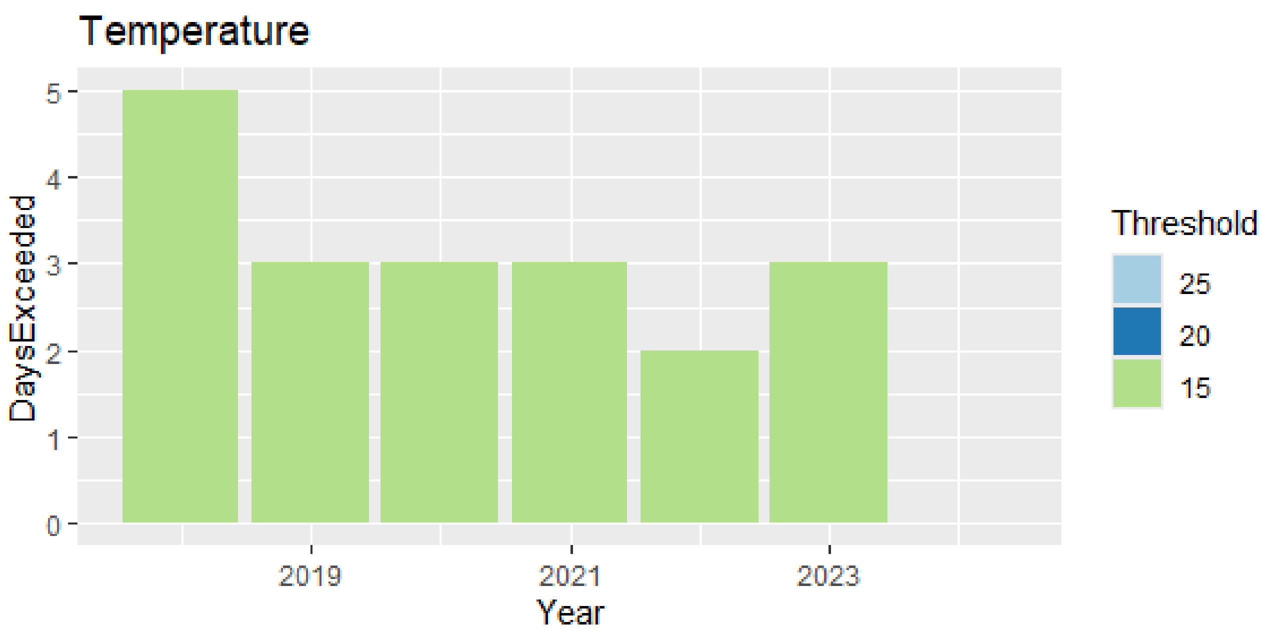
Temperature

Time Series Plots



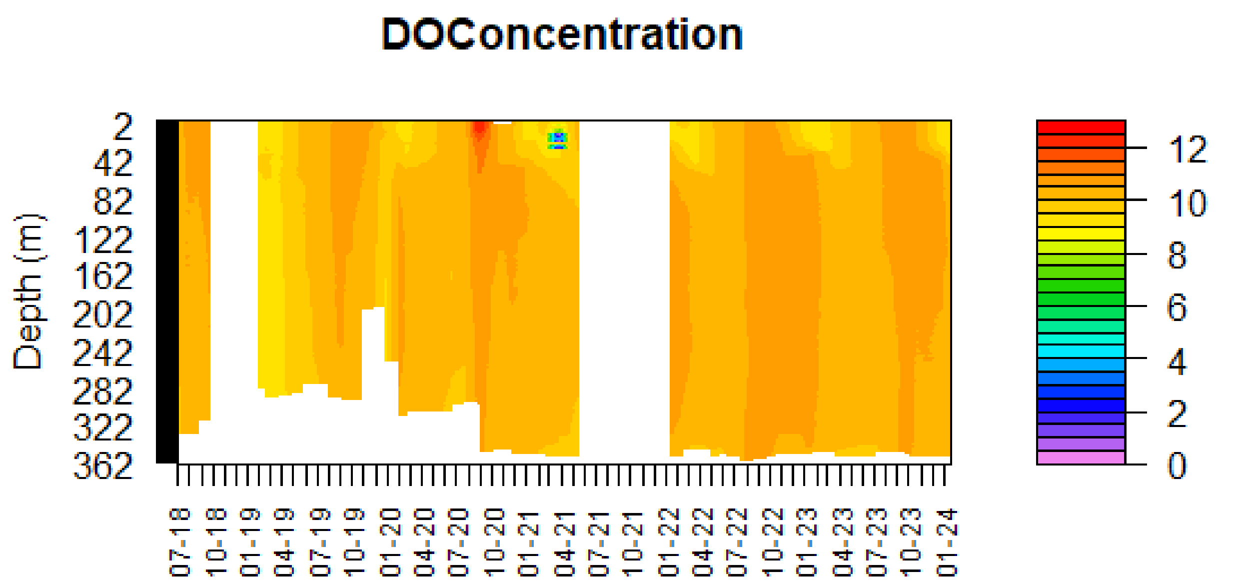
Thresholds - Days Exceeded

Year	15	20	25
2018	5	0	0
2019	3	0	0
2020	3	0	0
2021	3	0	0
2022	2	0	0
2023	3	0	0
2024	0	0	0



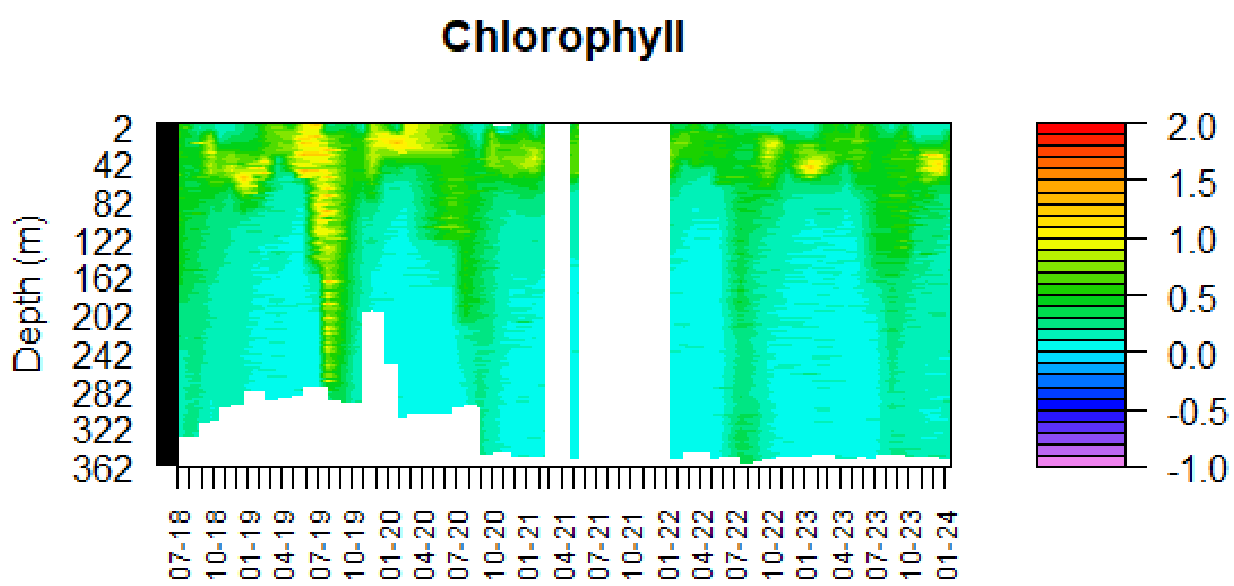
Dissolved Oxygen

Time Series Plots



Chlorophyll a

Time Series Plots

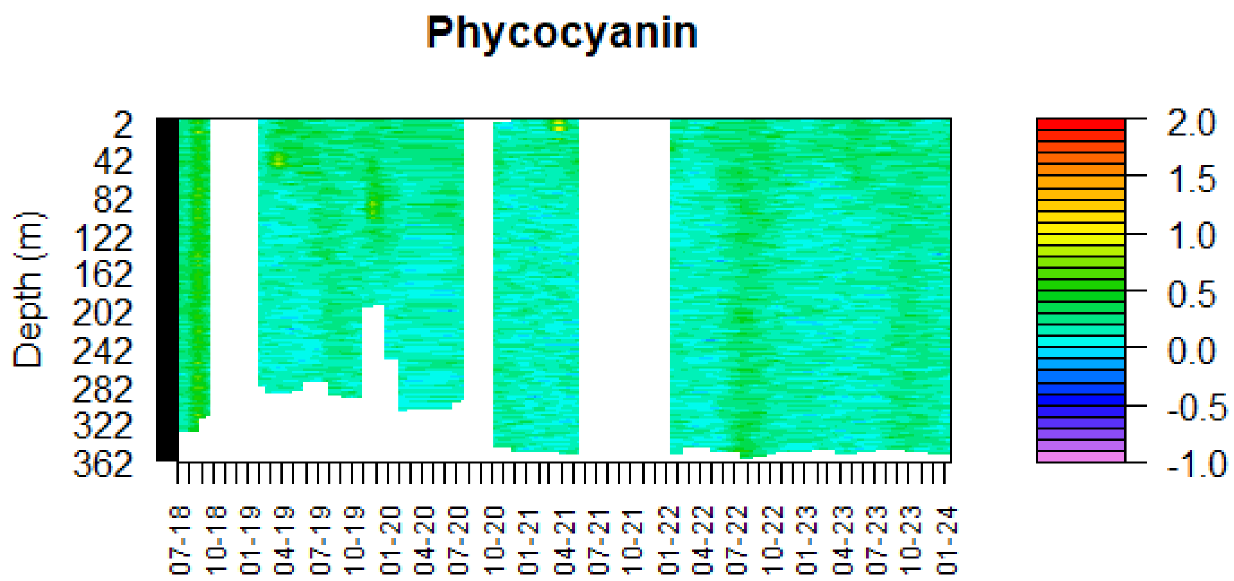


Metrics

Year	Annual Maximum Chla in Mixed Layer	Annual Median Chla in Mixed Layer	Annual Maximum Chla in Water Column	Annual Median Chla in Water Column
2018	1.423	0.552	1.822	0.223
2019	1.577	0.648	2.069	0.275
2020	1.382	0.554	1.382	0.176
2021	0.894	0.489	0.894	0.081
2022	1.418	0.499	4.250	0.127
2023	1.550	0.491	8.183	0.196

Phycocyanin

Time Series Plots

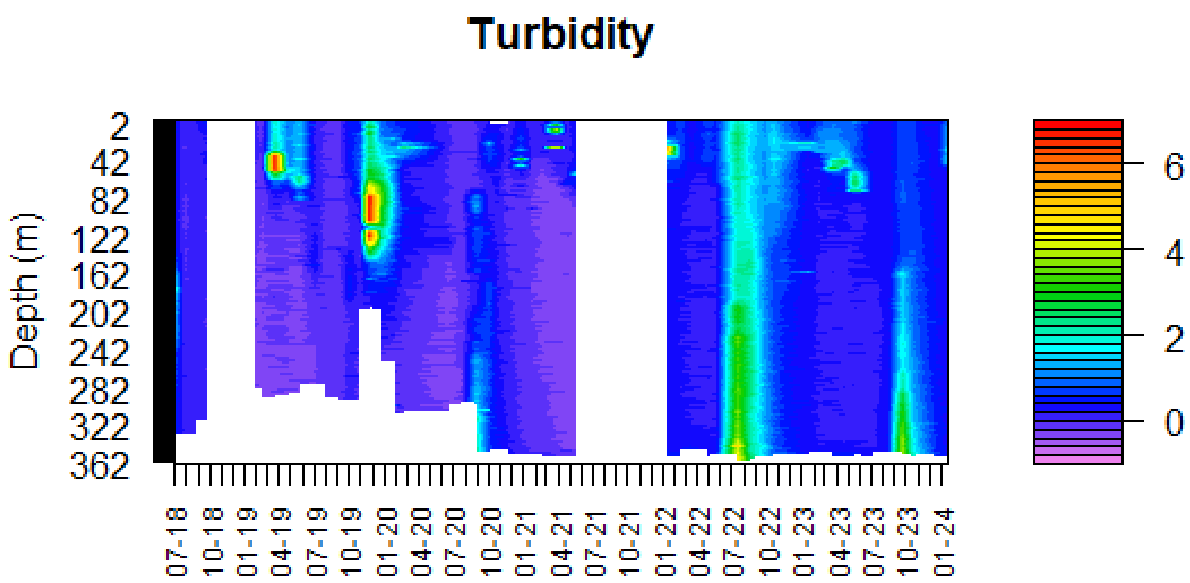


Metrics

Year	80th percentile mixed layer median (across year)
2018	0.3001420
2019	0.2427054
2020	0.1942000
2021	0.2395564
2022	0.2336220
2023	0.2209834

Turbidity

Time Series Plots



Thresholds - Dates Exceeded

Year	5
2018	1
2019	1
2020	6
2021	3
2022	6
2023	0
2024	0

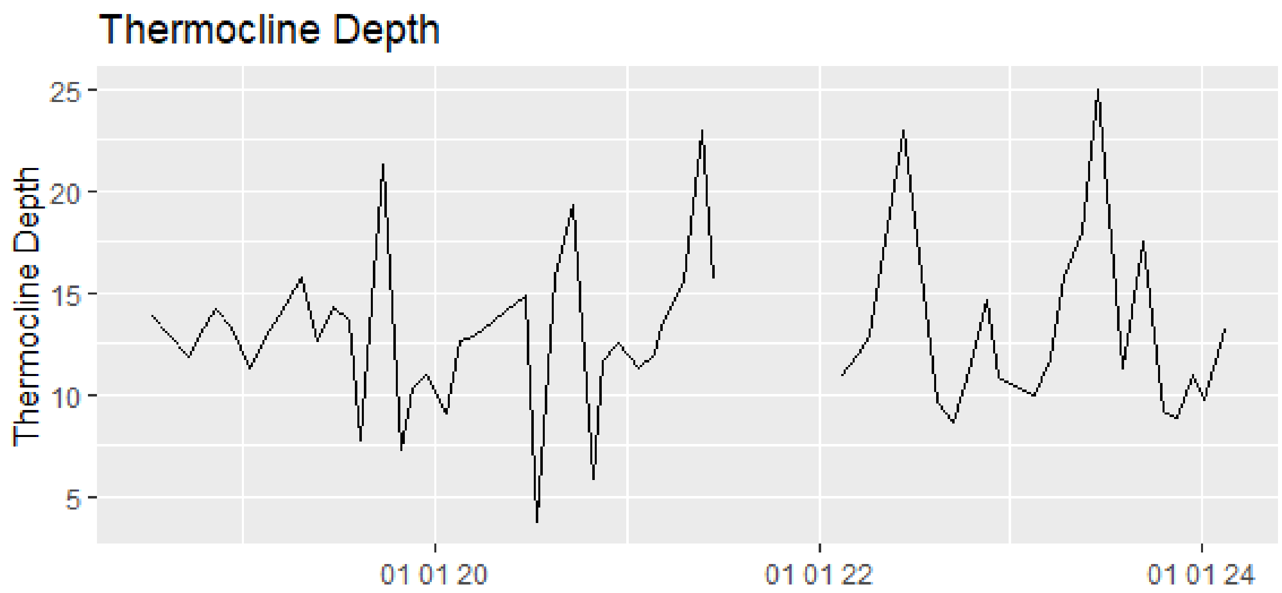
Metrics

Year	Annual Maximum Turbidity in Water Column	Annual Median Turbidity in Water Column
2018	13.782	0.045
2019	18.195	0.136
2020	161.284	0.0
2021	55.892	0.229
2022	41.487	0.721
2023	4.144	0.439

ORC CTD Summary Report

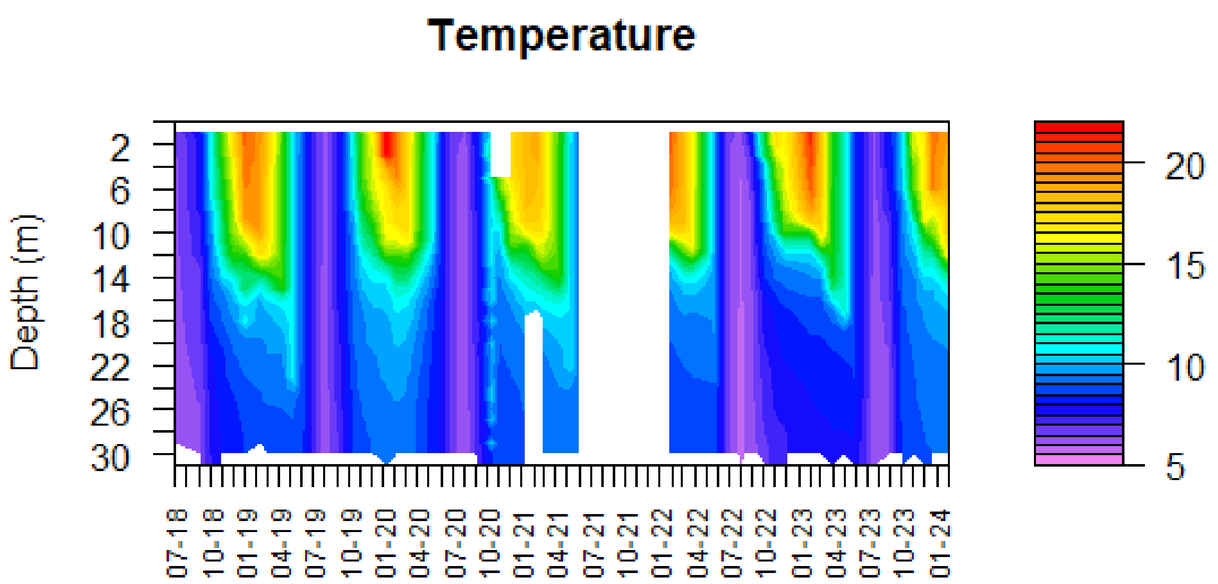
Lake Hayes mid-lake 2018-07-13 to 2024-02-14

Thermocline depth



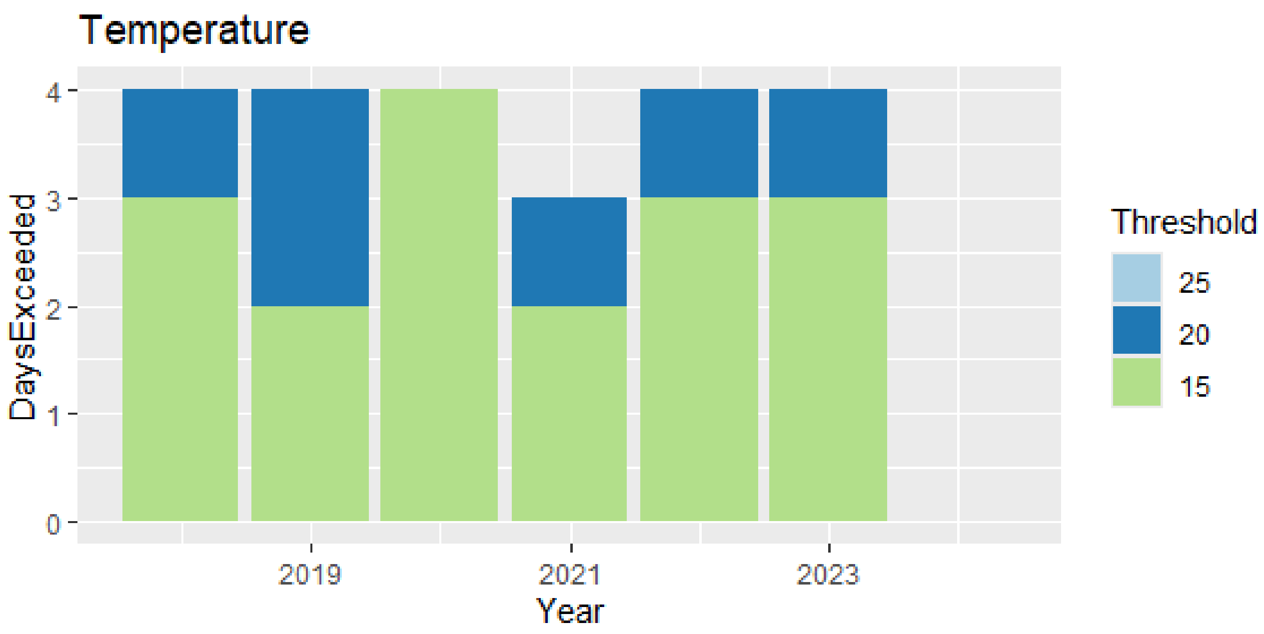
Temperature

Time Series Plots



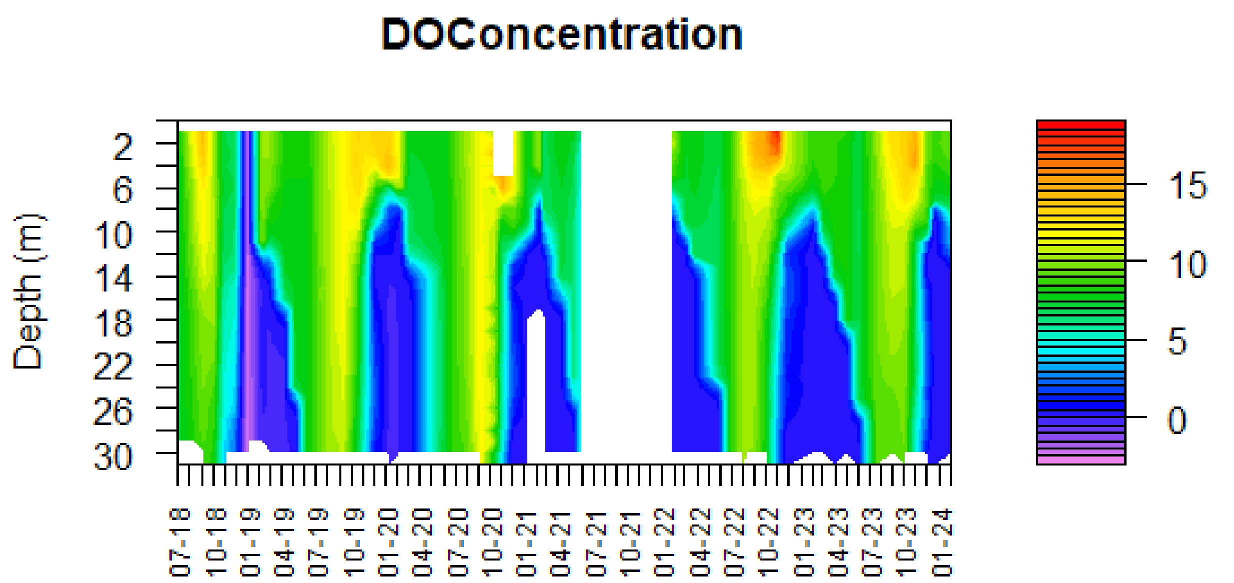
Thresholds - Days Exceeded

Year	15	20	25
2018	3	1	0
2019	2	2	0
2020	4	0	0
2021	2	1	0
2022	3	1	0
2023	3	1	0
2024	0	0	0



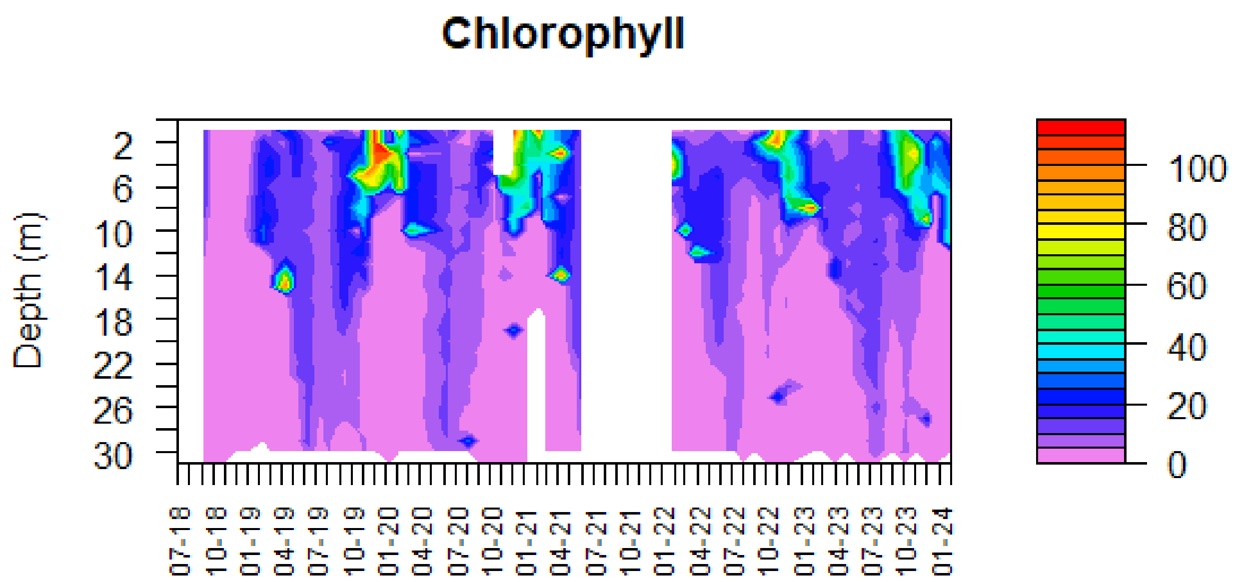
Dissolved Oxygen

Time Series Plots



Chlorophyll a

Time Series Plots

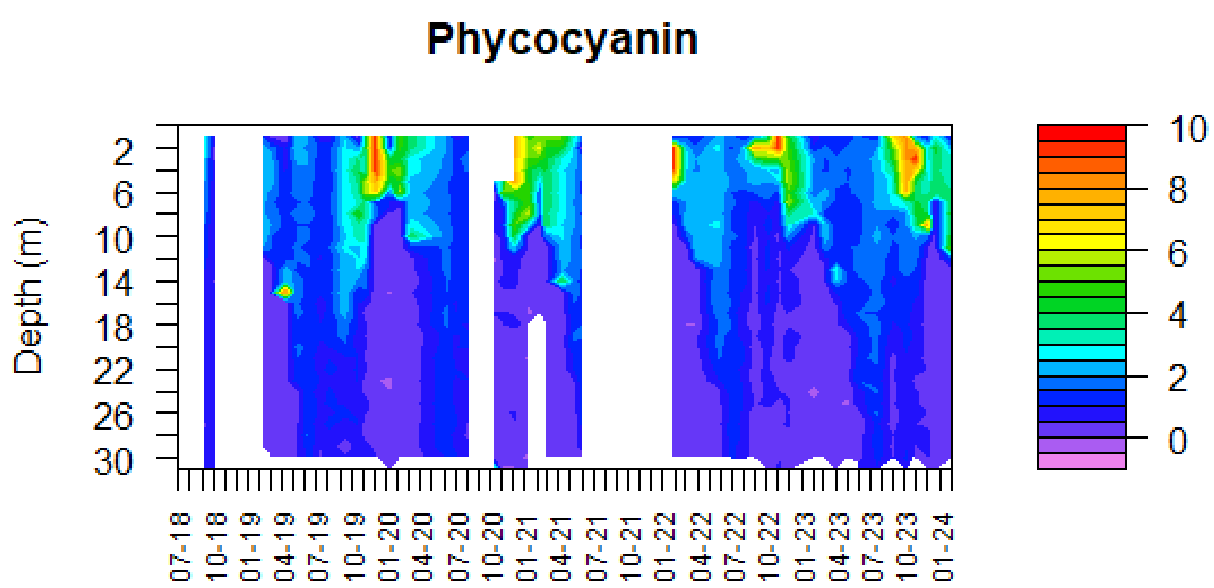


Metrics

Year	Annual Maximum Chla in Mixed Layer	Annual Median Chla in Mixed Layer	Annual Maximum Chla in Water Column	Annual Median Chla in Water Column
2018	299.651	1.045	299.651	0.648
2019	299.635	25.773	299.635	6.718
2020	299.639	37.862	299.660	4.625
2021	150.477	15.313	275.327	0.592
2022	275.296	11.725	275.296	5.353
2023	216.722	30.928	216.722	6.768

Phycocyanin

Time Series Plots

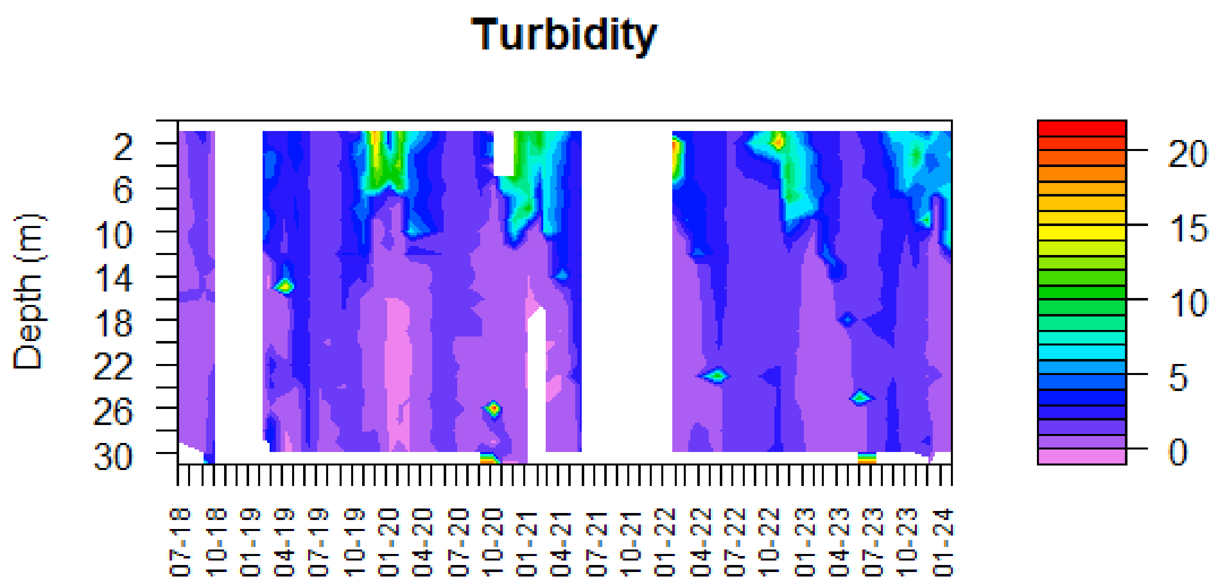


Metrics

Year	80th percentile mixed layer median (across year)
2018	1.898807
2019	4.857108
2020	4.903804
2021	2.246728
2022	2.711449
2023	3.949729

Turbidity

Time Series Plots



Thresholds (Schedule 15) - Dates Exceeded

Year	5
2018	6
2019	6
2020	10
2021	4
2022	11
2023	7
2024	0

Metrics

Year	Annual Maximum Turbidity in Water Column	Annual Median Turbidity in Water Column
2018	114.579	1.337
2019	19.528	1.167
2020	58.215	0.970
2021	111.408	0.973
2022	111.489	1.644
2023	47.006	1.828

Assessment of three lakes in the Otago Region using LakeSPI

Prepared for Otago Regional Council

June 2024

Climate, Freshwater & Ocean Science

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Report date: June 2024
NIWA Project: ORC24202

Quality Assurance Statement		
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[signature]	Approved for release by:	Michael Bruce

Contents

Tables

Figures

Executive summary

Otago Regional Council contracted NIWA to undertake LakeSPI surveys of three lakes in the Otago region (Hāwea, Whakatipu, Wānaka) using LakeSPI (Submerged Plant Indicators) in March 2024.

LakeSPI (Submerged Plant Indicators) is a bioassessment method that uses the development of native submerged plants, and the level of impact by non-native, invasive weeds to indicate lake ecological condition. LakeSPI Indices are reported out of a theoretical 100% and comprise:

- A Native Condition Index where a higher score means healthier, deeper, more diverse beds of native plants.
- An Invasive Impact Index, where a higher score indicates greater impact from exotic weeds.
- A LakeSPI Index that integrates the two supporting indices and provides five narrative categories of condition (Non-vegetated = 0%, Poor = >0-20%, Moderate = >20-50%, High = >50-75%, Excellent=>75%).

Lake Hāwea had a LakeSPI Index of 85%, placing it in the category of excellent ecological condition. The Native Condition Index was 82% on account of the deep extent (17 m to >20 m) of abundant charophyte meadows. Water level fluctuations within an operating range of 8 m limited some shallow plant community types but had also conferred some protection against development of abundant weeds beds and new incursions of weeds such as lagarosiphon, resulting in a low Invasive Impact Index of 8%.

Lake Whakatipu (LakeSPI Index 72.8%) and Lake Wānaka (LakeSPI Index 74.4%) had decreased slightly (≤8%) from an excellent ecological condition in 2020 to a high condition in 2024. Both these lakes possessed a diverse native vegetation (Native Condition Index 77% and 74%) but had moderate impacts from the invasive weed *Elodea canadensis* (Invasive Impact Index 29% and 22%).

Compared with available historical vegetation surveys, Lake Hāwea appears to have remained in a stable condition since the earliest vegetation surveys in 1983. Lakes Whakatipu and Wānaka both showed reduction in the depth extent of vegetation since 1982. *Elodea canadensis* appears to have been more prominent in Lake Whakatipu in 2024 than in 2020, although the reasons for recent expansion of this long-resident weed are not clear.

Compared to 314 lakes surveyed nationally, Lake Hāwea ranks within the top 20 lake positions for the LakeSPI Index and the other two lakes rank amongst the top 40 lakes. Regionally, there are a higher number of Otago lakes in the excellent, high and moderate LakeSPI categories than is the case nationally, however, the current sample set of surveyed lakes is small (11 lakes).

All three lakes were above the national bottom line for the attributes of Submerged Plants set under the National Policy Statement for Freshwater Management. Lake Hāwea and Lake Whakatipu fell into the A band and Lake Wānaka into the B band based on the Native Condition Index. Lake Hāwea and Lake Wānaka fell into the B band and Lake Whakatipu into the C band based on the Invasive Impact index.

We recommend that Lake Hāwea is resurveyed after five years and Lakes Whakatipu and Wānaka after three years. A schedule for LakeSPI monitoring should be developed with priorities and timing for re-surveys based on perceived lake value, stability and known threats to the lakes.

1 Introduction

1.1 Background

The Otago Regional Council (ORC) is responsible for managing Otago's water resources including 63 lakes in the region that are 10 hectares in size or larger. A number of lakes are designated as outstanding water bodies under the proposed Land and Water Regional Plan[1], including Lakes Whakatipu and Wānaka.

Amongst the threats to lakes and their ecology are land use changes, urban and agricultural intensification which can result in increased sediment or nutrient loads to water bodies. The introduction of alien aquatic invaders such as weeds or algae puts further pressure on vulnerable native ecosystems.

As one aspect of the ecological monitoring of Otago's Lakes, ORC has previously commissioned NIWA to apply the LakeSPI (Lake Submerged Plant Indicators) bioassessment method to priority lakes in the region. LakeSPI has been applied to over 300 lakes nationally to track and report on lake ecological health according to the health and diversity of the lake vegetation. In 2020, NIWA surveyed Lakes Hāwea, Whakatipu, Wānaka, Dunstan, Onslow and Hayes (Burton 2021). In 2023, NIWA surveyed Lake Waihola, Tomahawk Lagoon and Lake Tuakitoto (de Winton et al. 2023). Prior to this work, NIWA had applied LakeSPI to a further two lakes (Lakes Moke and Diamond) in 2007 (de Winton and Champion 2008).

In 2023/24, ORC commissioned NIWA to repeat LakeSPI surveys for Lakes Hāwea, Whakatipu and Wānaka. This report provides LakeSPI results for each lake accompanied by a brief description of vegetation character, notes on any historical vegetation surveys carried out and a discussion of LakeSPI results and any impacts or threats that may be facing these lakes. Recent LakeSPI results were also compared with those generated from historical vegetation surveys to identify changes over longer timeframes.

[1] Draft Land and Water Regional Plan: Proposed new rules and regulations for the Upper Lakes Rohe | Otago Regional Council (orc.govt.nz) https://www.orc.govt.nz/plans-policies-reports/land-and-water-regional-plan/proposed-changes-to-rules-and-regulations/upper-lakes-rohe

2 Methods

2.1 LakeSPI method

LakeSPI is a management tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and for monitoring changes in lakes. Key features of aquatic vegetation structure and composition are used to generate three LakeSPI indices:

- 'Native Condition Index' – This captures the native character of vegetation in a lake based on diversity and extent of indigenous plant communities. A higher score means healthier, deeper, diverse beds.
- 'Invasive Impact Index' – This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species. A higher score means more impact from introduced species, which is often undesirable.
- 'LakeSPI Index' – This is a synthesis of components from both the native condition and invasive impact condition of a lake and provides an overall indication of lake condition. The higher the score the better the condition.

Key assumptions of the LakeSPI method are that native plant species and high plant diversity represents healthier lakes or better lake condition, while invasive plants are ranked for undesirability based on their displacement potential and degree of measured ecological impact (Clayton and Edwards 2006, de Winton et al. 2012). Up to six native plant communities are recognised by LakeSPI: Emergents, Turf plants, Charophytes, Isoetes, Milfoils, and Pondweeds. In addition, up to 10 invasive weed species are recognised and contribute to the Invasive Impact Index.

Because lakes have differing physical characteristics that can influence the extent and type of submerged vegetation, each of the LakeSPI indices are expressed in this report as a percentage of a lake's maximum scoring potential. Scoring potential reflects the maximum depth of the lake to normalise the results from very different types of lakes. A lake scoring full points for all LakeSPI indicator criteria would result in a theoretical LakeSPI Index close to 100%, a Native Condition Index of 100% and an Invasive Impact Index of 0%.

A complete description of measured characteristics is given in the technical report and user manual at https://lakespi.niwa.co.nz/about but includes measures of diversity from the presence of key plant communities, the depth extent of vegetation and the extent that invasive weeds are represented. The LakeSPI method is supported by a web-reporting service found at https://lakespi.niwa.co.nz/, where scores for lakes assessed to date can be searched and displayed. This secure and freely accessible data repository allows agencies to compare lake scores with other lakes regionally and nationally as required.

2.2 Study lakes

Three lakes located within the Otago Region have been assessed for this report: Hāwea, Whakatipu and Wānaka (Figure 1).

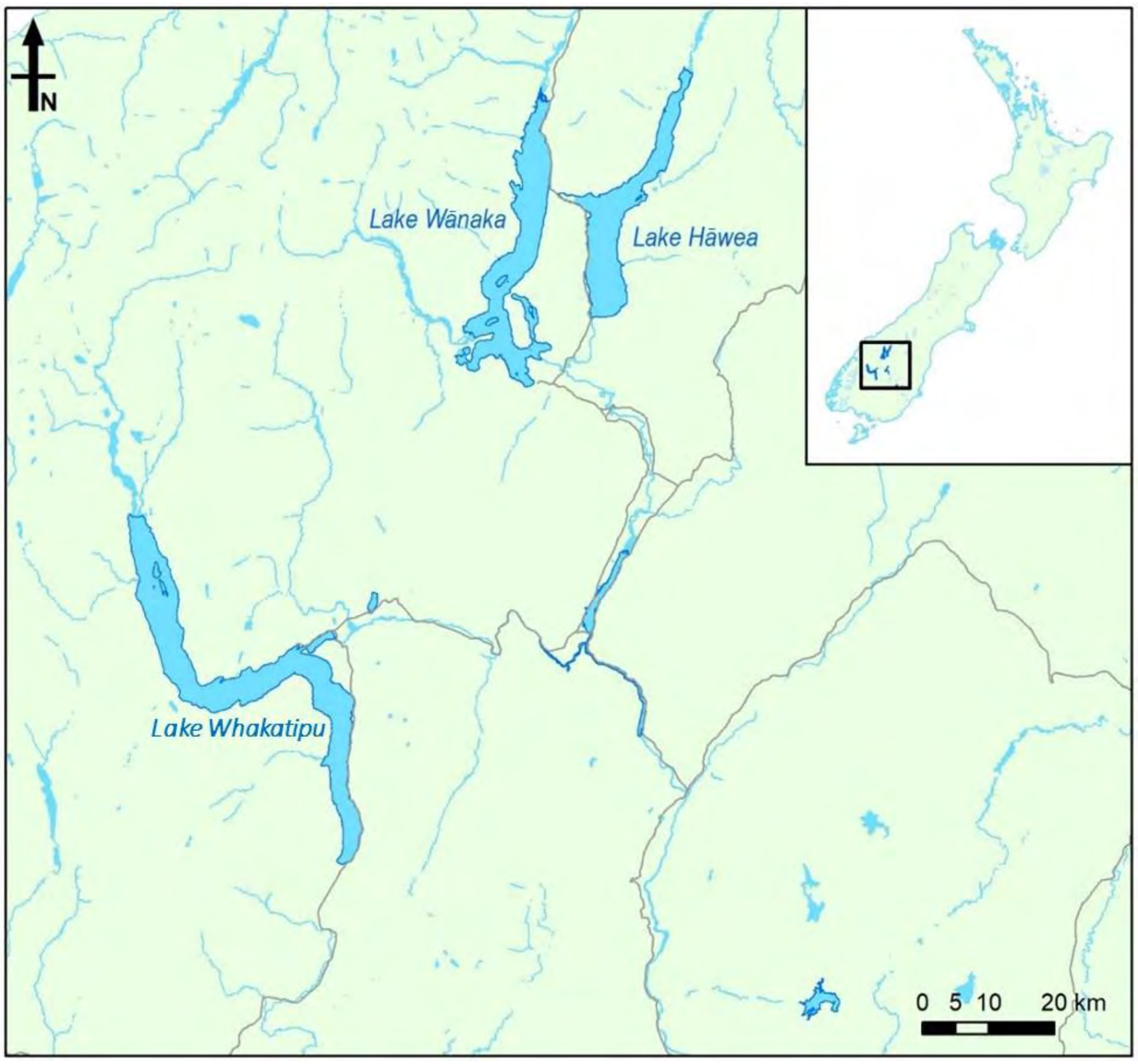


Figure 1. Map showing location of the three Otago lakes surveyed using LakeSPI for this report.

2.3 Field application

Lakes Hāwea, Whakatipu and Wānaka were assessed in March 2024 (Table 1). The LakeSPI method (Clayton and Edwards 2006) was applied to five LakeSPI baseline sites (Appendix B) selected within each lake. Baseline sites were initially selected to be representative of maximal vegetation development and situated away from local influences such as streams. Where possible sites were also aligned with those where historical survey data was available.

At each site divers recorded relevant vegetation characteristics on data sheets. Observations were then entered into the NIWA LakeSPI database and used to calculate LakeSPI indices for each lake. Additionally, an inventory of all submerged plant species encountered was also made (Appendix A). Species lists are beyond the scope of a regular LakeSPI survey but have been provided as additional records to support the lake by lake interpretation of results.

All equipment and boats were decontaminated between sites according to NIWA's standard operating procedures to prevent the spread of freshwater invasive species (Burton 2019). These precautions equal or exceed the Check, Clean, Dry protocols (MPI 2021).

Table 1: Otago lakes surveyed using LakeSPI in 2024 showing maximum lake depth, date of survey and number of sites surveyed.

Lake	Lake depth (m)	Survey date	Baseline sites
Lake Hāwea	384	19 March 2024	5
Lake Whakatipu	380	17 March 2024	5
Lake Wānaka	311	20 March 2024	5

2.4 LakeSPI status

For ease of reporting results, five lake condition categories are used to provide a description of a lakes status at the time of a survey. These categories are allocated according to the LakeSPI Index score:

Score	=	LakeSPI Category
>75%	=	Excellent
>50-75%	=	High
>20-50%	=	Moderate
>0-20%	=	Poor
0%	=	Non-vegetated

2.5 LakeSPI stability

Changes in LakeSPI indices can be assessed over multiple surveys to provide an indication of current stability in lake condition and the direction of any change. Where historical vegetation data was available, LakeSPI indices were generated from information recorded from the same current day baseline site locations. Guidelines (Figure 2) based on expert judgement suggest a scale of probabilities for ecologically significant change in lake condition over longer periods and multiple surveys, using averaged LakeSPI indices over repeated surveys. These guidelines considered variation by different observers and the response of LakeSPI scores to major ecological events in lakes. The significance for the various levels of change are:

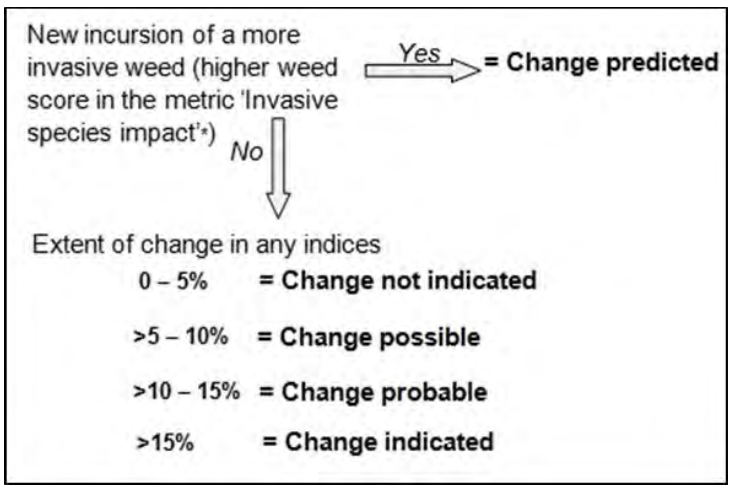


Figure 2: Guidelines for assessing the ecological significance of change in LakeSPI Indices over multiple surveys of a given lake.

In addition, the likelihood of a statistically significant change in LakeSPI scores over time was based on analysis of the direction and magnitude of change in indices across the surveyed sites. A paired t-test (Statistics Kingdom) was used to compare site results between surveys at the significance level $p < 0.05$.

2.6 National Policy Statement for Freshwater Management

The National Policy Statement for Freshwater Management (NPS-FM 2020) has included two LakeSPI indices as attributes in its National Objectives Framework (NOF) that require action plans (NPS-FM 2022[2], Appendix 2B, Tables 11 and 12). Attribute bands are related to Native Condition Index and Invasive Impact Index values as shown in Table 2. Any lake that falls below the national bottom line is considered degraded and may require councils to prepare a time-based action plan to achieve a target status. If the current state is below the national bottom line due to natural processes (e.g., naturally non-vegetated geothermal or peat lakes), a target attribute state below the national bottom line may be set. Currently, the Ministry for the Environment state that the Native Condition Index and Invasive Impact Index should be assessed every three years.

Table 2: National Objectives Framework attribute table for LakeSPI indices. Native Condition Index and Invasive Impact Index attribute bands from the NPS-FM (2020, Appendix 2B, Tables 11 and 12).

Attribute band	Native Condition Index	Invasive Impact Index
A	>75%	0*
B	>50 and ≤75%	>1 and ≤25%
C	≥20 and ≤50%	>25 and ≤90%
National bottom line	20%	90%
D	<20%	>90%

*Note Invasive Impact Index for non-vegetated lakes is not included in the A band.

[2] https://consult.environment.govt.nz/freshwater/npsfm-and-nesf-exposure-draft/user_uploads/exposure-draft-changes-to-npsfm-2020.pdf

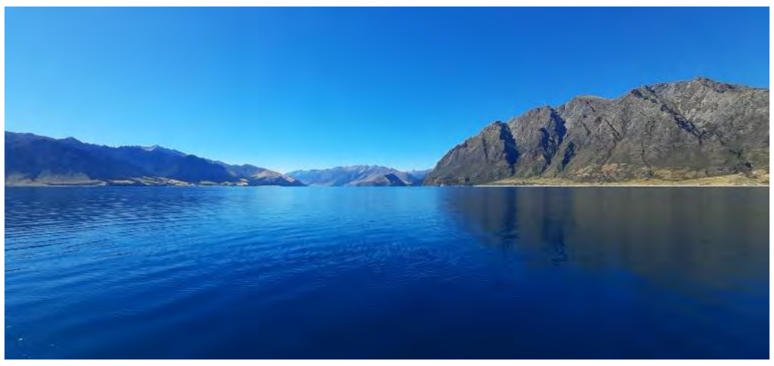
3 LakeSPI report cards

This section provides individual report cards for the Otago lakes surveyed in 2024 using LakeSPI. Table 3 presents LakeSPI results for each lake in order of their LakeSPI Index scores, with the indices presented as a percentage of maximum scoring potential. In the following section lakes are discussed in alphabetical order.

Table 3: Summary of current LakeSPI Indicesfor three lakes in the Otago Region in order of their overall lake condition.

Lake	Most Recent LakeSPI Survey	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall Condition
Hāwea	19/03/2024	85	82	8	Excellent
Wānaka	20/03/2024	74	74	22	High
Wakatipu	17/03/2024	73	77	29	

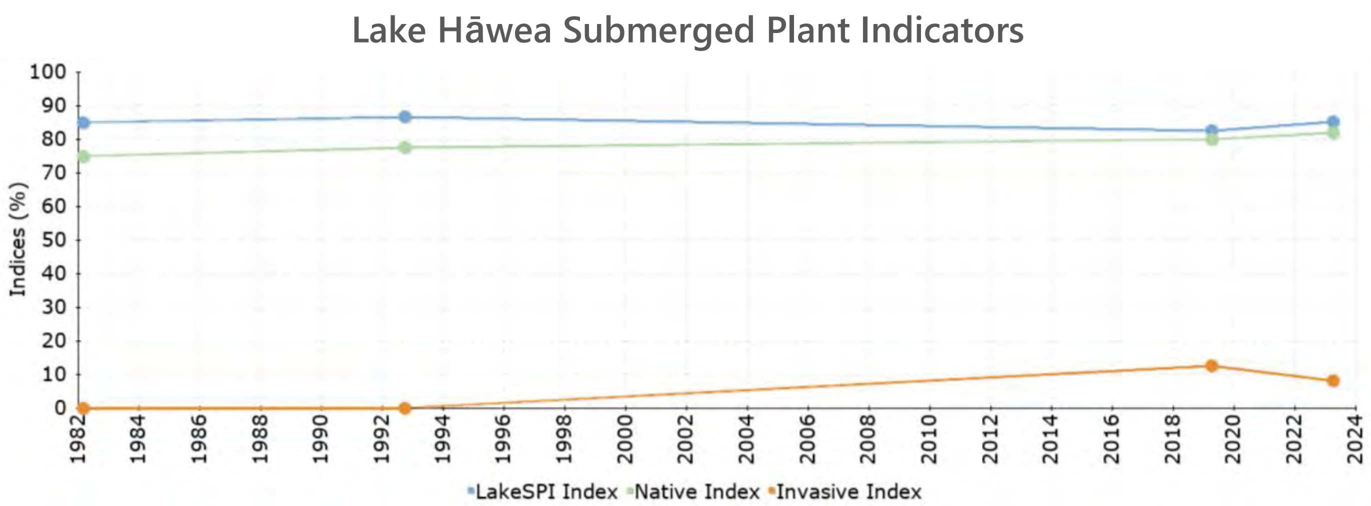
3.1 Lake Hāwea



Lake condition:	Excellent
Lake type:	Glacial/Hydro
Lake maximum depth:	384 m
Max depth of vegetation:	20+ m

3.1.1 Results

In 2024, Lake Hāwea was in an excellent ecological condition with a LakeSPI Index of 85% (Figure 3). This score reflects the presence of an extensive native plant community (Native Condition Index 82%) with very little impact from invasive weed species (Invasive Impact Index 8%).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2024	Excellent	85.2%	82.0%	8.1%
February 2020	Excellent	82.4%	80.0%	12.6%
December 1992 *	Excellent	86.5%	77.5%	0.0%
February 1982 *	Excellent	85.0%	75.0%	0.0%

**1982 & 1992 indicative only, based on limited data from historical sites.*

Figure 3: LakeSPI results for Lake Hāwea. LakeSPI indices expressed as a percentage of lake maximum potential.

Water level at the time of the survey (343.1 masl) was close to the lake's reported median[3]. In accordance with the operating range for this hydro-generation lake (8 m), the shallow littoral zone above approximately 6 m depth had extremely low plant abundance, and it was also frequently rocky.

[3] https://envdata.orc.govt.nz/AQWebPortal/Data

Charophytes dominated the submerged vegetation of Lake Hāwea. High cover (>75%) charophyte meadows were recorded at all sites that extended from c. 6 to 8 m down to depths of between 17 and >20 m depth. Lower covers of charophytes continued beyond 20 m at all sites. Meadows comprised a mosaic of species, with *Nitella pseudoflabellata* and *Chara divergens* dominating and *Chara australis* and *Nitella claytonii* also contributing (Figure 4a, b). A further three charophyte species were also recorded at low abundance (Appendix A).

Native pondweeds (*Potamogeton cheesemanii* and *P. ochreatus*) were recorded to an unusually deep depth of 8 m. While they were usually found at low cover (≤5%), pondweeds formed a band of higher cover at two sites within a 6 to 8 m depth range (Figure 4c).

Elodea (*Elodea canadensis*) was the only invasive weed recorded in Lake Hāwea. Elodea was recorded from only one site but formed high cover band between 5 and 7 m depth (Figure 4d).

Native milfoil (*Myriophyllum triphyllum*) was uncommon and generally limited to the rocky shallows from 2 to 5 m depth at low cover (≤5%). A native amphibious turf plant, *Crassula sinclairii*, was also recorded at one site at low cover (≤5%) at about 4 m depth. Both of these species are capable of growing on damp substrate during low lake level events, but they were very restricted in distribution to sandy pockets amongst shallow rocky substrate (Figure 4e).

Freshwater mussels (*Echyridella menziesii*) were common at all sites (Figure 4f).

3.1.2 Discussion

No significant changes in the LakeSPI Indices are apparent over 2020 to 2024, and indicative results from other sites surveyed in the 1980s and 1990s (Figure 3) suggest lake vegetation has been stable over the longer-term.

A low Invasive Impact Index of 8% from the recent survey indicated the minimal impact of the only weed species present, elodea. Elodea was first recorded in 1992, detected at two locations during wider surveillance for weeds, and it formed a complete cover between 4-6 m depth at one of these sites (Clayton 1993). Elodea and other vascular submerged plants (pondweed, milfoil and turf species) were associated with a shallow basin and a stream inflow where water ponding or damp substrates would have remained when lake levels were low.

An earlier 1982 survey (Clayton et al. 1986) recorded only charophytes and bryophytes with no submerged vascular plants recorded. They attributed the absence of these shallow to mid-depth range plants to the large water level fluctuations, up to 10 m before 1982, that dewatered the lake littoral. Since 1985, a more moderate operating range of 8 m have been consented and this is likely to have allowed the increase in vascular plants recorded during the recent surveys.

Lake Hāwea is adjacent to Lake Wānaka, which is a potential source of the invasive weed lagarosiphon (*Lagarosiphon major*) that can be transported to other lakes on contaminated boats and fishing equipment. However, it is unlikely that lagarosiphon would have significant impacts in Lake Hāwea on account of the water level fluctuations, which at 8 m have a greater range than the 6.5 m depth range recorded for lagarosiphon.

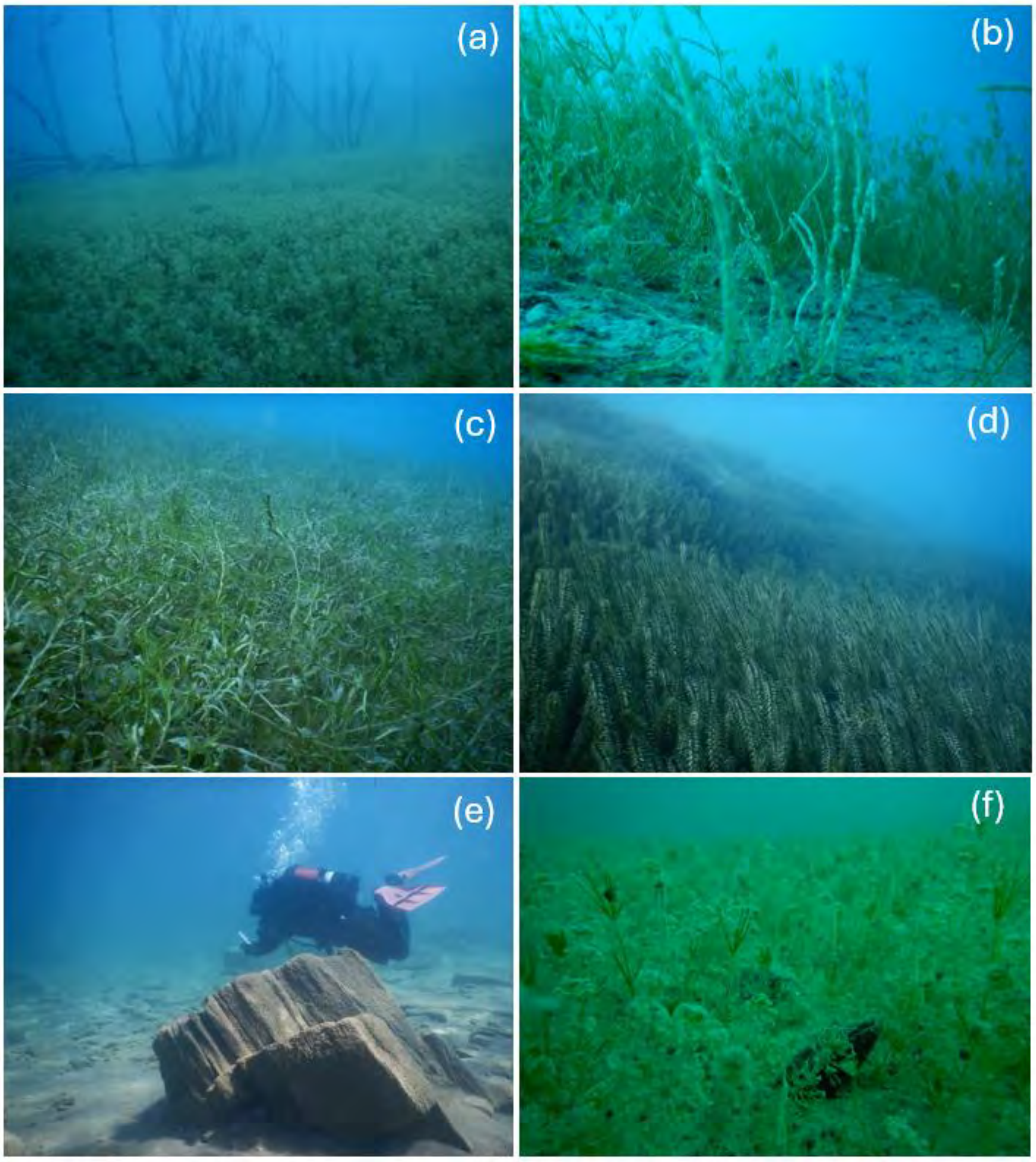


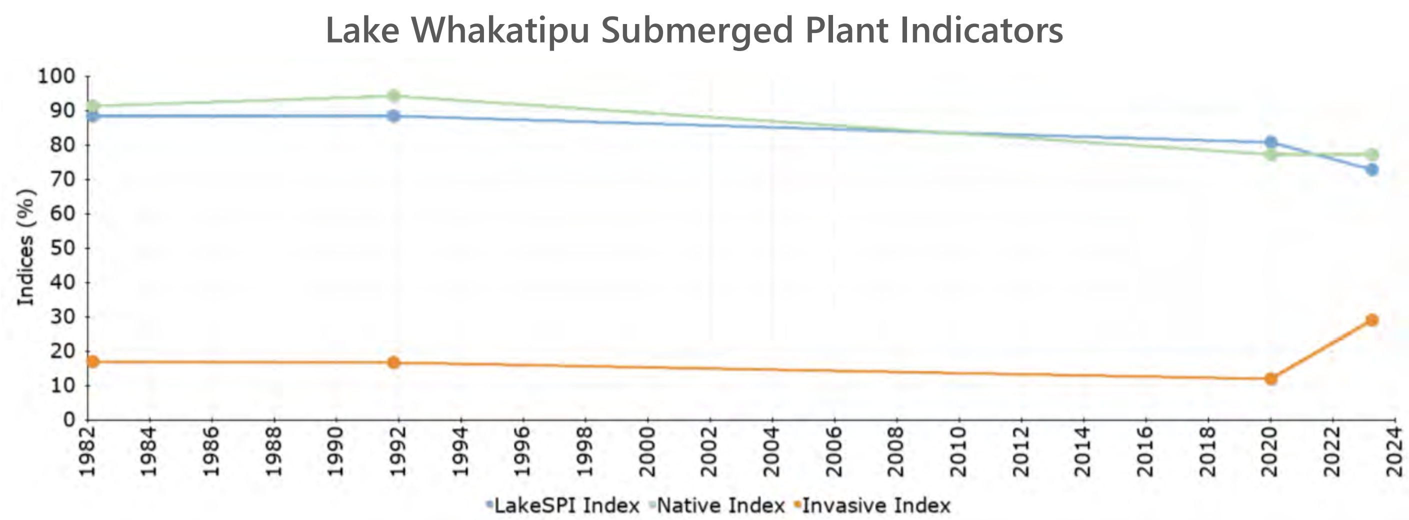
Figure 4: Submerged vegetation in Lake Hāwea in 2024. a) charophytes meadows with submerged trees in the background, b) close-up of deeper charophyte species *Nitella claytonii* (foreground) and *Chara australis* (background), c) a band of the native pondweed (*Potamogeton ochreatus*), d) the bed of invasive elodea (*Elodea canadensis*, e) diver swimming over bare, rocky shallows, f) a freshwater mussel surrounded by charophytes.

3.2 Lake Whakatipu

Lake condition:	High
Lake type:	Glacial
Lake maximum depth:	380 m
Max depth of vegetation:	20+ m

3.2.1 Results

In 2024, Lake Whakatipu was in a high ecological condition with a LakeSPI Index of 73%, close to the interface with the excellent category that the lake has previously been assessed (Figure 5). This result was driven by a relatively high Native Condition Index of 77% and a moderate Invasive Impact Index of 29% (Figure 5).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2024	High	72.8%	77.3%	28.9%
November 2020	Excellent	80.8%	77.3%	11.9%
January 1992 *	Excellent	88.5%	94.2%	16.7%
February 1982 *	Excellent	88.4%	91.3%	17.0%

**1982 & 1992 indicative only, based on limited data from historical sites.*

Figure 5: LakeSPI results for Lake Whakatipu. LakeSPI indices expressed as a percentage of lake maximum potential.

Charophytes were the most abundant community type recorded. High cover (>75%) charophyte meadows were recorded from all but one site, to depths of between 8 and >20 m depth. Meadows were comprised of mixed species including *Nitella claytonii* (Figure 6a), *Nitella pseudoflabellata* and

Chara australis. A further five charophytes (Appendix A) also contributed to the submerged vegetation at lower abundance.

Tall growing vascular plants included native pondweeds *(Potamogeton cheesemanii*, *Potamogeton ochreatus*), which were recorded at low covers (≤25%) to unusually deep maximum depths of 7 to 9 m (Figure 6b, c). The native milfoil (*Myriophyllum triphyllum*) also formed low covers (≤5%) at all sites, usually shallower than 3.5 m.

The invasive weed elodea (*Elodea canadensis*) was the only invasive species recorded in the lake (Figure 6c, d). It was common or formed open canopy beds at four sites, usually between 3.5 and 7 m depth.

Native quillwort (*Isoetes alpina*) dominated the shallow littoral zone at all sites, forming high cover swards (>95%) within a shallow range to depths between 3.3 and 4.8 m (Figure 6e,f). Six native turf plants (Appendix A) were recorded in the upper range of the quillwort bed at low individual cover (≤5%) to 2 m depth. The threat listed turf plant *Trithuria inconspicua* subsp. *brevistyla* (Threatened–Nationally Vulnerable, de Lange 2018) was recorded in 2020, and was still present in 2024 as part of the shallow plant community. Bryophytes, mostly mosses, were present attached to rocks in the wave splash zone and amongst the bases of quillwort in a similar depth range to the turfs.

Although deep-water bryophytes (mosses and liverworts growing at depths >10m) were also documented during a simultaneous investigation to the LakeSPI survey (de Winton et al. 2024), they are not included in the LakeSPI method, and were recorded beyond the diver's 20 m limits.

3.2.2 Discussion

Despite the reduction from excellent to high ecological status of Lake Whakatipu since 2020 (Figure 5), no statistically significant changes in LakeSPI Indices were detected due to variation between the sites. A closer look at the results indicated that some measures of native plant depth extent had decreased, and representation by the invasive weed elodea has increased since 2020.

In 2020, charophytes at >10% cover extended to ≥20 m at four sites, while in 2024 just two sites extended as deeply. In contrast, charophyte meadows were as deep or deeper in 2024 as they were in 2020, with the exception of one site. The absence of charophyte meadows at this one survey site could not be explained as slope and substrate appeared to be suitable. Overall, no clear trends in depth extent of submerged vegetation could be discerned over 2020 to 2024.

From an earlier survey in 1992 (de Winton et al. 1993), a selection of four sites in the same vicinity as 2020-2024 sites showed high cover (>75%) charophyte meadows extending >20 m depth. From a survey in 1982 (Clayton 1983), a selection of five sites in the same vicinity as 2020-2024 sites also indicated meadows extending >20m. As submerged vegetation is dependent on adequate light for net photosynthesis, water clarity is one of the major factors determining the maximum depth to which submerged plants can grow. The changes in submerged vegetation extent suggest marked reduction in the water clarity of Lake Whakatipu since these early surveys.

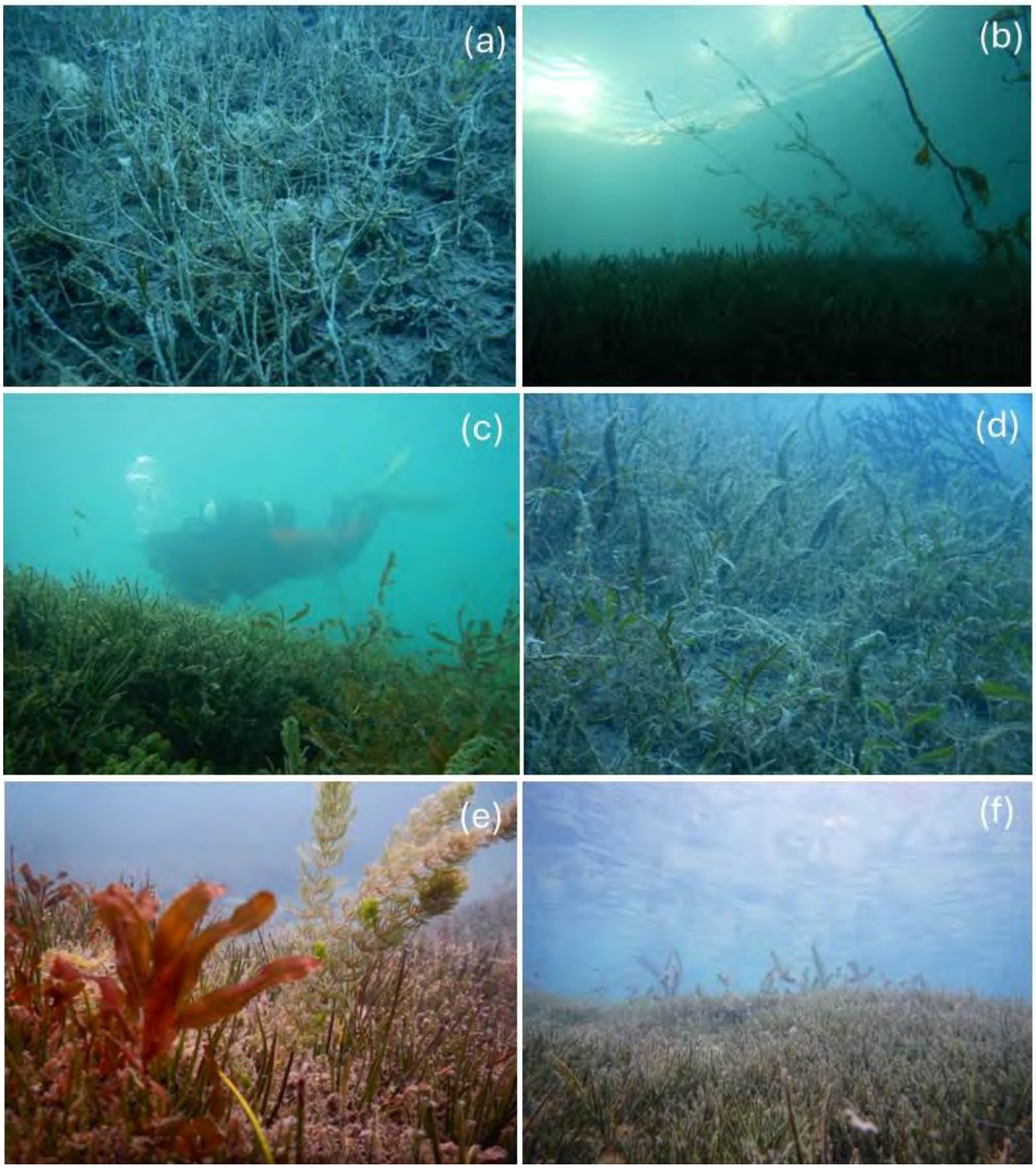


Figure 6: Submerged vegetation in Lake Whakatipu in 2024. a) the charophytes *Nitella claytonii* and *Nitella pseudoflabellata* contributing to the deeper meadow, b) the red pondweed (*Potamogeton cheesemanii*) silhouetted against the water surface and, c) contributing to mixed vegetation with charophytes, and the invasive weed elodea (*Elodea canadensis*), d) elodea forming an open canopy with native pondweed, e) quillwort (*Isoetes alpina*) with emergent milfoil (*Myriophyllum triphyllum*) and red pondweed, f) a sward of quillwort in shallow water.

In 2024, elodea was more prominent in the lake vegetation than it was in 2020, being recorded at double the number of sites. This has led to a higher Invasive Impact Index value in 2024 and a greater 'penalty' on the LakeSPI Index. Elodea has been present in Lake Whakatipu since at least 1970 (Hill 1970), therefore is likely to have colonised all available habitat. However, earlier fluctuations in abundance have been detected (de Winton et al. 1993) suggesting development of this weed may respond to as yet unknown factors. Invasive buttercup, *Ranunculus trichophyllus,* recorded in 1992 (de Winton et al. 1993), was not recorded during the 2020 or 2024 survey.

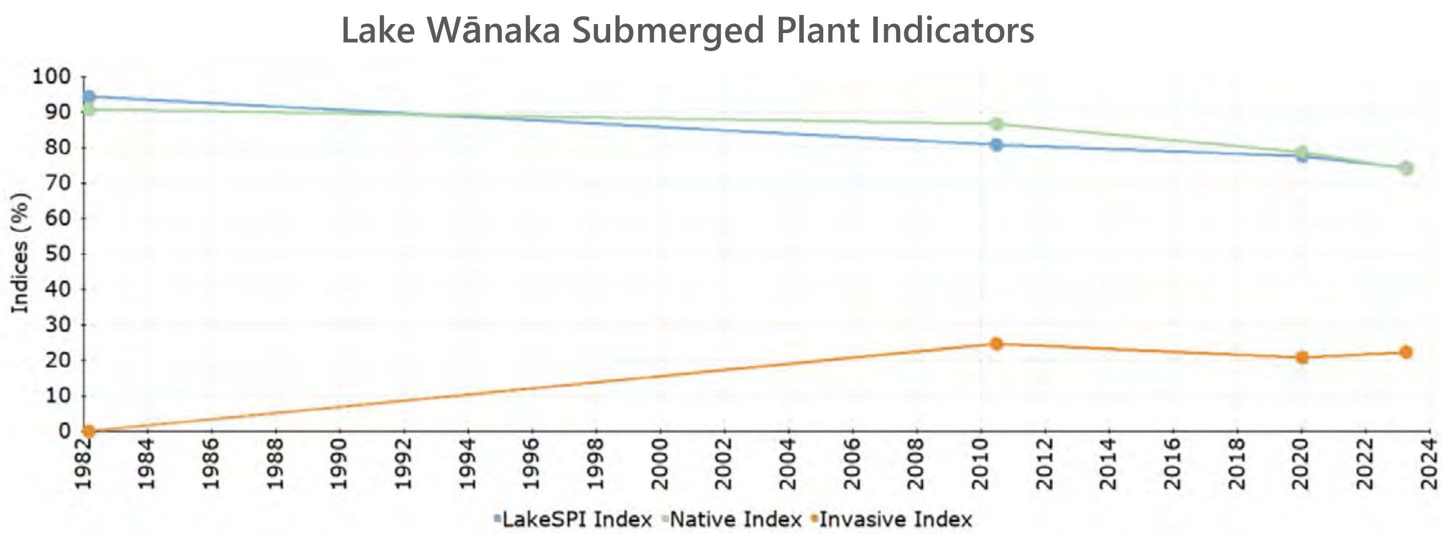
The threat of invasion by the weed lagarosiphon (*Lagarosiphon major*) remains. Repeated incursions have been detected and eradicated from Lake Whakatipu at the Frankton Arm, Queenstown Bay and Kingston since at least 2007 and a lagarosiphon plant was removed from shoreline near to Walter Peak (Clements 2023). Lagarosiphon is locally established at the lake outlet (upper Kawarau River) and is the closest and most likely source of new incursions to Lake Whakatipu as boat dispersed fragments, as well as longer distance transfer from Lake Dunstan and possibly Lake Wānaka.

3.3 Lake Wānaka

Lake condition:	High
Lake type:	Glacial
Lake maximum depth:	311 m
Max depth of vegetation:	20+ m

3.3.1 Results

In 2024 the ecological condition of Lake Wānaka decreased slightly to the high category, with a LakeSPI Index of 74% (Figure 7). This score remained close to the threshold for an excellent condition (>75%) and was driven by a high Native Condition Index of 74% and a moderate Invasive Impact Index of 22% (Figure 7).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2024	High	74.4%	74.0%	22.2%
November 2020	Excellent	77.6%	78.7%	20.7%
February 2011 *	Excellent	80.7%	86.7%	24.7%
February 1982 *	Excellent	94.4%	90.7%	0.0%

**2011 & 1982 indicative only based on limited data from historical sites.*

Figure 7: LakeSPI results for Lake Wānaka. LakeSPI indices expressed as a percentage of lake maximum potential.

Charophytes were the most abundant plant community. High cover (>75%) charophyte meadows were recorded from three out of the five sites to a maximum depth of 19.7 m (Figure 8a).

Meadows usually comprised *Nitella claytonii*, *N. pseudoflabellata and*, *Chara divergens* (previously known as *C. braunii*), and with an additional five charophyte species (Appendix A) contributing to the lake vegetation across the vegetated littoral zone.

Tall growing native plants included red pondweed *(Potamogeton cheesemanii*) that generally grew down to depths between 6.5 and 9 m at covers of 6-51% (Figure 8b, c). Two native milfoils (*Myriophyllum propinquum*, *M. triphyllum*) were observed at low covers (<25%) growing amongst other plants down to a maximum depth of 5.3 m. (Figure 8d).

Elodea (*Elodea canadensis*) was the only invasive weed recorded from LakeSPI sites. It was recorded from three sites growing between 4.2 and 7.0 m depth. Elodea varied in abundance, being recorded as scattered shoots, to forming an open canopy (Figure 8e), to forming closed canopy patches.

Native quillwort (*Isoetes alpina*) dominated the shallow littoral zone, forming high cover swards (51 – 95% cover) at all sites to depths of 4.2-6.6 m (Figure 8f). A diverse assemblage of low growing native turf plants comprising nine species (Appendix A) was found in the shallower portion of the quillwort bed to a maximum of 2.8 m depth. Turf plants were found at typically low individual covers (≤25%), with the most common species being *Glossostigma diandrum*. Also, bryophytes were commonly found amongst the bases of quillwort and on rocks in the shallower wave-wash.

Although deep-water bryophytes were documented at some LakeSPI sites during a parallel investigation (de Winton et al. 2024) these communities are not considered in the LakeSPI method and are beyond the attainable diving depths of the survey (>20 m).

3.3.2 Discussion

Although Lake Wānaka saw a reduction in LakeSPI Index that saw it reclassified into the high ecological condition category, none of the changes were statistically significant due to variability amongst the sites. Over the longer term, there appears to have been some reduction in lake ecological condition according to LakeSPI (Figure 7), although differences in survey methodology and site location between 1982 and recent surveys contributes to some uncertainty.

For instance, from the 1982 survey (Clayton 1983) the depths for charophyte meadows at the historical sites closest to the 2024 sites were ≥20 m at four sites but meadows were not recorded at a fifth site. Across all 50 sites surveyed in 1982 (Clayton 1983), average depth extent and charophyte covers were 19.8 m at 45% cover for *Chara australis*, 17.1 m at 12% cover for *Nitella pseudoflabellata*, and 25 m at 12% cover for *Nitella claytonii* (as *N. hookeri* var *tricellularis*).

In 2011, three of the baseline LakeSPI sites were surveyed and all recorded charophyte meadows growing down to between 15 and 18 m depth. In 2020 four of the five baseline sites recorded meadows to depths between 11 and 17.5 m. In 2024, charophyte meadows were not recorded at two sites, but the remaining three sites recorded meadows to depths between 13.6 and 19.7 m.

These results suggest a reduction in the occurrence and depth extent of deep-water vegetation in Lake Wānaka since the 1982 survey. As water clarity is one of the major factors determining the maximum depth to which submerged plants can grow this reduction in plant depth extent is likely the result of declining water clarity.

Lagarosiphon (*Lagarosiphon major*) has been present in Lake Wānaka since 1972 (Hughes and McColl 1980), but an intensive management program is undertaken to prevent the spread of lagarosiphon and has progressively contained it along some shorelines (de Winton and Zabarte-Maeztu 2024).

Lagarosiphon has not been recorded at any of the baseline LakeSPI survey sites during 2020 or 2024. Should control works within Lake Wānaka cease and lagarosiphon be allowed to spread unchecked, we could expect a significant decrease in LakeSPI scores in the future.

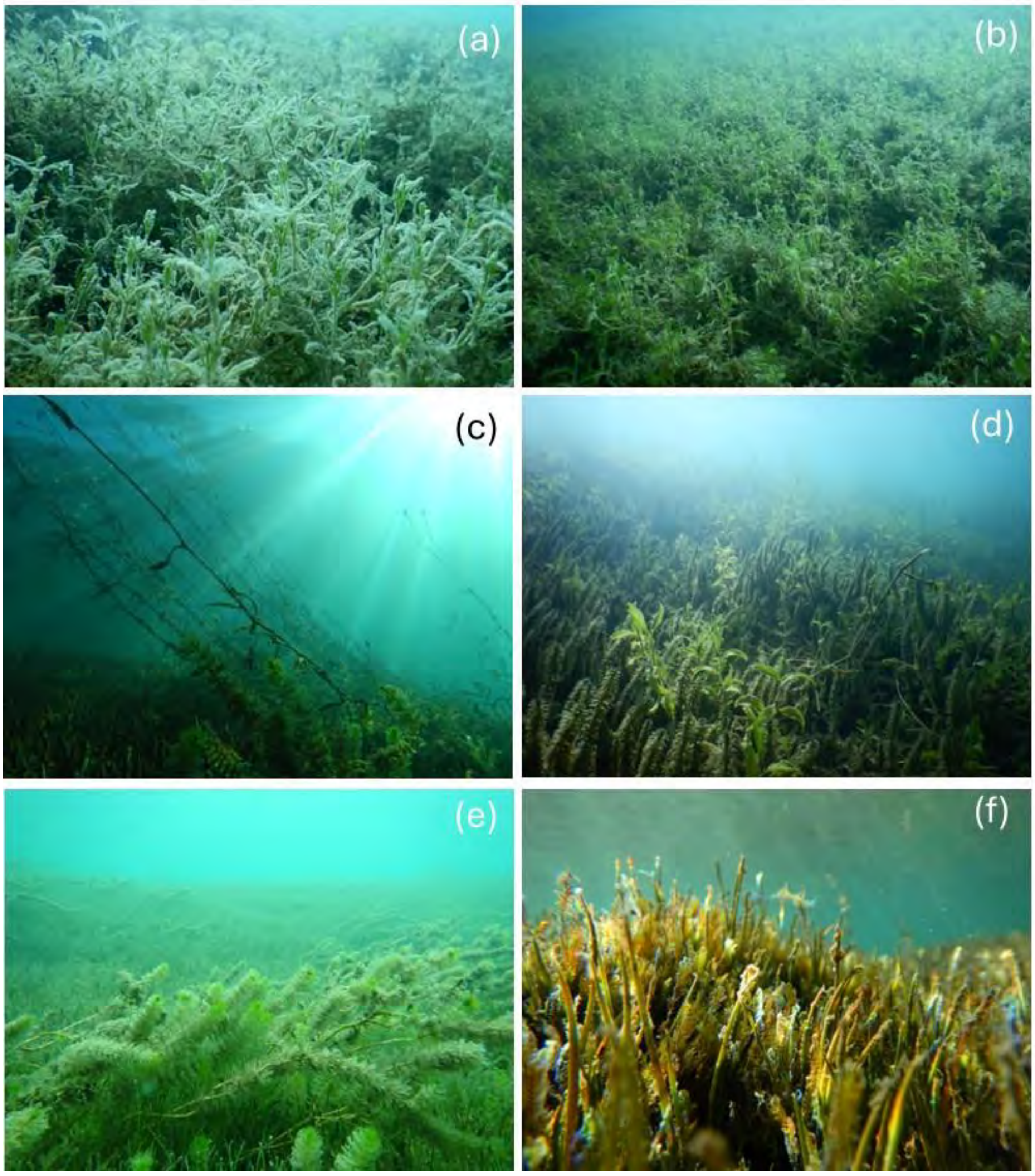


Figure 8: **Submerged vegetation in Lake Wānaka in 2024.** a) charophyte meadow, b) red pondweed (*Potamogeton cheesemanii*) growing as a canopy above charophytes, c) red pondweed and milfoil (*Myriophyllum triphyllum*) growing above quillwort (*Isoetes alpina*), d) invasive weed elodea (*Elodea canadensis*) with scattered pondweed, e) milfoil within the quillwort bed, f). shallow growing quillworts and bryophytes.

4 Discussion

4.1 Lake condition

Three alpine lakes in the Otago Region were reassessed for this 2024 report. The current LakeSPI status for these lakes comprises Lake Hāwea in excellent condition and Lake Wānaka and Whakatipu just dipping below the excellent ecological condition category (LakeSPI Index <75%) into the high category (Table 4) for the first time.

Lake Hāwea ranks within the top 20 lake positions nationally for the LakeSPI Index (Table 4, Figure 9). The other two lakes rank amongst the top 40 lakes nationally, with Lake Wānaka at a rank of 36th equal and Lake Whakatipu at 39th (Table 4, Figure 9).

Table 4: Summary of 2024 LakeSPI results for lakes in the Otago region with overall condition category and invasive weed history.

Lake	LakeSPI Index (%)	Overall Condition	Rank in region	Worst weed present	National rank†
Hāwea	85	Excellent	1	Elodea	14
Wānaka	74	High	2	Elodea*	36
Wakatipu	73	High	3	Elodea*	39

** Lagarosiphon not recorded any LakeSPI sites.*

† Based on LakeSPI Index to 1 decimal place.

4.2 Changes in status

Lake Hāwea remained in excellent condition on account of substantial native vegetation (Native Condition Index 82%). Water level fluctuations do limit some shallow plant community types, but also confers some protection against development of abundant weeds beds and new incursions of weeds such as lagarosiphon. Hence, this lake has low levels of impact from invasive weed species (Invasive Impact Index 8.1%).

Lake Whakatipu and Lake Wānaka appear to have decreased slightly in ecological condition according to LakeSPI results in 2024. However, the change since 2020 is minor, being 8% for Lake Whakatipu and 3.2% for Lake Wānaka. For Lake Whakatipu, the aquatic weed elodea appeared to be more prominent during this years' survey, but the reasons for this are not clear as elodea has been present in the lake for decades. Both of these lakes may have undergone reductions in the depth extent of plant development over the longer-term (since 1980/90's).

Lagarosiphon (*Lagarosiphon major*), is known from Lakes Wānaka and Whakatipu but the weed is being managed for progressive containment or eradication at most shorelines (de Winton and Zabarte-Maeztu 2024, Clements 2023) and lagarosiphon was not recorded from any LakeSPI baseline sites.

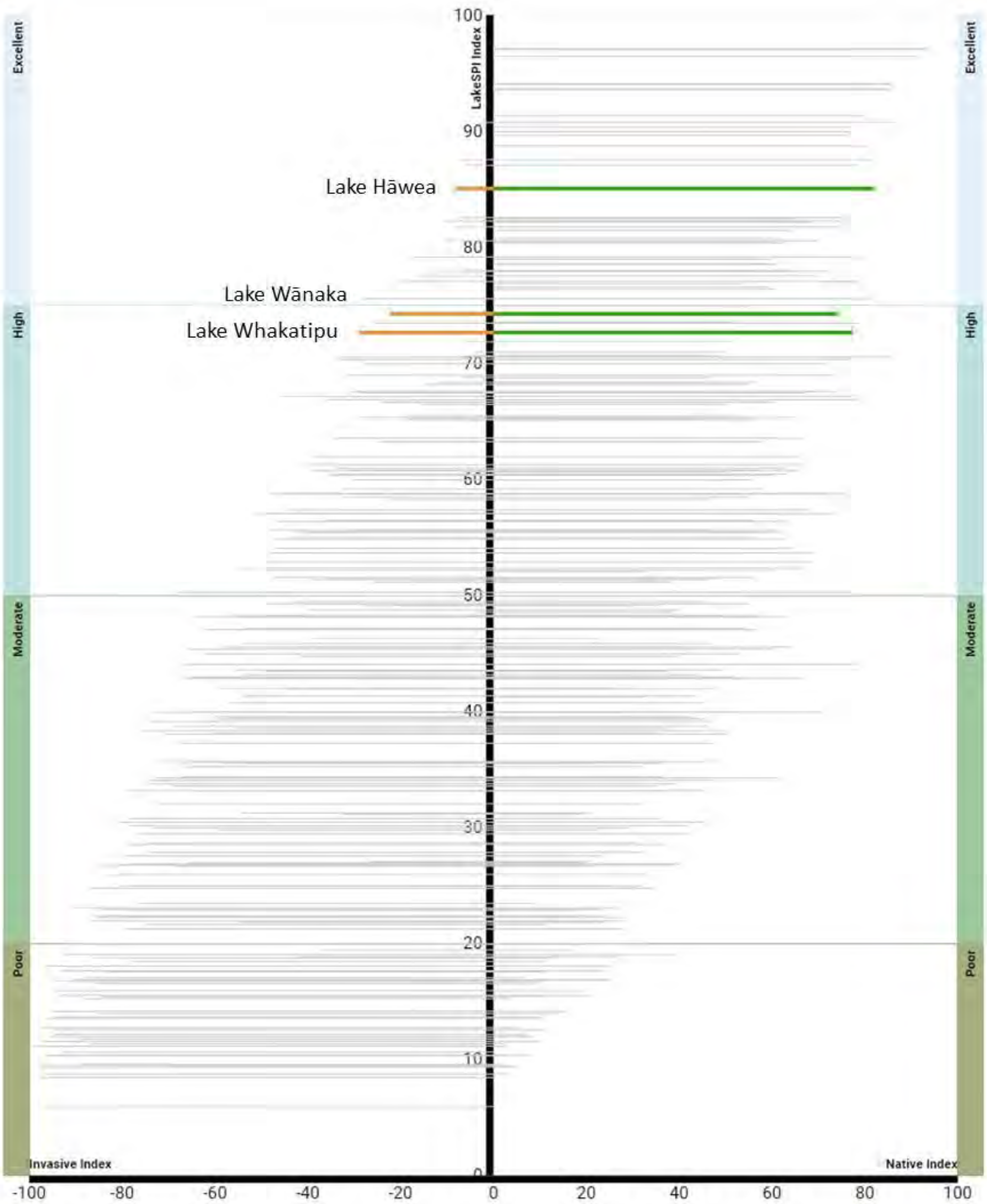


Figure 9. LakeSPI Indices based on the latest results of 314 lakes in grey. LakeSPI scores are plotted on the vertical axis, with the Native Condition Index plotted on the right-hand horizontal axis, and the Invasive Impact Index on the left hand to show the negative influence on the LakeSPI score.

4.3 National comparison

Compared with lakes nationally, the updated results for Otago Region shows a higher proportion of lakes in the excellent, high and moderate LakeSPI categories than is the case nationally (Figure 10). In contrast, only one lake in the Otago Region, Lake Tuakitoto, falls into the lowest quality category for ecological condition of non-vegetated, According to LakeSPI results nationally, a higher proportion of lakes fall into the lowest two categories (poor and non-vegetated) than is the case for Otago Region. The current sample set of surveyed lakes for the Otago region is small, so care must be taken when interpreting this overall comparison.

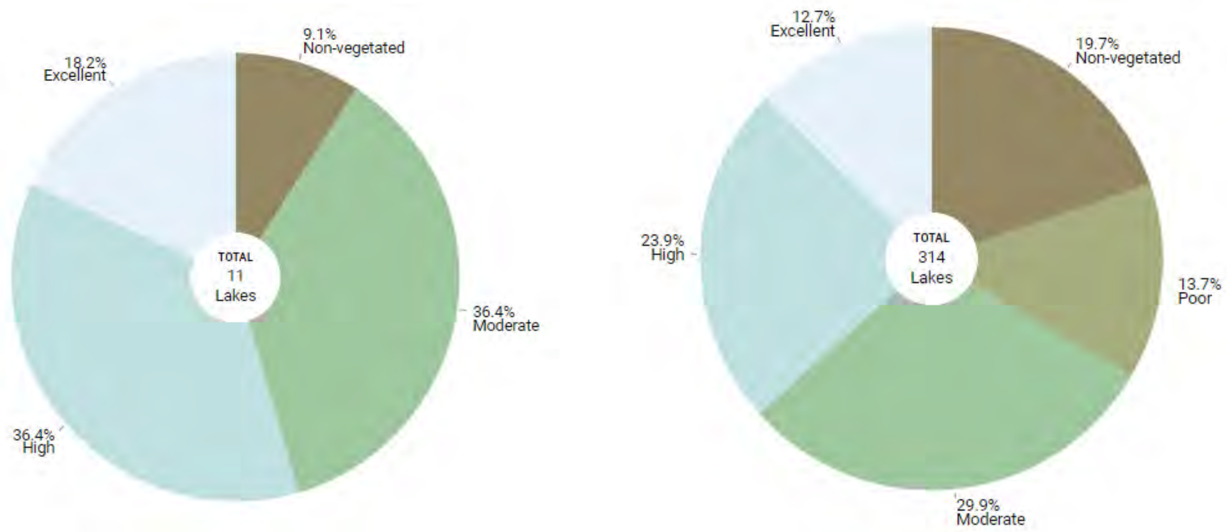


Figure 10. Proportion of lakes that fall into each of five categories of LakeSPI Index for the region (11 lakes) and nationally (314)

4.4 National Policy Statement for Freshwater Management 2020

All three of the Otago lakes were above the national bottom line set under the National Policy Statement for Freshwater Management 2020 (MFE 2022). Attribute bands for the component indices of LakeSPI, the Native Condition Index and Invasive Impact Index are given in Table 5.

Lake Hāwea remains in the same bands for submerged plant attributes as documented in 2020 (Table 5). Since 2020, Lake Wānaka has dropped from an A band for Native Condition Index to a B band (>50 and ≤75%), although the change in scoring of the index was <5%. Lake Whakatipu changed from a B band for Invasive Impact Index to a C band (>25 and ≤90%).

Table 5: Attribute bands for the Native Condition Index and Invasive Impact Index measured for the three Otago lakes surveyed in 2024. Changed bands since 2020 are shown in bold. Bands A to C B are above the national bottom line.

Lake	Native Condition Index (%)	Invasive Impact Index (%)
Hāwea	A	B
Wānaka	**B**	B
Whakatipu	A	**C**

5 Recommendations

LakeSPI surveys are generally recommended every five years for lakes that are considered stable. However, the National Policy Statement for Freshwater Management (MFE 2022) suggests attributes for Submerged Plants (natives and invasive species) be monitored at least once every three years.

We recommend:

- Lake Hāwea is monitored again using LakeSPI after five years, in 2029.
- Lakes Whakatipu and Wānaka are monitored again in 2027.

Currently, a small number of lakes in Otago Region (11) have been surveyed using LakeSPI and for two of these lakes, the assessments are over 10 years old. It is recommended that:

- a schedule for LakeSPI monitoring be developed with priorities and timing for re-surveys based on perceived lake value, stability and known threats to the lakes.
- Such a schedule prioritises natural satellite lakes in the catchment of the larger lakes (e.g., Moke, Diamond - Whakatipu, Dispute, Sylvan, Diamond - Wānaka) as additional sentinels for lake ecological condition in the region.

6 Acknowledgements

Many thanks to Hugo Borges (ORC) for his company and help during the survey of Lake Whakatipu, Hāwea and Wānaka. The considerable efforts of the NIWA field team of Aleki Taumoepeau, and Lois Olsen are also acknowledged.

Figure 11. Hugo Borges (ORC) on Lake Hāwea in March 2024.

7 References

Burton, T. (2019) Standard Operating Procedure (SOP) Preventing the spread of freshwater invasive species. Version 2 A – 27 June 2019. *NIWA Internal Report.*

Burton, T. (2021) Assessment of six lakes in the Otago Region using LakeSPI. *NIWA Client Report* 2021193HN. Prepared for Otago Regional Council: 44.

Clayton , J. (1983) Quick survey of aquatic plants in Lake Wānaka. In: Hoare, R. A. (ed) 1983. Design of water quality surveys. *Water and Soil Miscellaneous Publication No 63*, Wellington.

Clayton, J. (1993) Resource evaluation and operational programme for lake weeds: the upper Clutha and Kawarau catchment areas. *NIWA Client Report*: 106. Prepared for Otago Regional Council.

Clayton, J. Schwarz, Coffey, B. (1986) Notes on the submerged vegetation of lake Hāwea, 20:2, 185-189.

Clayton, J., Edwards, T. (2006) Aquatic plants as environmental indicators of ecological condition in New Zealand lakes. *Hydrobiologia*, 570: 147–151.

Clements, D. (2023) Lake Whakatipu and Kawarau River Lagarosiphon Control Works 2022/23. *NIWA Client Report* 2023271HN. Prepared for Toitū Te Whenua Land Information New Zealand; 27.

de Lange, P.J., Rolfe, J.R., Barkla, J.W., Courtney, S.P., Champion, P.D., Perrie, L.R., Beadel, S.M., Ford, K.A., Breitwieser, I., Schönberger, I., Hindmarsh, R., Heenan, P.B., Ladley, K. (2018) Conservation status of New Zealand indigenous vascular plants, (2017 revision). *New Zealand threat classification series 22*. Department of Conservation, Wellington: 82.

de Winton, M., Champion, P. (2008) Vegetation surveys of lakes associated with the South West New Zealand Heritage Area. *NIWA Client Report* HAM2008-050. Prepared for Department of Conservation.

de Winton, M., Clayton, J., Wells, R., Tanner, C. (1993) The submerged vegetation of Lakes Wakatipu, Lochnagar, Moke, Dispute and Alta; Kawarau River catchment, South Island, New Zealand. *NIWA Ecosystems Publication No. 1*. March 1993. ISSN 1172-3726

de Winton, M., David, S., Olsen, L., Taumoepeau, A. (2024) Deep-water bryophyte monitoring in Lake Whakatipu, Wānaka and Hāwea. *NIWA Client Report* 2024159HN. Prepared for Otago Regional Council.

de Winton, M., David, S., Taumoepeau, A. (2023) LakeSPI surveys for three lowland Otago Lakes. *NIWA Client Report*: 20232155HN. Prepared for Otago Regional Council: 34.

de Winton, M.D., Beever, J.E. (2004) Deep-water bryophyte records from New Zealand lakes. *New Zealand Journal of Marine and Freshwater Research,* 38: 329-340.

de Winton, M.D., Clayton, J.S., Edwards, T. (2012) Incorporating invasive weeds into a plant indicator method (LakeSPI) to assess lake ecological condition. *Hydrobiologia*, 691: 47–58.

Hill, C. F. (1970) Report on visit to South Island lakes. Report to Electricity Division, Ministry of Energy: 9.

Hughes, H. R., McColl, R. H. (1980) Aquatic weed control in Lake Wānaka. DSIR Information Series No 143.

MFE (2022) National Policy Statement for Freshwater Management 2020. (https://consult.environment.govt.nz/freshwater/npsfm-and-nesf-exposure-draft/user_uploads/exposure-draft-changes-to-npsfm-2020.pdf)

Ministry of Primary Industries (2007) https://www.mpi.govt.nz/dmsdocument/29426/direct

Appendix A Species list for three lakes in the Otago Region.

Table 1: Submerged aquatic plant species recorded for three lakes in the Otago Region, based on LakeSPI surveys carried out in 2024.

	Hāwea	Whakatipu	Wānaka
Invasive species			
Elodea canadensis	✓	✓	✓
Juncus bulbosus			
Lagarosiphon major			
Ranunculus trichophyllus			
Tall native vascular plants			
Myriophyllum propinquum			✓
Myriophyllum triphyllum	✓	✓	✓
Potamogeton cheesemanii	✓	✓	✓
Potamogeton ochreatus	✓	✓	
Stuckenia pectinata			
Charophytes			
Chara australis	✓	✓	✓
Chara divergens (previously *C. braunii*)	✓	✓	✓
Nitella claytonii	✓	✓	✓
Nitella sp. aff. *cristata*			
Chara acanthopitys (previously *C. fibrosa)*		✓	✓
Chara globularis	✓		✓
Nitella masonae			
Nitella hyalina	✓	✓	✓
Nitella leonhardii			
Nitella pseudoflabellata	✓	✓	✓
Nitella stuartii	✓		
Nitella subtilissima		✓	
Nitella tricellularis	✓	✓	✓
Turf plants			
Bryophyte spp.		✓	✓
Callitriche brutia			
Crassula sinclairii	✓	✓	✓
Elatine gratioloides		✓	✓
Eleocharis pusilla			✓
Glossostigma elatinoides			
Glossostigma diandrum		✓	✓
Isoetes alpina		✓	✓
Lilaeopsis ruthiana		✓	✓
Limosella lineata		✓	✓
Myriophyllum pedunculatum			✓
Pilularia novae-hollandiae			✓
Ranunculus limosella			✓
Ruppia polycarpa			
Trithuria inconspicua subsp. *brevistyla*		✓	

Appendix B Location of LakeSPI baseline sites for three Otago lakes

Table 2: Location of LakeSPI baseline sites for three lakes in the Otago Region.

Lake	Site	Location (Latitude, Longitude)	
Hāwea	A	-44.58254023	169.3190279
	B	-44.51553614	169.3040041
	C	-44.4367025	169.302626
	D	-44.46257693	169.2458949
	E	-44.59332221	169.2514978
Whakatipu	A	-44.90515281	168.4160187
	B	-45.0347559	168.4439134
	C	-45.07652376	168.508077
	D	-45.06110944	168.5868164
	E	-45.04836408	168.6223388
Wānaka	A	-44.65390644	169.0495732
	B	-44.63660024	169.0282062
	C	-44.56073614	169.0775632
	D	-44.52579609	169.0782889
	E	-44.6241506	169.0962682

9.4. Deep Lakes Technical Advisory Group update

Prepared for:	Environmental Science and Policy Committee
Report No.	GOV2465
Activity:	Governance Report
Author:	Ben Mackey, Manager Science
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	4 December 2024

PURPOSE

[1] The purpose of this paper is to provide and update to Council Committee on the formation and progress of the Otago Deep Water Lakes Technical Advisory Group, and share the initial outputs from the Group.

EXECUTIVE SUMMARY

[2] The Otago Deep Water Lakes Technical Advisory Group (TAG) was formed in April 2024 at the request of the Otago Deep Water Lakes Management Working Group. The TAG's purpose is to provide technical advice to the Management Working Group, primarily regarding potential monitoring and research programmes to enable informed management of lake health.

[3] The TAG has met monthly and traversed the state of existing knowledge, risks to the lakes, and developed a detailed set of knowledge gaps. This work was presented to the Managment Working Group in September.

[4] The TAG's focus now moves to developing a range of potential research and modelling programmes that will allow ORC and other stakeholders to better understand the state, trends, pressures, and management needs of the Otago Deep Lakes. These options will be presented to the Management Working Group for consideration in 2025.

RECOMMENDATION

That the Committee:

a) ***Notes** this report.*

BACKGROUND

[5] Otago's deep-water Lakes — Wanaka, Wakatipu, and Hawea — have traditionally been considered in a pristine state due to good water quality and clarity. The incursion of lake snow, changing land use patterns, and adverse trends detected in some state of the environment monitoring, have generated concern about long-term lake health and the adequacy of existing lake management.

[6] A key dataset in galvanising concern about the state of Otago's deep-water lakes is the trend of chlorophyll *a* which has been measured quarterly since 2016. Chlorophyll *a* is a measure of algal biomass in the water column, and has shown an increasing trend in all three deep lakes since regular measurements commenced in 2016 (Fig. 1).

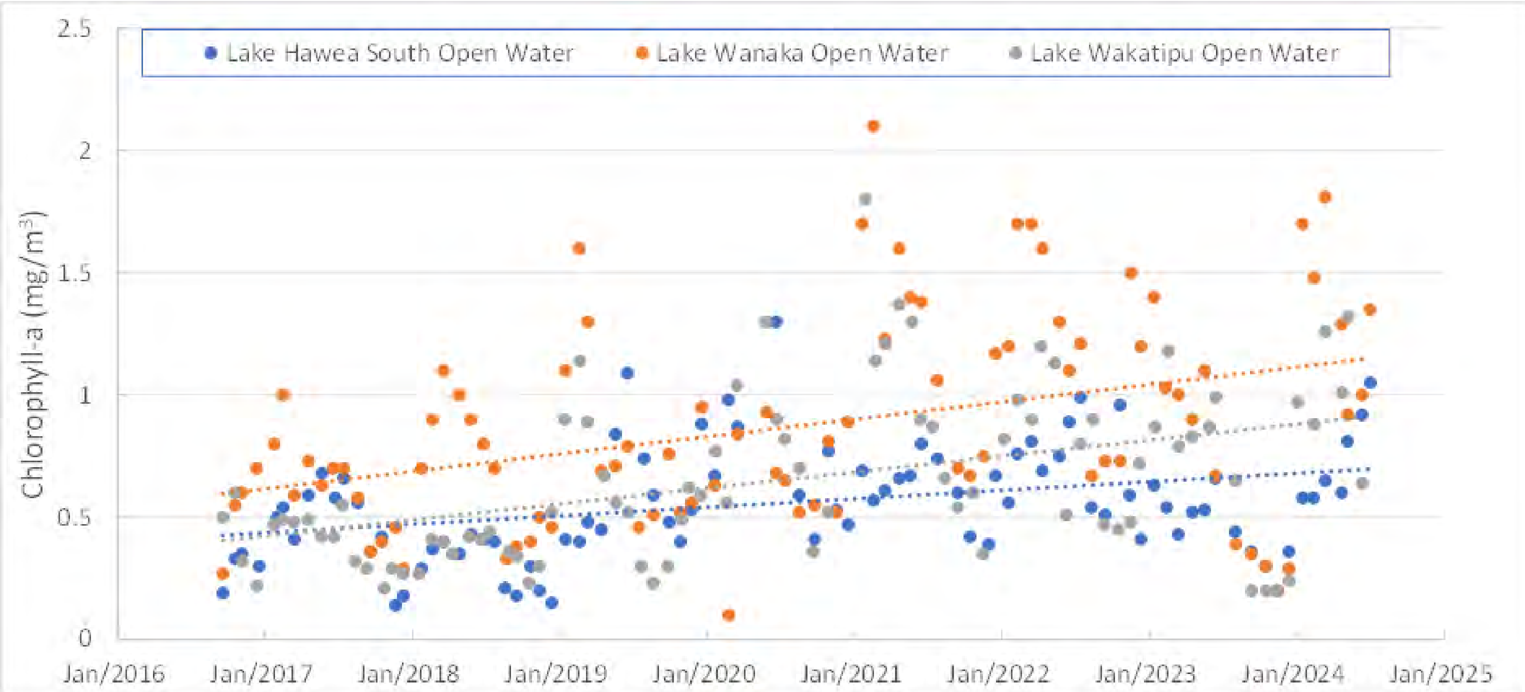


Figure 1. Time series of chlorophyll a data showing recent increases in algal biomass in the open water sites of the three lakes, between 2016 and 2024.

[7] Wai Wanaka summarised concerns about the lake health in a strategy report in 2021 which was provided to the Parliamentary Commissioner for the Environment[1]. The Commissioner wrote to ORC's Chief Executive Dr Pim Borren in December 2022, querying what ORC was doing to manage the lakes' health. Dr Borren's response to the Commissioner in December 2022 noted that, among other actions, ORC broadly supported establishing multi-agency a panel of experts to develop a work programme for Otago's deep lakes.

[8] In response, the Otago Deep Water Lakes Management Working Group was formed in 2023. The Management Working Group has membership spanning Councillors, Iwi representatives, senior ORC staff, and representatives from DOC, MFE, and Wai Wanaka. The Management Working Group developed Terms of Reference for a Technical Advisory Group, and this group was assembled in early 2024.

[9] As noted in the TAG's Terms of Reference, the purpose of the TAG is to advise the Deep Lakes Management Working Group by:

a. Providing a review and assessment of the nature and extent of existing data and research available for Lakes Whakatipu, Wānaka and Hāwea and their catchments, and the suitability and sufficiency of this research for lakes management decision making.

b. Recommend key research questions for approval by the ORC Otago Deep Lakes Management Group.

c. Developing recommendations for a coordinated programme of research to fill any important information gaps, with the primary goal of informing evidence-based management to support the NPS-FM (2023), NPS-IB (2023), and ORC Land and Water Plan, as they relate to the Lakes Whakatipu, Wānaka and Hāwea and their catchments.

[1] Robertson, D., 2021: Understanding and protecting Otago's deepwater lakes – A job for nature strategy for Wai Wanaka. 48p.

[10] The TAG membership includes representatives from NIWA, ORC, MFE, DOC, Landcare Research, Wai Wanaka and the Universities of Otago and Waikato. Currently the membership stands at 16.

[11] The TAG membership currently is as follows:

Member	**Organisation**
Dr Jason Augspurger	Otago Regional Council
Hugo Borges	Otago Regional Council
Mark Crawford	Otago Regional Council
Dr Ben Mackey (Chair)	Otago Regional Council
Dr Dean Olsen	Freestone Freshwater Ltd
Dr Simone Langhans	Otago Regional Council
Dr Marc Schallenberg	University of Otago
Dr Phil Novis	Manaaki Whenua-Landcare Research
Dr Neale Hudson	NIWA
Dr David Plew	NIWA
Dr Aidin Jabbari	NIWA
Dr Clive Howard-Williams	NIWA
Ben Youngman	Wai Wanaka
Dr Deniz Özkundakci	University of Waikato
Dr Kohji Muraoka	Ministry for the Environment
Dr Craig Woodward	Department of Conservation

DISCUSSION

[12] Through December 2024 the TAG has had five full meetings, and has systematically reviewed the state of existing knowledge, examined worst credible scenarios for the lakes, developed key questions, and undertaken a substantial exercise to identify and classify knowledge gaps. Other work has been to assess the relevance of overseas examples to the management of Otago's deep lakes.

[13] In October, the TAG held an interactive session with Andy Bruere, the Lakes Operations Manager for the Bay of Plenty Regional Council. The Rotorua Te Arawa Lakes TAG has been in operation since the 1980's, and several members of the Otago TAG have also been involved in the Rotorua Te Arawa Lakes TAG. It was very beneficial to learn about the activities and challenges faced by the well-established Rotorua group.

[14] A key theme has been the limitations of the NPS-FM attribute tables to provide for adequate management targets for the lakes. The attribute tables in the NPS-FM which apply to lakes were developed for application across New Zealand, and arguably are not a suitable target for Otago's large deep lakes. The Lake attributes are largely within the A band in terms of the NOF Framework. However, due to the potentially sensitive nature of the deep-water lakes, there is concern that lake health may deteriorate despite attributes remaining in the A-band. Further, extremely low nutrient concentrations present in the lakes may make degrading trends difficult to detect.

[15] Another common theme was that although the lakes are large, and generally have good water quality, overseas examples highlight how sensitive large lakes can be to external

stressors, such as an input of nutrients. They are not inherently resilient, and once change starts to occur, it can happen quickly and be very difficult to arrest. The TAG acknowledges the challenge of resourcing research into Otago's deep-water lakes, when there is a perception they are in good health and resilient to change.

[16] The TAG had significant discussions around the identification of 'tipping points' and what needs to be measured or monitored to identify change. Experience from other lakes show that a lake's response to change is not always linear; understanding how a lake will respond to external factors is critical in actively managing lake health. A stressor-response framework was proposed as a mechanism to do this. In this framework an understanding of the relationship between a measurable lake value (e.g., clarity) and a stressor (nutrients, invasive species, climate) is developed.

[17] The primary output from the TAG to date has been a report presented to the Otago Deep Water Lakes Management Working Group in September (attached here as appendix A). The report summarised the formation and rationale for the TAG, reviewed existing information, and identified key questions. A collation of knowledge gaps was a major exercise, with gaps classified into five general themes. These are:

i. Lake management and community engagement
ii. Budgets (water, nutrient, heat, oxygen, etc)
iii. Fundamental lake processes (hydrodynamics, mixing etc)
iv. Historic data and trajectory
v. Maturaka Māori

[18] The next substantive task for the TAG is to develop a set of potential research and monitoring programmes to present to the Management Working Group. The Management Working Group may then bring options to Council for consideration, potential funding, and implementation.

[19] Several representatives from the TAG will participate in a wānanga with Mana Whenua representatives prior to the December Council Committee meeting. The purpose of this meeting is to review progress to date, and discuss Mana Whenua understanding of the deep Lakes and future involvement in the TAG's development of work programmes.

[20] The TAG will meet in person for a 2-day workshop in February to develop potential research and monitoring programmes. It is intended to develop 2-3 different options requiring different levels of resourcing, which seek to answer different questions, or provide a greater degree of certainty.

OPTIONS

[21] This paper is for noting only.

CONSIDERATIONS

Strategic Framework and Policy Considerations

[22] TAG has identified the attribute thresholds in the 2020 NPS-FM tables may not provide appropriate targets for the deep-water lakes long term. Currently, in addition to attribute bands, the draft Land and Water Regional Plan contained a trend component to help address this deficiency until appropriate targets could be derived for these lakes.

[23] However in the future, further management actions (both regulatory and non-regulatory) may be required to ensure the health of the lakes is protected.

Financial Considerations

[24] TAG is currently being supported from the Science Lake programme. TAG will identify a set of potential monitoring and research programmes which may require resourcing decisions in the future.

Significance and Engagement

[25] Not applicable at this stage. Will be relevant when the Council considers resourcing potential monitoring and research programmes.

Legislative and Risk Considerations

[26] Not applicable.

Climate Change Considerations

[27] The impact of a changing climate on the lakes is a key research question identified by TAG.

Communications Considerations

[28] Not applicable at this stage.

NEXT STEPS

[29] A wānanga with TAG and Mana Whenua representatives is planned for late November, just ahead of this Committee meeting. The full TAG membership has planned a two-day in-person workshop in February to develop a set of work programmes. Potential research programmes to present to the Otago Deep Water Lakes Management Working Group in 2025.

ATTACHMENTS

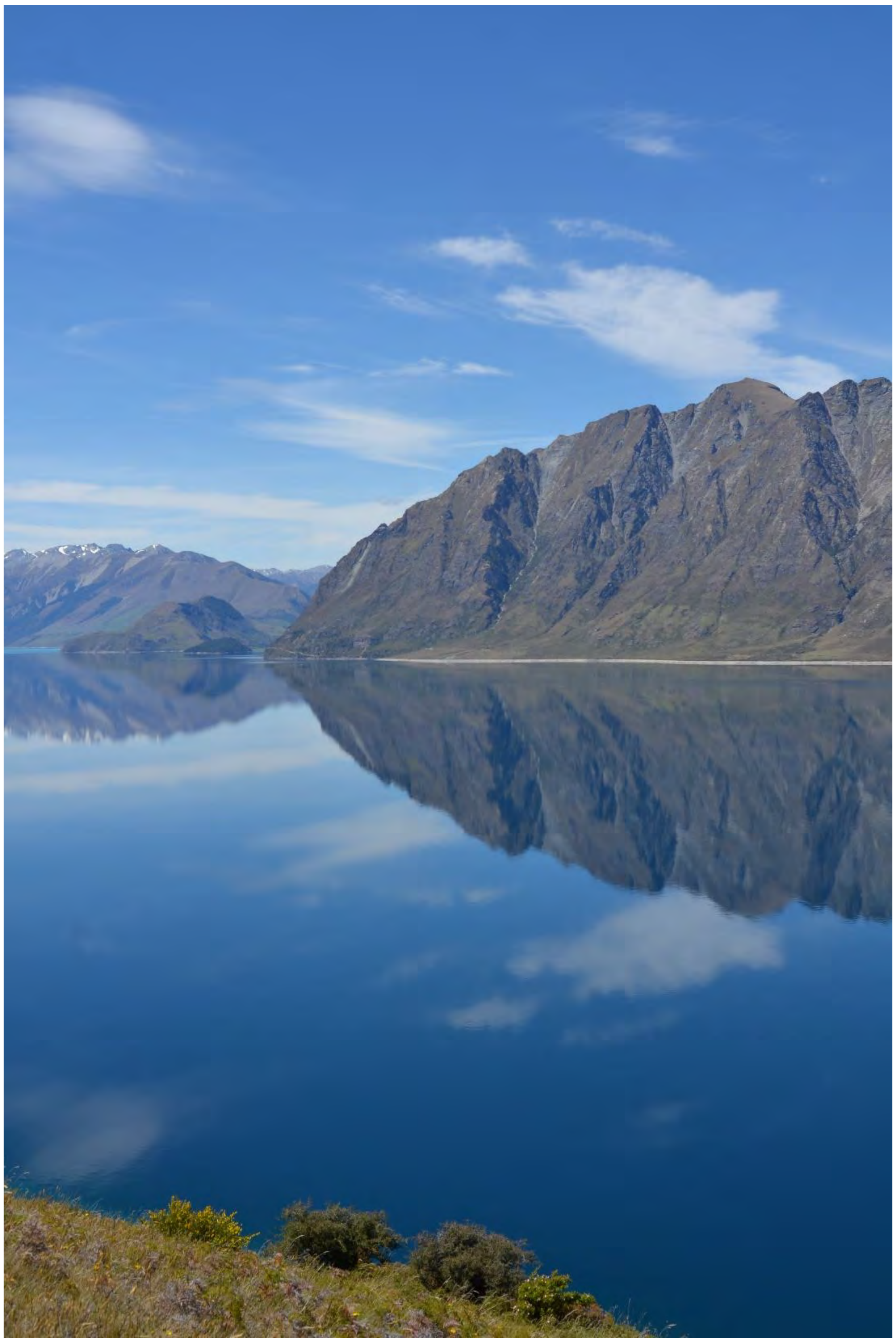
1. Otago Deep Lakes TAG - update for Management Working Group - September 2024 [**9.4.1** - 34 pages]

1

Otago Deep Water Lakes Technical Advisory Group

September 2024 Progress Report to:

Otago Deep Water Lakes Management Working Group



1. Background

Otago's deep-water lakes (Lakes Hāwea, Wānaka and Whakatipu Waimāori[1]) are highly valued by local communities and local rūnaka, and visitors from throughout New Zealand and abroad. This, combined with public concern about the potential for hydro-electric development in Lake Wānaka, led to the establishment of the Lake Wānaka Guardians in the 1970s. Community concerns over the future of Lakes Wānaka and Hāwea and the upper Clutha/Mata-Au catchment led to the formation of Wai Wānaka in 2016 and the preparation of a Community Catchment Plan for the upper Clutha catchment[2].

Otago Regional Council (ORC) previously monitored the trophic state of Lakes Wānaka and Whakatipu Waimāori over a three-year period every decade, with monitoring occurring over the period 2006-2009[3] with another round of monitoring originally planned for 2016-2019. However, the community expressed concerns over the adequacy of this monitoring approach as well as the effects of "lake snow"[4] and the effects of development in the catchments of the Lakes. These concerns, along with the requirements of the National Policy Statement for Freshwater Management (NPSFM), led to a review of the monitoring conducted on these lakes and the establishment of an on-going water quality monitoring programme in the deep lakes (which began in 2017). Lake monitoring buoys were established in Lakes Wānaka and Whakatipu Waimāori in 2023.

The information gathered by monitoring provides useful information about the state of a system that can guide decision-making, but it does not necessarily provide the information required to understand how that system operates and/or the level of detail required to undertake active management of the system. This is the case for Otago's deep-water lakes. Targeted investigations and research would be required to address these knowledge gaps and to underpin long-term lake management. Previous applications for contestable research funding for a research programme to improve understanding, monitoring and management of New Zealand's large, deep lakes have been unsuccessful to date. Experience from large lakes overseas show that these lakes may not be resilient to change, and appear to be highly vulnerable, yet the fundamental science to underpin meaningful management is lacking.

Further concerns were raised in 2021 following the observation of an apparent increasing trend in chlorophyll *a* concentrations[5]. This report, authored by Don Robertson from Wai Wānaka prompted the Commissioner of the Environment to write a letter to the ORC Chief Executive in late 2022, enquiring as to what ORC were doing about the lakes. ORC responded, proposing (among other things) the establishment of the Otago Deep Water Lakes Management Working Group. The working group asked for this Otago Deep Water Lakes Technical Advisory Group (TAG) to be formed, to report back to them and primarily provide technical advice about managing the lakes.

[1] https://kahurumanu.co.nz/atlas
[2] https://waiWānaka .nz/wp-content/uploads/2022/02/FINAL-Upper-Clutha-CCP-Dec-2021.pdf
[3] https://www.orc.govt.nz/media/6192/web-version-otago-lakes-trophic-status.pdf
[4] Lake snow is a sticky, biological material made up of groups of the algae *Lindavia intermedia* that exudes sticky strands that lead to clumpy of algae and other organic matter. Lake snow fouls fishing lines and clogs water filters and intakes.
[5] Robertson D (2021). Understanding and protecting Otago's deepwater lakes. A Jobs for Nature Strategy for WAI Wānaka. WAI Wānaka, Wānaka. 48 p. https://waiWānaka .nz/wp-content/uploads/2022/11/Understanding-and-protecting-Otagos-deepwater-lakes.pdf

The objectives and deliverables of TAG have been identified as:

- Review of existing information
- Assess suitability of the information for informing management of the lakes
- Gap analysis
- Develop a costed research programme, including a range of options with different price points which could be used to answer a range of questions. This is the end product which would be presented back to the working group for consideration.

The inaugural meeting of the TAG was held on 4 April 2024. After this first meeting, four further meetings have taken place (9 May, 13 June, 11 July, 8 August 2024). Meetings are scheduled for the second Thursday of each month.

2. Make up of Otago Deep Water Lakes Technical Advisory Group

The Deepwater Lakes TAG is currently made up of members from the Department of Conservation, Freestone Freshwater Ltd., Manaaki Whenua/Landcare Research, National Institute of Water and Atmosphere (NIWA), Ministry for the Environment, ORC, University of Otago, University of Waikato and Wai Wānaka.

Concerns have been raised by members of the TAG regarding the need for mana whenua representatives with an interest in the Otago Deepwater Lakes and to provide Mātauraka Māori on the TAG. Sandra McIntyre (Mana Taiao/Principal Planner, Aukaha) attended the TAG meeting on 8 August 2024 on behalf of relevant rūnaka. She suggested an alternative approach to mana whenua representation on the TAG: a wananga/workshop approach which would be more consistent in the way mana whenua prefer to work, rather than having an individual member (or members) appointed to the TAG.

The TAG also discussed how having key staff from the Otago Fish & Game Council and the Queenstown Lakes District Council on the TAG could provide valuable input to the TAG's work.

3. Overview of science work done to date as presented by TAG members

At the TAG's second meeting on May 9, 2024, TAG members were asked to report and summarise research that had been carried out to date on Lakes Whakatipu Waimāori, Wānaka and Hāwea. That meeting comprised the following presentations:

- Water quality programme in the Upper Lakes (Hugo Borges, ORC)
- ORC modelling (Jason Augsperger, ORC)
- ORC data on land use, climate, soils and economy of the Queenstown Lakes District (Mark Crawford, ORC)
- Alpine lakes research programme (Ben Youngman, WAI Wānaka)
- NIWA's Lake Wānaka Project update (David Plew, NIWA)
- University of Otago research (Marc Schallenberg, University of Otago)
- *Lindavia intermedia* (Phil Novis, Manaaki Whenua-Landcare Research)

A summary of the above work follows, in two sections: (1) ORC's State of the Environment (SOE) monitoring and (2) other investigations.

3.1 State of the Environment (SOE) monitoring

3.1.1 Deepwater Lakes

The SOE monitoring effort by ORC was reviewed and revised at the end of 2016, so useful time series data on water quality principally begin at that time. Prior to 2017, ORC monitored the trophic state of Otago's deep-water lakes over a three-year period in every decade. Monitoring occurred between 2006 and 2009[6], and was planned to be repeated in 2016-2019. The three year monitoring programme was replaced with a continuous monitoring programme that started in 2017 in response to community concerns, and to give effect to national legislation, regulation and guidance. The intent of this monitoring is to enable assessment of the general state of the environment in the deep-water lakes. Since the revised programme was implemented in 2016, the monitoring provides a useful record of changes over the past ~8 years.

One of the issues identified based on historical monitoring was that the standard laboratory tests for phosphorus (total and dissolved reactive phosphorus) had a detection limit that meant that a high proportion of sampling results came back as "below detection". This was identified as an issue for trend analysis. To address this issue ORC staff collaborated with staff from other regional councils and testing laboratories to establish an accredited test for phosphorus with a lower detection limit than was previously available, and this was implemented within ORC's SOE monitoring.

Ecological monitoring has included macrophyte[7] monitoring to calculate the Lake Submerged Plant Indicators (LakeSPI), which characterises the ecological condition of lakes based on the composition of native and invasive plants growing in them. LakeSPI monitoring has been undertaken in Lake Wānaka in 1982, 2011, 2020 and 2024 and in Lakes Whakatipu Waimāori in 1982, 1992, 2020 and 2024[8]. Additionally to the standard LakeSPI monitoring, ORC have started monitoring deep water bryophytes (submerged plants) in the three lakes (Whakatipu Waimāori , Wānaka and Hāwea).

Lake monitoring buoys were established in Lakes Wānaka and Whakatipu Waimāori in 2023 to take high frequency measurements of a range of variables to a depth of 65 m. Sampling was limited to 65 m depth due to the capabilities of the currently used technology. There are plans to collect data from deeper levels within these lakes using fixed-depth instruments.

Trophic level index values for all three deep-water lakes are microtrophic (Lake Hāwea: 1.4, Lake Wānaka: 1.7, Lake Whakatipu Waimāori: 1.6). All attributes in the Otago deep-water lakes are in the A-band of the National Objectives Framework (NOF), except for submerged plants (invasive species); in this attribute the three lakes are in the B-band (Ozanne et al. 2023[9] reproduced in Appendix A). However, this reflects the limitations of the NOF, which is intended to be applied to lakes across Aotearoa New Zealand; it has limited applicability to Otago's 'near pristine' deep-

[6] https://www.orc.govt.nz/media/6192/web-version-otago-lakes-trophic-status.pdf
[7] Macrophytes are vascular plants
[8] https://www.lawa.org.nz/explore-data/otago-region/lakes
[9] Ozanne R. Levy A & Borges H (2023). State and Trends of Rivers, Lakes, and Groundwater in Otago 2017 – 2022. May 2023. Otago Regional Council, Dunedin. 132 p. plus appendices.

water lakes. Of more interest are trends in water quality attributes in these lakes. Five-year trends for key water quality attributes indicate that chlorophyll *a*-concentrations have increased at most sites in all three lakes, while adverse trends in nitrogen (nitrate-nitrite nitrogen, total nitrogen) and Secchi depth have been recorded in Lake Wānaka (Ozanne et al. 2023[10] reproduced in Appendix A). However, such short-term trends should be interpreted with caution, as they may reflect short- to medium-term patterns influenced by natural factors such as climate variation, rather than an underlying increasing trend driven by anthropogenic factors.

3.1.2 Lake tributaries

Prior to the water quality network review in 2016, there were two water quality monitoring sites in the catchments of the deep-water lakes: Matukituki at West Wānaka and Dart at The Hillocks. Both sites were located at the long-term hydrological monitoring sites on large, braided rivers (Dart at the Hillocks, Matukituki at West Wānaka). Following that review, the network of monitoring sites was expanded to 23 river sites, including 3 sites in tributaries of Lake Hāwea, 6 sites in Lake Wānaka and 13 sites in Lake Whakatipu Waimāori.

Most water quality attributes at most sites complied with the A-band status of the NOF, with the main exceptions being the two urban tributaries (Wānaka's Bullock Creek at Dunmore Street Footbridge and Horn Creek at Queenstown Bay) (Ozanne et al. 2023[11] reproduced in Appendix A). Water quality trends at the two long-term sites indicate that nitrate-nitrite nitrogen concentrations have increased over the last ten years, while *Escherichia coli* concentrations have increased over the last 20 years (Ozanne et al. 2023[12] reproduced in Appendix A).

The limited number of historical water quality monitoring sites has prevented the consideration of how surface water quality in the deep-water lake catchments has changed over time. The inclusion of 20 additional water quality monitoring sites in these deep-water lake catchments has expanded the range of sites monitored well beyond the two large, braided rivers historically monitored to cover a wider range of river, catchment, and land use types as well as urban streams. This has greatly enhanced our understanding of the variation in water quality within these catchments and how it is changing through time.

3.2 Other investigations

The presentations summarised independent studies on the lakes and their catchments that have been carried out by various researchers.

3.2.1 ORC modelling

The ORC undertakes and commissions catchment and hydrological modelling, which estimates water, nutrient and sediment load to lakes and can be used to model in-lake concentrations. The modelling carried out to date has focused on a regional scale and is useful for indicating broad scale patterns. These models represent the lakes in a relatively simple way; they do not

[10] Ozanne R. Levy A & Borges H (2023). State and Trends of Rivers, Lakes, and Groundwater in Otago 2017 – 2022. May 2023. Otago Regional Council, Dunedin. 132 p. plus appendices.
[11] Ozanne R. Levy A & Borges H (2023). State and Trends of Rivers, Lakes, and Groundwater in Otago 2017 – 2022. May 2023. Otago Regional Council, Dunedin. 132 p. plus appendices.
[12] Ozanne R. Levy A & Borges H (2023). State and Trends of Rivers, Lakes, and Groundwater in Otago 2017 – 2022. May 2023. Otago Regional Council, Dunedin. 132 p. plus appendices.

incorporate many inherent characteristics of the large southern lakes, such as mixing patterns, seiche, nutrient sensitivity, and other factors. For instance, the regional modelling utilized the NOF bands as nutrient thresholds. However, the Lake's current state puts them in the top of the A-band. Therefore, these band thresholds are not necessarily suitable nutrient concentration targets for management. Substantial improvements in understanding could be made through development of bespoke models for these systems.

3.2.2 ORC land use

The ORC holds large amounts of data which provides context to the condition of the deep-water lakes, including data on climate, soils, land use and economics. Much of this information is available in map/GIS form. This information was typically mapped at a national or regional scale. While useful for broadscale patterns, the mapping has large limitations, and inaccuracies, at a farm or property parcel scale.

The land use in the Upper Lakes catchments, of which 54% is conservation estate, may be perceived to have limited scope for land use change with respect to agricultural use. However, this fails to account for the increased intensity of land use through added productivity and changed forage systems across the productive land, and its associated nutrient losses. It also doesn't account for the land use pressures from land fragmentation, urban growth, (with the Lakes district having the largest population growth between July 20178 and June 2020), lifestyle-type property development, and higher environmental impacts from tourism activities.

3.2.3 WAI Wānaka[13]

WAI Wānaka commissioned studies on urban storm water and on eel/tuna distributions in lake tributaries.

3.2.4 NIWA

NIWA presented its current work developing coupled models of catchment hydrology, lake hydrodynamics and water quality for Lake Wānaka and its catchment. The goal of this project is to evaluate if modelling is useful for predicting the effects of climate change and land-use on large deep lakes. The work undertaken to inform the models includes:

1. Measuring water circulation patterns in Roy's Bay using drifters in a project commissioned by WAI Wānaka.
2. Profiling of temperature, conductivity, dissolved oxygen, fluorescence (chlorophyll-*a)*, turbidity and photosynthetically active radiation (light) at 14 sites in Lake Wānaka, and surface and hypolimnetic nutrient sampling at 8 of these sites. This sampling was undertaken monthly from April 2022 to June 2023, and quarterly since then.
3. Deployment of instruments to measure current velocity, oxygen and temperature at 5 locations. These moorings were deployed March 2024, and will be retrieved Feb/March 2025
4. High resolution bathymetry mapping of Lake Wānaka (March/April 2024).

At the time of this report, a hydrological model for the catchment and a 3D hydrodynamic model of the lake have been developed. The lake hydrodynamic model captures features such as

[13] The Wai Wanaka TAG representative was away when this report was compiled, and this summary does not fully represent the breadth of activities the organisation has been involved with.

seasonal stratification, internal waves and river inflows plunging into the deep parts of the lake. The profiling and water quality sampling indicates that Stevensons Inlet may be more eutrophic than the rest of the lake, with higher nutrient concentrations and evidence of low hypolimnetic oxygen concentrations developing during summer stratification. Work is currently underway to incorporate water quality in the catchment model (nutrients, sediments) and lake model (nutrients, phytoplankton, dissolved oxygen).

3.2.5 University of Otago

Researchers at the University of Otago have carried out occasional studies on the lakes since the early 1990s. This work has focused on a wide range of issues including:

1. **Picocyanobacteria as early warning indicators of eutrophication.** This work showed that, prior to the recent dominance by the invasive diatom *Lindavia intermedia*, tiny picocyanobacteria were the most abundant phytoplankters in these lakes. The picocyanobacteria where shown to respond to small increases in nutrient availability, indicating that their dominance in these lakes is related to how nutrient poor these lakes are and that changes to their abundance and dynamics are warning signs of departures from pristine nutrient conditions in the lakes.
2. **Microbial food webs and energy flow.** This work examined potential bottle necks in the microbial food web that could affect how both carbon and energy flow from phytoplankton up to zooplankton and ultimately to fish in these lakes. This work informs how the invasion of these lakes by *Daphnia pulicaria* in the early 2000s increases carbon and energy flow in these lakes.
3. **Potential climate change impacts on mixing and on phytoplankton productivity** in Lakes Wānaka and Whakatipu Waimāori (Tina Bayer's PhD). This work examined how predicted future changes in temperature and wind will affect the mixing regime of the lakes and how this in turn is likely to affect phytoplankton productivity (i.e., the base of the food web).
4. **Relationships between pastoral land use and nutrient inputs among streams and rivers flowing into Lake Wānaka** (Amy Weaver's PhD, funded by ORC). Amy's thesis showed that agricultural development in the subcatchments of Lake Wānaka increases the flow of nitrate and dissolved organic carbon from the subcatchments to the lake. This has implications for the nitrogen, carbon and oxygen budgets of the lake and is likely to increase phytoplankton growth and biomass.
5. **Decision support framework for multi-stakeholder lake and catchment management plans** (Simone Langhans' European Commission Marie-Sklodowska-Curie research project which produced information that fed into WAI Wānaka's Community Catchment Plan). Simone worked closely with the communities, stakeholders and regulatory authorities in a collaborative exercise to identify key values, measurable attributes, and management actions that are most likely to lead to the safeguarding of the values of the lakes.
6. **Picocyanobacterial community structure** in Lakes Wānaka and Wakatipu Waimāori (Lena Schallenberg's PhD). This research advanced understanding of the picocyanobacterial communities in these lakes by making use of advanced molecular techniques to determine which cyanobacterial taxa live in the lakes, their spatial distribution in the lakes (vertical and horizontal), as well as their seasonality.
7. **Kōaro habitat use in Lakes Wānaka and Wakatipu Waimāori** (Jason Augspurger's PhD). This work revealed that substantial landlocked kōaro (*Galaxias brevipinnus*) populations

live in the lakes and tend to be concentrated at sites where rivers flow into the lakes. This indicates that river mouths are hotspots for these native fish.

8. **Lake snow, including assessing the likely timing of incursion of *L. intermedia*** using sediment cores and likely mechanism of spread into the lakes. Among other work done with Phil Novis (see Landcare Research section below), sediment core analyses were undertaken to identify the likely dates of incursion of *Lindavia intermedia* to the lakes.

3.2.6 Landcare Research

Landcare Research led an MBIE-funded Smart Ideas research programme that focused on *Lindavia intermedia*, the diatom associated with lake snow production. This work, and other small contracts with councils and DOC in collaboration with University of Otago and NIWA, involved:

1. Genetics - development of high resolution markers showing that North America is the most likely origin of *L. intermedia* in New Zealand.
2. Using these markers to develop molecular methods for quantifying *L. intermedia* and chitin production.
3. Use of these methods to (A) survey >100 New Zealand lakes using sediment DNA collected by the Lakes380 programme, showing lakes at the most risk of incursion and demonstrating that humans are the most effective vectors of the species, and (B) survey 50 lakes in the Pacific Northwest of North America, showing that two closely related genotypes of *L. intermedia* occur there (of which New Zealand appears to have one), that putative parasites of *L. intermedia* exist but appear to have been transferred here with their host, and that water quality is the most likely explanation for the wider occurrence of lake snow here than is known in North America.
4. Examining relationships between *L. intermedia* and environmental factors in the lakes, the best predictor of lake snow abundance being nitrate concentrations.
5. Study of *L. intermedia* populations in Nelson Lakes and the Maitai Reservoir above Nelson City, showing that lakes with similar trophic status as the deep-water Otago lakes may have vastly less or even no lake snow, overturning a prevailing hypothesis on lake snow drivers.

3.2.7 Overview of presentations

The presentations did not cover all studies that had been carried out (e.g., other NIWA studies on *Lagarosiphon major* and on littoral food webs were not discussed). They highlighted that over the past c. 35 years, a range of targeted research studies has been carried out on the lakes, but that, apart from research on lake snow, comprehensive and cohesive research programmes on the lakes have been lacking.

The objective of <u>monitoring</u> is typically to assess the state of the monitored system and to detect any changes in the state of that system over time. While the data collected during such monitoring may contribute to the management understanding of the system, it is important to recognise that directed research effort will be needed to understand the key drivers of the system to underpin future management decisions/frameworks.

The current ORC monitoring programme in the deep water lakes has resulted in significantly increased knowledge of conditions and trends (such as changes in chlorophyll *a*, which was pivotal in the formation of this group). Although routine monitoring and strategically planned research work should not be confused, monitoring practices should be frequently reviewed and, where relevant, new methods and technologies should be adopted when appropriate and feasible to do so (e.g. within budget constraints). For instance, in the near future the potential for eDNA methods to deliver information on processes within the lake, such as turnover of different nutrients, could be explored. Companies that routinely service analytical needs for councils, such as Hill Labs, are now investing in eDNA methodology and this will make the use of these techniques increasingly convenient and affordable. However, development of specific assays relevant to the deep lakes ecosystem will be required to maximise the information return from such tests.

3.3 Worst credible scenarios

Drawing on the considerable knowledge of the TAG members, a discussion was had regarding how serious the degradation of the lakes could be and how future degradation could manifest. Acknowledging that the deep Otago lakes are considerably different to smaller lakes, which have been much more thoroughly studied, the TAG discussed the trajectories of other large lakes associated with the European Alps and also the Laurentian Great Lakes (Canada/US).

Many large, pre-alpine lakes in Europe, such as Lake Constance and Lago Maggiore, had indeed undergone severe eutrophication in the 1970s and 1980s. The degradation trajectory was exponential in Lake Constance, which went from a baseline total phosphorus concentration of c. 5 μg/L (oligotrophic) to c. 80 μg/L (supertrophic) in only ~20 years. It then required effort for roughly 20 years, costing in excess of 3.5 billion Euros, to restore the lake to its pre-eutrophication condition. The eutrophication experience of Lake Constance and other large, European pre-alpine lakes illustrates that large, deep pre-alpine lakes are not inherently resilient or resistant to eutrophication. In fact, many TAG members believe that they are quite sensitive, although there can be time lags between increasing stressors and lake responses.

Climate change signals are much stronger in Europe than they are in Aotearoa New Zealand. Lago Maggiore and other pre-alpine lakes on the south side of the European Alps have a mixing regime known as oligo-holomixis, which means that the water columns of the lakes only fully mix in some winters, while remaining stratified in most winters. This affects the oxygen concentrations in the bottom waters of the lakes as the bottom waters are prevented from equilibrating with the atmosphere in most years. Therefore, oxygen depletion in the bottom waters of these lakes is more severe than in our lakes. However, a warming climate in central Otago is likely to shift our deep lakes toward a tipping point where they may not mix in some winters. The loss of oxygen in bottom waters of lakes has many negative effects, especially if the waters become devoid of oxygen. In such situations, the habitat is no longer available for fish and chemical changes occur in the lake bed sediments that can result in the recycling of phosphorus back into the water column, potentially fuelling algal proliferation. It is not clear whether this already occasionally occurs in Otago's lakes during winter, but if it does, it seems to be a rare occurrence.

Finally, Otago's large, deep lakes have been colonised by non-native species (e.g., salmonids), some of which are invasive (e.g., *Lagarosiphon major*, *Daphnia pulicaria*, *Lindavia intermedia*). The experiences of the Laurentian Great Lakes highlight that invasive species can have large impacts on lake functioning, fisheries and water quality. For example, the invasion of the lakes by lamprey in the 1950s had serious impacts on native salmonids in the lakes. Invasion by zebra mussels also changed the water quality dramatically in the more eutrophic lakes. The Laurentian

Great Lakes have been intentionally and non-intentionally colonised by over 100 non-native species and research from those lakes indicates that even in such large lakes, invasive species often cause large changes in the functioning of the lakes and in the ecosystem services that people derive from the lakes. The interactions are often complex, as one might expect when invasive species interact with native and other invasive species. Research on food webs in the Laurentian Great Lakes has shown that changes to the foodwebs caused by invasive species can either exacerbate or mitigate eutrophication, thus affecting resistance and resilience to nutrient loading and availability.

3.4 Key overarching questions informing the discussions of the TAG

The information reviewed by the TAG raises some key questions that underpin much of the discussions that the TAG has had about the lakes:

1. Are the big, deep, pre-alpine, Otago lakes likely to function differently to most other well-studied lakes, that tend to be much smaller?
2. What are the key differences in how the bigger, deeper lakes function?
3. Are the deep Otago lakes inherently resistant and resilient to changes in stressor levels or are they sensitive to stressors?
4. What sort of lag times, if any, might we expect between a change in stressor level and the resulting lake response?
5. Are Otago's big, deep lakes changing? If so, is this cause for alarm?
6. How can we improve understanding of the above?
7. Does SOE monitoring need to be changed/improved for these lakes in particular?
8. Do these lakes need to be managed differently than other lakes?

These key questions also influenced our discussions about key knowledge gaps, a summary of which follows.

4. Knowledge gap analysis

A research proposal focused on the Otago deep lakes and led by the University of Otago was submitted to the MBIE Endeavour funding round in 2022, but was not successful. The proposal addressed key knowledge gaps regarding Lakes Wānaka, Whakatipu Waimāori, and Hāwea, as determined by the team of scientists on the bid, together with numerous research partners (including the ORC) and stakeholders who were consulted during the development of the proposal. At the June 13 meeting of the TAG, Marc Schallenberg presented the MBIE proposal as a starting point for TAG discussions about key knowledge gaps concerning the lakes.

At the July 11 and August 8 meetings, the TAG discussed a range of knowledge gaps that hinder our understanding of how these lakes function and thereby affect the ORC's ability to confidently monitor and manage the lakes. The knowledge gaps that emerged from the TAG discussions fell into the following five broad categories: (1) Lake management and community engagement, (2) budgets, (3) fundamental lake processes, (4) historical context, and (5) mātauraka Māori. The knowledge gaps are briefly discussed below. The TAG's draft table of knowledge gaps, with more detailed information, is found in Appendix B.

Lake management and community engagement encompasses work to be done to clarify and solidify community support for lake management plans and actions. The TAG acknowledged that some work had been done by the ORC and WAI Wānaka on community values related to the lakes, but felt that the translation of the values into planning limits and actions plans was less effective. The TAG discussed the multi-criteria decision analysis approach used by WAI Wānaka (led and facilitated by Simone Langhans) as a means to help establish evidence-based, community-supported limits on land use. The TAG also discussed the paucity of information available on iwi values, specifically for Otago's deep lakes. Other areas that could benefit from investigations include the improvement of passage for migratory fish on the Clutha River, local calibration and validation of Overseer-type catchment models, and improved predictions of future development pressures in the catchments and the associated stressors on the lake ecosystems that future development is likely to exacerbate.

Knowledge gaps related to lake management and community engagement

- Public awareness of lake degradation risk; and science and monitoring results
- Setting lake specific thresholds
- Iwi values
- Trajectory of future development and likely associated pressures
- Lake/sea connection for fish
- Spatial/temporal decision support framework
- OverseerFM® additional validation

Budgets are tools for linking catchment conditions to lake conditions[14]. The TAG identified major knowledge gaps in various mass and energy budgets for the lakes. Such budgets involve quantifying inputs to the lakes, outputs from the lakes, and transformations within the lakes (where applicable). Thus, estimating mass loadings to the lakes is an important aspect of constructing budgets. Nutrient and other contaminant budgets require a water budget (water balance) be estimated as contaminants flow in and out of the lakes along with water flows. The oxygen budget refers to oxygen in the hypolimnion (which is the bottom layer of water in the lakes). Organic carbon inputs will, to some extent, decompose in the hypolimnion, driving oxygen depletion.

Knowledge gaps related to budgets include:

- Water balance
- Nutrient budget
- Heat budget
- Oxygen budget
- Sediment, organic carbon, urban, emerging, and other contaminants

The TAG also identified knowledge gaps related to how *fundamental lake ecological processes* operate differently in our large, deep lakes. It is acknowledged that the three Otago lakes are among the largest lakes (in terms of depth, surface area, and volume) in Aotearoa New Zealand and that their large size specifically affects some aspects of lake functioning in ways that are not yet well understood. For example, our understanding in these lakes of how nutrient stressors relate to ecological responses (e.g., algal biomass, lake snow, etc.) is poor. Specific attributes that are likely to be unusual in such lakes compared to better-studied, smaller lakes include

[14] Verburg P, Schallenberg, M, Elliott S, McBride C. (2018). Nutrient budgets. Pp. 129-163 *In:* Hamilton, D, Collier, K, Howard-Williams, C, Quinn J (*eds*) Lake Restoration Handbook: A New Zealand Perspective. Springer.

thermal stratification and mixing, food webs and nutrient cycling. Furthermore, invasive species found in these lakes potentially affect stressor-response relationships and ecological tipping points. However, we currently have little understanding of this.

Knowledge gaps related to fundamental lake processes include:

- Mixing dynamics/hydrodynamics
- Food webs
- Climate impacts
- Invasive species / missing species
- Inability to measure phosphorus
- Nutrient behaviour/cycling in lakes/effects on primary production
- Identification of tipping points

The TAG also highlighted that the identification of management targets for these lakes would benefit from some understanding of the *historical variability of water quality* in the lakes. For example, are the recent increasing trends in chlorophyll *a* observed in the lakes unprecedented or are they consistent with normal range of historical variability in the lakes? While the lakes are in a relatively pristine condition compared to many other monitored lakes in Aotearoa New Zealand, there have been some major historical changes in their catchments that could have altered water quality, such as the raising of the water level of Lake Hāwea, activities related to historic gold or scheelite mining, land use intensification due to high country land tenure review, rapid urban expansion, as well as incursions of game fish, invasive macrophytes, zooplankton and phytoplankton. Understanding historical water quality in the lakes would help understand how variable water quality has been, reveal any sensitivities and/or resilience to historical stressors, and it would clarify whether current increasing trends in algal biomass are unprecedented or not.

Knowledge gaps related to historical data and trajectory include:

- Historical changes in land use, and their quantification
- Variability of historical state
- Formal review of known information
- Periodic loading from earthquakes

Finally, the TAG acknowledges that it has very little understanding of mahika kai values and *mātauraka Māori* in relation to these lakes. A better understanding of these would help devise lake research and monitoring programmes that protect Māori values.

Knowledge gaps related to Mātauraka Māori include:

- Role of Mātauraka and the importance of mahika kai

4.1 Fit-for-purpose research: assumptions and uncertainty

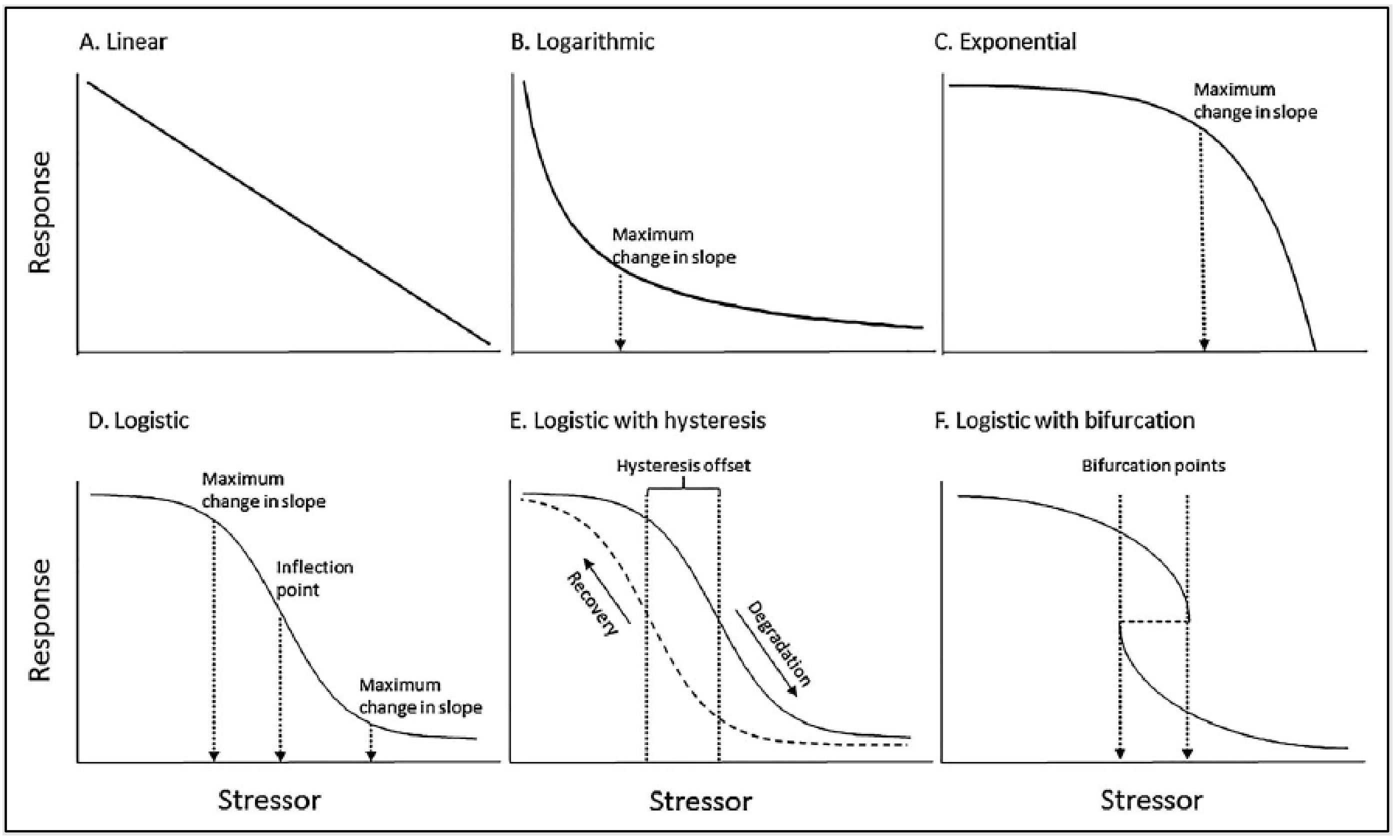
Reviewing current information and producing a list of knowledge gaps was the TAG's first step in satisfying the terms of reference. The TAG discussed the fact that the monitoring and research required to fill the different knowledge gaps suggests various research approaches, methodologies, and investments. The TAG discussed the task of determining how fit-for-purpose different projects might be. For example, the amount of uncertainty in the output of a study can vary greatly. There will be a need to estimate how certain the science information could be, given the assumptions inherent in the various methodologies, given limitations of the various datasets available, given our initial lack of understanding of how these systems function, etc. An important part of the TAG's work will be to produce a prioritised set of recommended research and monitoring projects to the Management Working Group that aligns well with the needs and demands of the ORC.

5. A stressor-response framework suggested to help identify values to safeguard and the key stressors linked to those values

At the August 8 TAG meeting, Marc Schallenberg gave a presentation outlining how the use of a conceptual stressor-response framework could assist in the prioritisation of future investigations.

The stressor-response framework[15,16] identifies measurable lake values (e.g., water clarity, fisheries, mahika kai) together with the main stressors that impact on the values (e.g., nutrient availability, invasive species, climate). The values should be attributes of lake condition that respond to stressors through a known, or hypothesised, stressor-response relationship (Fig. 1). Knowledge of such relationships can help identify whether tipping points, ecological resilience, and/or sensitive domains in a relationship exist, and at which stressor levels these features might manifest.

Other lake attributes ("mediators") may mediate the stressor-response relationship (e.g., zooplankton grazing pressure, macrophytes competing against algae for nutrients, etc.). Therefore, such mediators should also be identified and considered when managing lakes using the stressor-response framework.



[15] Larned ST, Schallenberg M. (2018) Stressor-response relationships and the prospective management of aquatic ecosystems. *New Zealand Journal of Marine and Freshwater Research* 51: 78-95.
[16] Schallenberg M. (2020) The application of stressor-response relationships in the management of lake eutrophication. *Inland Waters*. 11:1-12. DOI: 10.1080/20442041.2020.1765714.

Fig. 1. Potential shapes of stressor-response relationships and associated features such as tipping points, ecological resistance and hysteresis (differences between degradation and recovery tipping points). Source[14].

The stressor-response framework could be used to prioritise future investigations on the lakes using the following protocol:

1. Identify key lake values and define measurable attributes of the values (i.e., ecological response variables). This step is strongly linked to ORC's Catchment Action Plan development process which started in August 2024 together with the Upper Lakes Integrated Catchment Group.
2. Identify the stressor(s) most likely to impact the values.
3. Identify any attributes of the lakes that may alter the stressor-response relationship (mediators).
4. Based on the identified key stressor-response relationships, select the (1) response attribute, the (2) stressor attribute and (3) any relevant mediator attributes to study, measure, and/or monitor.
5. This protocol ensures that effort is put into monitoring values, stressors, and mediators that together affect how important lake values respond to anthropogenic pressures.

The scientific information underpinning Lake Taupō's nitrogen cap-and-trade system was based on linear stressor response relationships that had been demonstrated for the Lake Taupō catchment[15]. For example, cow stocking rate was shown to be linearly related to catchment nitrogen yield and lake total nitrogen concentrations were shown to be linearly related to chlorophyll *a* concentrations. The stressor-response relationships showed no evidence of ecological resistance, resilience or tipping points. This provided confidence to the Waikato Regional Council regarding how the lake would respond in the long term to the reduction of nitrogen fertiliser use in the catchment, underpinning the nitrogen cap-and-trade policy.

Another example of the use of stressor-response relationships in lake management is the case of Waituna Lagoon, which studies had shown to be at risk of losing its seagrasses/macrophytes due to eutrophication. Environment Southland commissioned studies investigating the risk to the macrophyte community of current and future simulated nutrient loads[15]. The studies identified that the stressor-response relationship between nitrogen loading and seagrass biomass is strongly non-linear, characterised by tipping points. Therefore, Environment Southland developed nutrient load limits for Waituna Lagoon that were designed to safeguard the seagrass community by reducing the nitrogen loads to below the tipping points identified by the research. The studies also revealed that the opening regime of the lagoon was a mediating factor, affecting the impact of nutrient loads on seagrasses. This led to new guidelines regarding the opening regime of the lagoon – guidelines specifically designed to safeguard the seagrass/macrophyte community by mitigating the impacts of nutrient loads.

6. Next steps

As mentioned above, the next step in the TAG's work is the prioritisation of future work needed to better understand and manage the lakes. There are a range of opportunities to for the TAG to seek input from others on this prioritisation exercise.

Through a sub-contract to the University of Otago, the TAG is undertaking a comprehensive collation of information on historical changes to the lakes and their catchments. The material will include published and unpublished papers, reports and data. A searchable database of relevant information sources will be produced together with a report that summarises the information collected and provides a historical timeline for major changes that have occurred in the lakes and their catchments. This work will be completed by the end of 2024.

With the completion of the above work, the TAG's work will transition from that of information review and gap analysis towards a focus on monitoring and research programme development, with an eye on eventual implementation. To assist with this, the TAG will hold a meeting with the CEO of Environment Bay of Plenty (EBoP), Andy Bruere. For over 20 years, EBoP has worked closely with Waikato University and other science providers to develop management strategies underpinned by research and monitoring data for the Te Arawa/Rotorua lakes. The TAG will discuss with Andy the successes and challenges of integrating limnological research with policy development from the point of view of the Te Arawa/Rotorua Lakes. This will give the TAG some ideas about how best to progress to the next stage of its work.

The TAG is on track to provide the Otago Deep Water Lakes Management Working Group a set of monitoring and research options for consideration in 2025.

7. Conclusions

Otago's highly valued deep-water lakes are changing and this has led to calls from scientists and the community to improve monitoring and to collect technical information that will improve long-term management of these systems. Available monitoring data provides some cause for concern, with chlorophyll *a* concentrations increasing in recent years (Fig. 2) along with increasing nitrogen concentrations and decreasing water clarity in Lake Wānaka (Appendix A). Furthermore, nitrate-nitrite concentrations in the Matukituki River have increased over the past ten years (Appendix A). Together with increasing catchment development and agricultural intensification, especially in the upper catchments, the recent changes in water quality highlight the need for improved understanding and greater protection for these highly valued lakes.

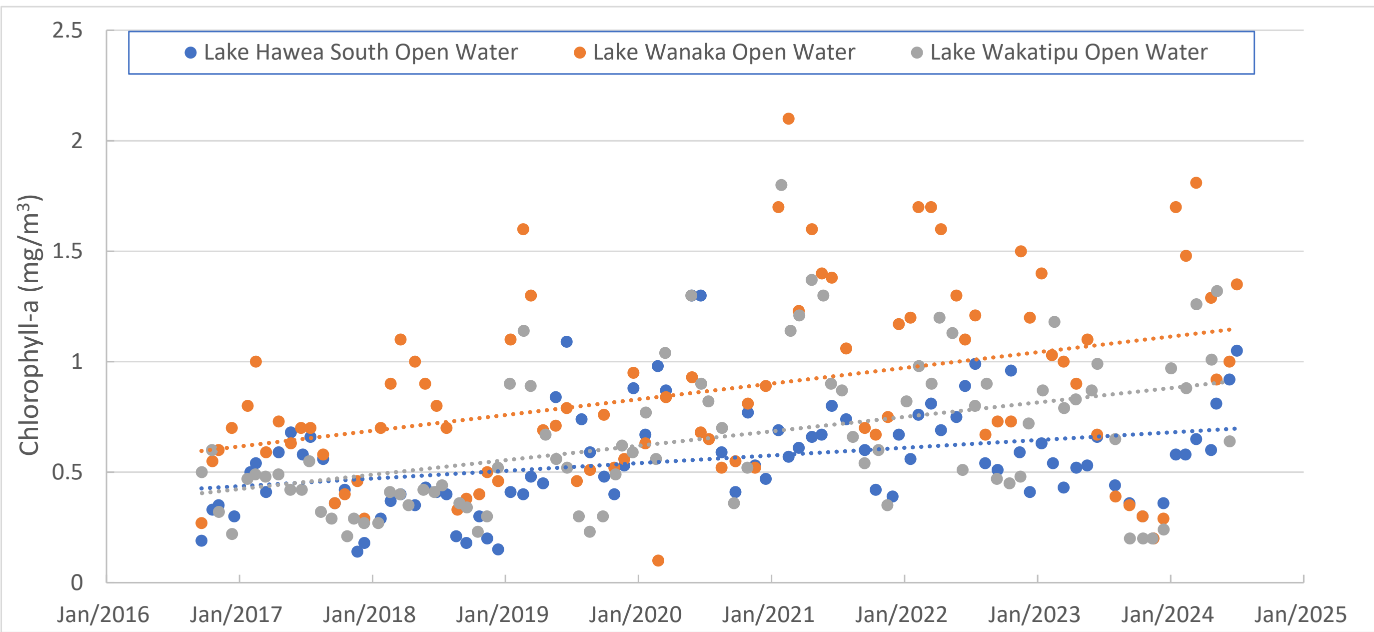


Fig. 2. ORC chlorophyll *a* data showing recent increases in algal biomass in the open water sites of the three lakes. Algal biomass in Lakes Wānaka and Whakatipu Waimāori roughly doubled between the years 2016 and 2024, while the biomass in Lake Hāwea increased by c. 50%.

Appendix A

Long-term state and trends in the deep-water lakes and their catchments.

The following tables are reproduced from Ozanne et al. (2023)[17]. Interpretation of these tables is guided by the following:

- The level of confidence categories used to convey the confidence that the trend (or step change) indicated improving water quality is based on the table below.

Categorical level of confidence trend was decreasing	*Colour used in report*	*Value of C_d (%)*
Virtually certain		0.99–1.00
Extremely likely		0.95–0.99
Very likely		0.90–0.95
Likely		0.67–0.90
About as likely as not		0.33–0.67
Unlikely		0.10–0.33
Very unlikely		0.05–0.10
Extremely unlikely		0.01–0.05
Exceptionally unlikely		0.0–0.01

- Grades for sites that did not meet the sample number requirements are shown as white cells with coloured circles.
- The white cells indicate sites for which the variable was not monitored.
- A small square in the upper left quadrant of the cells indicate the site grade for the baseline period (2012-2017) where the sample numbers for that period met the minimum sample number requirements.
- Cells containing a black dot indicate site/variable combinations where the trend was evaluated as zero.

[17] Ozanne R. Levy A & Borges H (2023). State and Trends of Rivers, Lakes, and Groundwater in Otago 2017 – 2022. May 2023. Otago Regional Council, Dunedin. 132 p. plus appendices.

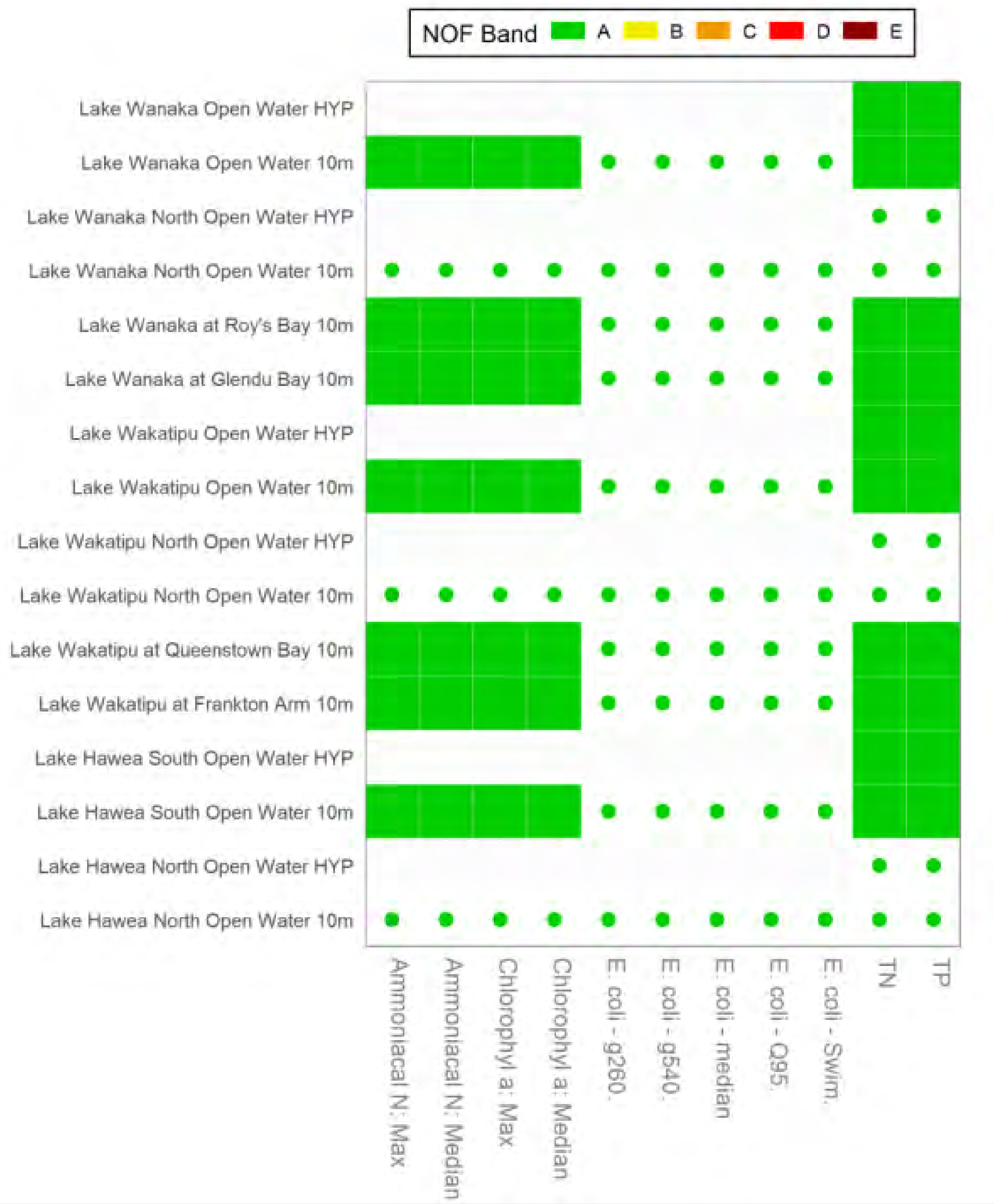


Fig. A1. Comparison of attribute states at various sites in Lake Hāwea, Wānaka and Whakatipu Waimāori.

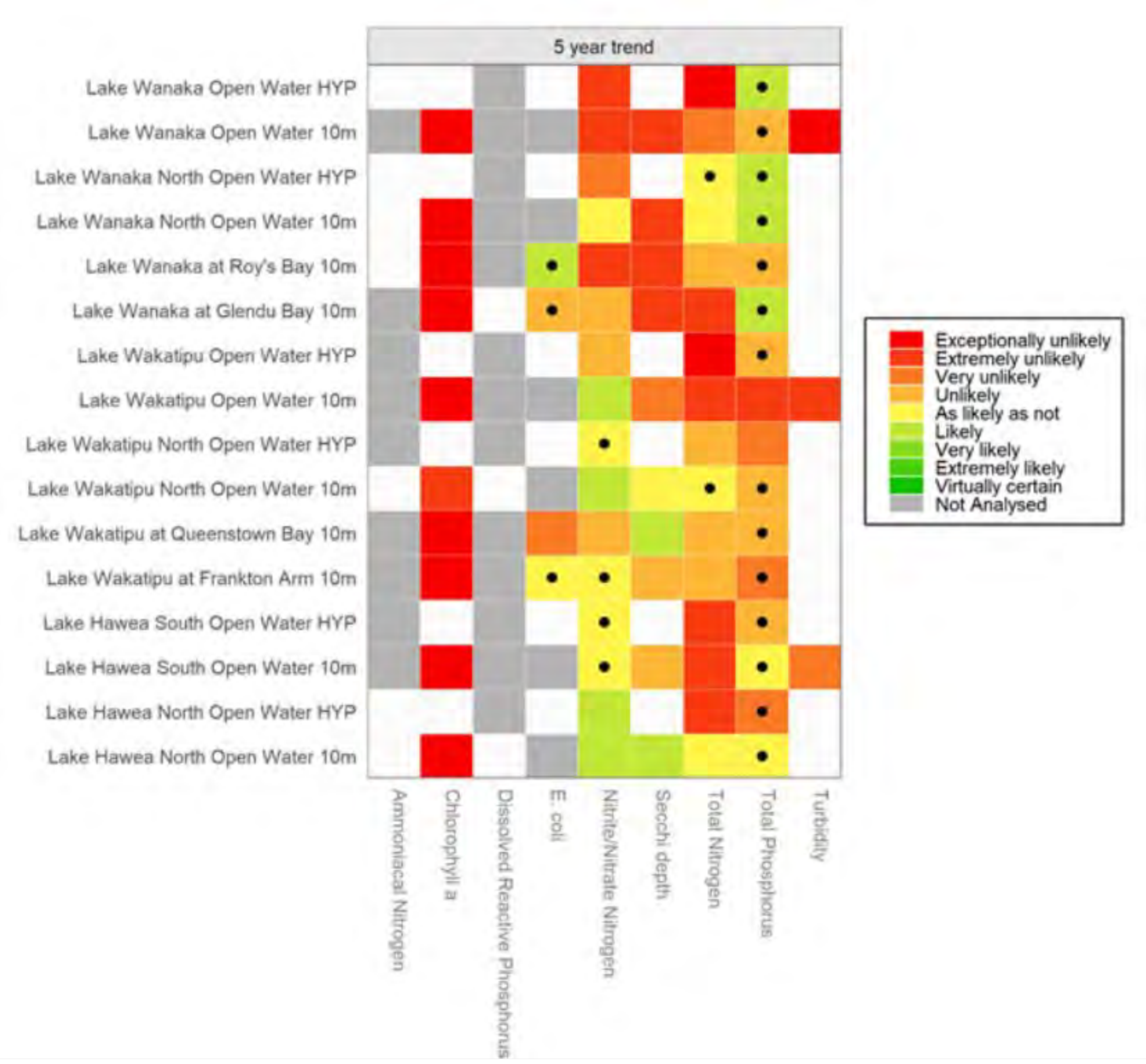


Fig. A2. Comparison of attribute 5-year trends at various sites in Lakes Hāwea, Wānaka and Whakatipu Waimāori.

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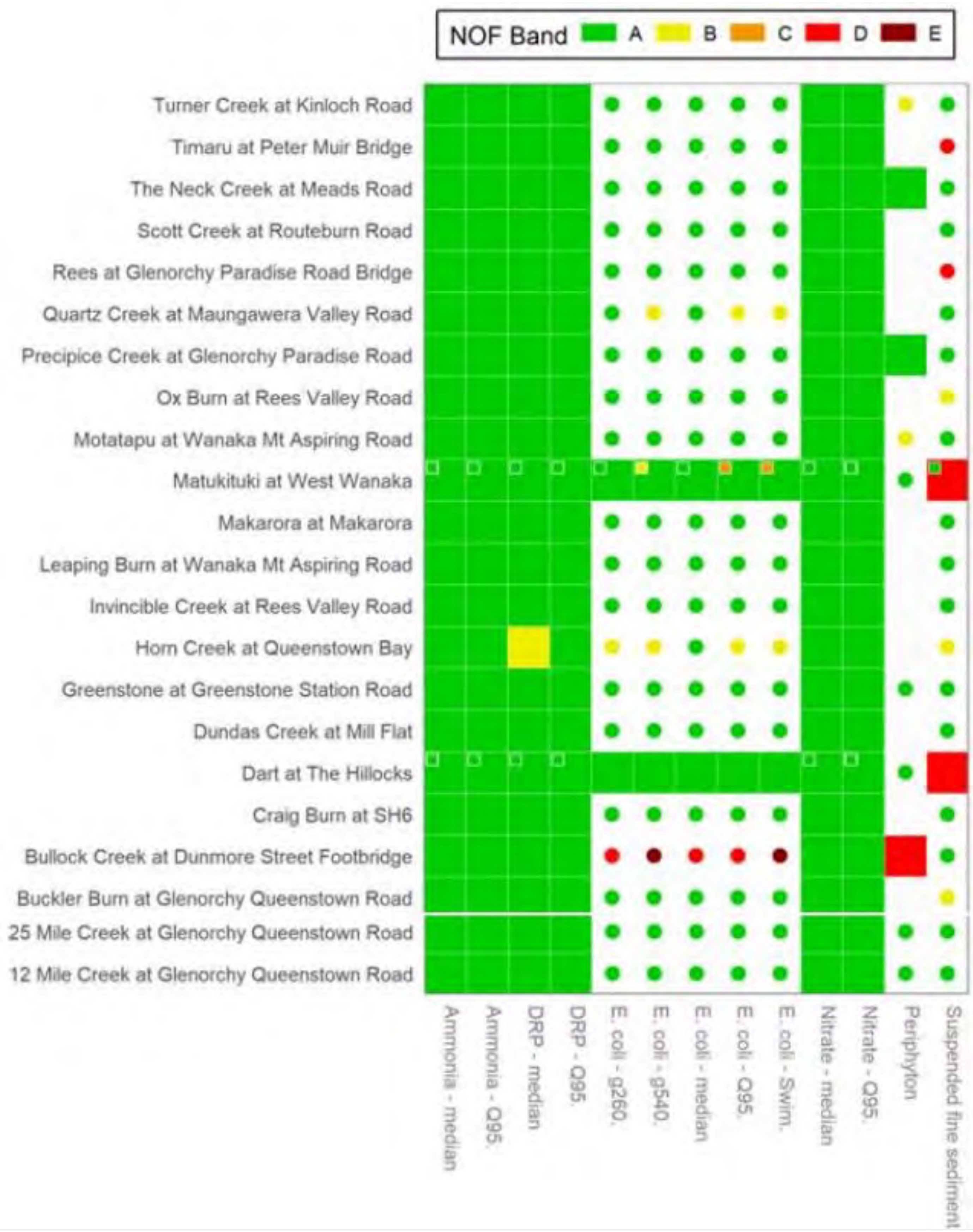

Fig. A3. Comparison of attribute states in tributaries of Lakes Hāwea, Wānaka and Whakatipu Waimāori.

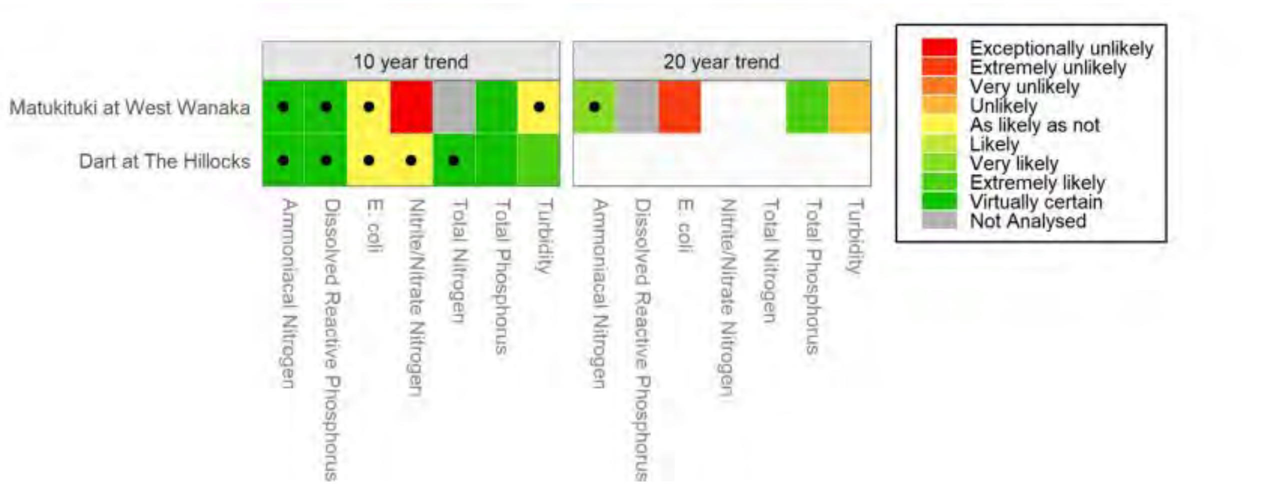

Fig. A4. Comparison of attribute 10-year and 20-year trends at two long-term monitoring sites in tributaries of Lakes Wānaka and Whakatipu Waimāori.

Appendix B: Draft table of knowledge gaps identified by the TAG

Theme	**Topic**	**Explanation**	**Reason / Importance**	**How to address?**	**Where / spatial extent**	**Duration?**	**Leveragability / utility**	**Dependencies**	**Cost/Time/Resources**	**TAG scope? Is it a realistic project?**
	Explainer	*What is the knowledge gap?*	*Why does this matter? What key question does it tie into?*	*What sort of investigation/programme would fill gap? Additional data/monitoring, modelling? Lit review? Public survey?*	*Which lakes / rivers / catchments. Extent of study/project? No. of sites?*	*Duration of monitoring, how long would an investigation take? (e.g., 5 years monitoring data)*	*Could the data be used in other investigations or models? Is it multiple use? Outputs critical for other work?*	*What other data/information does this depend on? E.g., a lake model X requires 5 years profile data and nutrient budget etc*	*Estimate of what it would take to do. Required expertise? Estimated costing? Hardware?*	*Within this TAG's scope to advise on or recommend actions? Potential Funding appetite / probability of successful outcome/ is it tractable for Regional Council?*
1. Lake management and community engagement	Public awareness of lake degradation risk; and science and monitoring results	People think lakes are resilient – no danger of degradation	Public apathy / resistance to any protection efforts or funding	Public education campaign?	Wānaka, Queenstown/Tahuna, (Hāwea)	Multi-year coms programme	May increase public appetite for further research or management	Potentially requires supporting data, adverse trends, other examples	Could be done as a join comms effort from the contributing partners led by ORC; and combined/ aligned with CAP meetings	Important for overall lakes programme, TAG could have input but impetus likely sits with others
	Setting lake specific thresholds, limits,	Knowing quantitative limits on land use that will	An effective Land and Water Plan	One option would be to use a collaborative process with stakeholders and	This should either be applied to the three catchments of the big lakes, or could	1 year, multiple workshops with the community	The land use limits so defined would highlight the key stressor-	Needs to be done in conjunction with community	Could be done as part of the CAP development process?	

Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
		safeguard the lakes' values yet allow some development		scientists (perhaps building on the multi-criteria decision analysis framework used by Wai Wanaka to develop the Upper Clutha Catchment Management Plan which elucidated the community values).	potentially be done once for all three lakes together		response relationships that need research and refinement	around values, outcomes sought		
	Iwi values	Knowing iwi values, the goals and pressures for these values and ways to measure their health and impact, respectively	An effective Land and Water Plan based on our partnership with mana whenua	Collaborative process with mana whenua (e.g. using multi-criteria decision analysis)	One process for the whole Upper Lakes area	1 year of working through the process	Arguably underlies all other investigations	Requires mutual respect and clear communication	Significant time investment and expectation management potentially required	This will be done through the CAP development process with the Upper Lakes Integrated Catchment Group (ULICG) once mana whenua representatives are appointed to the ULICG.

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Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
	Trajectory of future development and likely associated pressures	How will the catchments be developed? What associated affect, loads	Can predict potential future loads, forecast risk to lakes	Assess permissibility of land use regulations, subdivisions etc. What is maximum theoretical development potential under current regs?	All catchments	One-off exercise	Useful for scenario modelling, exploring most adverse development / loading scenario	Requires demographic projections as well as projections for economic development and associated pressures		Out of scope for TAG. TAG could commission this work and consider the effects of future development, but it isn't the appropriate forum to undertake this assessment
	Lake/sea connection for fish	What required to restore connectivity for migratory fish (eels)?	Restoring fish connectivity would help restore the mauri of the lakes and catchments	Study on most effective protocols for trap-and-transfer over dams on the Clutha River. This should involve discussion with the eel trap-and-transfer programme at Manapouri	Roxburgh, Clyde and Hawea Dams	1-to-3 years	The data on transfers of fish could help with studies on the food webs of the lakes and on the mahika kai potential	Probably need some estimates of elver survival, once transferred	This work should probably be Maori-led	
	Spatial/temporal decision support framework									
	Overseer limited validation in high altitude wet climates	If the ORC is going to rely on catchment models to estimate	Land use-nutrient flux models are a tool for estimating the impacts of land use activities on downstream aquatic ecosystems. If this tool	Some of this work has already been carried out by ORC/AgResearch. A stocktake is	Sites for this work are the areas in these catchments that are developed	3-to-5 years	The data would be fed into catchment models which can be used to estimate loads	Would need to know which land-use/catchment	AgResearch is probably best placed to do this work Would involve FANZ and	A pending publication by AgREsearch may address

Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
		nutrient and sediment loads, then the models used should be properly calibrated for the soils, geology, topography and climate of the catchments of these lakes	is to be use for these catchments, it needs to be fit-for-purpose. In a different direction it enables the group to note the variation that exits within farm systems and highlights high risk factors of those systems.	required and then any gaps in our understanding could be targeted with future studies The level of data available is limited and additional data could be quickly gathered to ensure more accurate representations of extremely complex systems. This data an be used as well for validation.	and are suitable for future development		(current and projected). It would enable a base level of mitigations being applied by these systems and data on the systems which can be used in later years to measure change.	models would be used so that the appropriate input data can be collected	Industry bodies plus OverseerFM Ltd. Capability for ORC to model	some of these questions
2. Budgets	Water balance	Much of the catchments of these lakes are ungauged including major tributaries (e.g. Makarora, Hunter)	Needed for nutrient load calculations and hydrodynamic/water quality models. Some will be more important than others	Flow sites on major tributaries BUT cost and practicalities (braiding, flooding, mobility of bed) need consideration. Correlation/modelling based on existing sites? Might be possible to lump some catchments together based on rainfall and weather patterns	Ideally all streams/rivers and other major water sources Groundwater sources important (Missing component of nutrient/water budget. Potentially long lag between landuse pressure and nutrients entering lake/other water body)	Multi-year Some short-term investigations may help refine estimates	Could be used in resource assessment, and provide important hydrological context for ecological data		$10-20K per site per year? Maybe more on large rivers that may require jetboat or heli-gauging	Yes

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Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
				(e.g. minor eastern tribs, minor western tribs). Also need to address evaporation from the lake surface in a meaningful way; this is linked to the heat budget item below.						
	Nutrient Budget: What are the sources of nutrients, relative contributions to total load, composition from different sources. Inputs, outputs, direction of change	Essential to understand current state	Nutrient concentrations in inputs over time, weighted by flow (=loading). Inputs need to cover categories of land use (natural (DoC estate), rural extensive, rural intensive, rural intensive irrigated, rural lifestyle, urban residential, urban commercial) Continuous sampling to assess seasonal changes Event-based sampling to estimate discharge-concentration relationships	Nutrient sampling of inflows. Inflow measurement (see above).	Whole catchment	Multi-year Some short-term investigations may help refine estimates	Quantify contemporary nutrient loadings	Flow measurements Water quality sampling		Within scope and capability
	Heat budget	Knowledge of heat	Critical to understand the stratification, mixing and hydrodynamics, and	Monitoring buoy, inflow/outflow temperature and	Lake centre, river mouths, discharge	Continuous (profile)	Data will inform many other critical areas.			Within scope and capability

Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
		balance over time.	to predict the impact of the changing environment.	volume monitoring/estimation, meteorological observation, 3d modelling, heat budget analysis, stability analysis						
	Oxygen budget		Important to understand dynamics in hypolimnion and conditions for nutrient cycling/retention/transformation(s). Understand the chemical/biological oxygen demand. Metabolism Understanding the oxygen budget in lake ecosystems is crucial as it serves as an indicator of ecosystem health, influences biogeochemical processes, and impacts water quality. Adequate dissolved oxygen levels support diverse aquatic life and ensure the balance of nutrient cycling, while low oxygen conditions can lead to hypoxia, harming biodiversity and producing toxic substances. Additionally, oxygen dynamics are intertwined with climate	Hypolimnetic sampling, monitoring buoy Need to consider sources of oxygen demand in the bottom waters; allochthonous vs autochthonous sources of organic material can alter oxygen demand from hypolimnetic to sediment oxygen demand. Delivery of organic matter from the catchment will be important; plunging inflows, changes in land use	Lake surface and lake bottom. Profile Catchment inputs of organic matter – need to link to hydrodynamic work to understand fate of inflows in the lake (e.g., underflow vs. Overflow) Sediment oxygen demand measurements	Continuous Long-term Possibly supplemented with one-off or period SOD measurements	Data will inform many other critical areas.	Buoy		Within scope and capability

Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
			change effects and carbon sequestration processes.							
	Sediment, organic carbon, urban, emerging and other contaminants.	Organic matter loads are associated with nutrient loads and with oxygen depletion	Agricultural development is associated with increase organic matter loads to the lake. Climate warming will likely also increase organic matter loads. Organic matter inputs provide organic N and P. Organic C inputs are a driver of oxygen depletion.	Studies on the contributions of terrestrially-derived organic matter to the in-lake availability of N and P. Studies on the oxygen depletion potential of organic matter inputs from the catchment to the lakes.	The three lakes and main river inflows.	1-year project	This data would feed into the projects on oxygen and nutrient budgets and on in-lake nutrient cycling	Water balance		Potentially
3. Fundamental lake processes	Mixing dynamics/hydrodynamics	How does climate affect stratification and mixing?	Essential to understanding how nutrients are retained, mixed and transformed within the lake. Indicates rate of change. Do river plumes plunge? How far along bed do they travel? How does climate affect light nutrient availability to phytoplankton?	Buoy data, monthly CTD casts, depth-integrated sampling Hydrodynamic modelling	At a minimum, deep-water sites in the three lakes. Preferably also in bays of Lake Wanaka	Cover a range of conditions/seasons, and preferably multiple years as the climate varies from year to year	This data links to studies on modelling effects of climate on the lakes and to studies on food webs because differences in length of stratification period, changes in temperature, etc. Affect many organisms in the lake food webs	River inflows/outflows and temperatures, meteorology, lake observations (temperature profiles)		Yes
	Food webs	Link between trophic levels, flow	How do changes in lake productivity affect other important foodweb	Biodiversity surveys, stable isotope analyses, gut	Could be done in one lake (e.g., Wanaka would be best), but could	2-to-3 years	Links to work on the impact of invasive species,	Data on open water habitat use by fish and	Would make an excellent PhD study	

Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
		of energy and nutrients	components, all the way up to fisheries? How much of the lakes' productivity occurs in the water column, in the sediments, in the open waters, in the bays, in the littoral zones, in the "estuaries"? Are there productivity hotspots in the lakes?	content analyses, use of Bayesian mixing models	preferably be done in the three lakes.		nutrient loads, and climate change	zooplankton using sidescan sonar		
	Climate impacts	How does climate variation affect key lake values?	Causes of apparent changes? What changes might be expected in a changing climate? Future climate change may mitigate or exacerbate the effects of more localised and manageable anthropogenic changes (e.g., nutrient loading, invasive species) to the lakes. If climate warms substantially, the lakes may not fully mix in some years (we have some evidence that this may already occur). This could cause relatively major changes in many aspects of lake functioning.	Lake buoy data is essential for this work. Previous assessment (Tina Bayer's PhD) Analysis of local climate projections from recent GCM downscaling and of historical climate trends from local met stations. Hydrodynamic modelling to predict lake response (temperature, mixing) under climate change scenarios.	All three lakes. Should focus on deep, open water sites as well as shallow bays.	Assuming all the relevant data for a hydrodynamic model were available, a one off study would take 1-to-2 years.	The information would be essential for predicting future trajectories of lake functioning and water quality as well as interpreting historical trajectories of water quality.	Water balance, heat budget (potentially sediment loads), lake buoy and CTD data.		Yes

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Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
	Invasive species / missing species	What effects do invasive species such as L. intermedia (lake snow), Daphnia 'pulicaria', trout, lagarosiphon have on key lake values such as water quality, fisheries, drinking water supply, tourism, etc.	Could lake values including water quality, either exacerbating or mitigating effects of anthropogenic stressors such as nutrient loading Climate warming and increasing nutrient loads (i.e., increasing productivity) will likely make the lakes more suitable habitats for potential invasive species (e.g., perch)	Quantitative research project involving multiple trophic levels and concurrent measurement and analysis of environmental predictors	All three deep-water lakes recommended due to their inherent contrasts	One year of field work may be enough; another year to analyse and write up. For studies on more than one invasive species, additional time would be needed.	Strong linkage to foodwebs investigations. Interrelated to studies of nutrient dynamics and climate change.	Requires collaborative approach with researchers of different expertise from several institutes	Two years, budget from recent MBIE bid suggests at least $500K required. Could be more if more than one invasive species is studied.	Within scope for TAG, may be too expensive for council, but may be able to attract co-funding
	Nutrient behaviour/cycling in lakes/effects on primary production in lake	Some nutrients (e.g. phosphorus) too low to be measured and thus ineffective as a sentinel of change	P is generally assumed to be limiting nutrient in freshwater, therefore it should regulate primary production. However, P is cycled rapidly by phytoplankton, lost to sediments in biomass, and, therefore, its availability to phytoplankton is not detected by current simple measurements of dissolved reactive P concentrations. This	New methods. E.g. refocus on measuring nutrient availability by measuring phytoplankton enzyme responses to nutrient availability.	Wānaka to start with. Open water vs bays/littoral/inlets/urban; different water particle fractions	Initially, this could be examined two-three times per year. The work could be extended for several years	Informative regarding interpreting the relationship between external nutrient loading and phytoplankton biomass,.. Potentially links to lake snow work, foodwebs, nutrient	Info already published. No dependencies on other lake projects.	50-75K first year? Thereafter reduced cost. Needs molecular capability and enzyme assays, boat support.	Yes, may be able to start with internal contestable funding without ORC. $50K recently acquired for this from MWLR

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Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
			work would provide a more sensitive method to understand and monitor P availability in these nutrient poor lakes. Similar work could be undertaken looking a nitrogen availability as well as how dissolved organic carbon loads could influence nutrient cycling rates.				budgets and climate change.			
	Identification of tipping points	Are key lake values subject to sudden tipping points in relation to stressor levels? Is change non-linear?	With regard to managing key lake values, do we need to worry about sudden changes in those values or will changes in values likely be gradual, with increasing stressor levels? Will ORC have time to respond to any changes apparent in monitoring data or is it likely that changes in key values (e.g., water clarity, fisheries, etc.) could happen suddenly and dramatically?	Literature study of how other large, deep, pre-alpine lakes (e.g., Lake Taupo, Lake Constance, Lake Geneva, Lago Maggiore, etc) have responded to various pressures such as increasing nutrient loads, climate change, etc. Were the responses gradual or sudden? If sudden, where along the stressor gradient did the tipping points occur?	Literature studies of other, similar lakes. This project could also examine historical trajectories in our 3 lakes from sediment core analyses, once these studies have been done. Have their been tipping points in the past? Or have the lakes responded gradually					Yes

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Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
4. Historic data / trajectory	Quantify Historic / changing land use and hydrology	Interpretation of historical lake condition can be facilitated by understanding historical anthropogenic changes that have occurred in the catchment and with respect to lake hydrology and ecology (e.g., salmonid introductions, invasive species, etc.)	Qualitative risk tool, proxy for nutrient inputs. This information helps understand the past (and potentially future) relationships between anthropogenic changes and lake condition	Archival aerial photos, farm records, land records, land use modelling including urban development consent records for discharges and adjusted for loads and where sited.	Catchments of the three lakes as well their outflows.	<1yr	The information informs work on stressor-response relationships and assists with interpreting historical trajectories of water quality in the lake.	Potentially farm records, local knowledge, otherwise public data. This is a stand-alone project and does not rely on other projects in this table.	Potential geog/GIS grad student project. Potentially expert judgement. Historical review including texts, maps, photographs.	Within scope and capability
	Historical variability of water quality of the lakes	How variable has water quality in the lakes and rivers been in the past? What	Are the trends observed today within normal variability?	Sediment cores from each lake . At least central site main basin. Dating cores (radiocarbon, lead210). Explore multiple down core indicators of	At least one core from the main basin of each lake.	Core collection and analysis, reporting allow ~ 3-4 years. This would be an excellent PhD project.	This information will help understand the shapes of stressor response relationships in these lakes. It will also help	Use of proxies or indicators for water quality will use existing datasets (transfer functions).	Cores required for diatoms, eDNA, stressor proxies, etc.. Main costs, fieldwork, dating. University of Otago Geology Department	Important component that is very feasible. Perhaps the only way to get the historical

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Theme	Topic	Explanation	Reason / Importance	How to address?	Where / spatial extent	Duration?	Leveragability / utility	Dependencies	Cost/Time/Resources	TAG scope? Is it a realistic project?
		degree of change in water quality is historically unprecedented?		water quality/ecosystem change through time. E.g. diatoms, algal. pigments, bacterial eDNA. Also quantify proxies related to stressors, such as phosphorus loads, sediment loads.			establish historical variation in lake water quality, which can inform limit setting. Data will be compared with outputs from lake models. Effects of land use changes and nutrient reductions.		has the capability to core such deep lakes. Various cost scenarios depending on student funding and applying for dating through research institutes like ANSTO. Max $80 k	context for land use changes and lake response.
	Formal review of published and unpublished water quality data from the lakes and their inflows	What data already exist that can inform how water quality has changed over time in the lakes and inflows	What data do we already have? Historic trends in water clarity and potentially other water quality attributes.	Collation of water quality data from a search through published papers, unpublished report, unpublished datasets, etc.	The three lakes and their inflows	<1-year project	This data will inform other projects that deal with water quality of the lakes, such as the modelling work (e.g., hindcasting/validation) and palaeolimnological work.	This study fits together with the other historical studies. Together they would provide multiple lines of evidence about historical variability and change in lake conditions	We have the capability to do this. Together with collation of other historical data, this combined work is estimated to cost c. $25k.	Yes
	Periodic loading from earthquakes, esp. Alpine Fault	Effect of major sediment pulse ~300yr,	Potential major periodic disturbance to lakes	Lakebed coring?	From headwaters of all western rivers/catchments			Possibly a modelling scenario	Unknown – probably an academic research question	Natural cyclic phenomena, not really a

Theme	**Topic**	**Explanation**	**Reason / Importance**	**How to address?**	**Where / spatial extent**	**Duration?**	**Leveragability / utility**	**Dependencies**	**Cost/Time/Resources**	**TAG scope? Is it a realistic project?**
		also C, organics								management issue
5. Mātauranga	Role of Mātauranga – esp. re eels									

9.5. Annual Surface Water Quality Report

Prepared for:	Environmental Science and Policy Committee
Report No.	GOV2461
Activity:	Governance Report
Author:	Helen Trotter, Scientist – Water Quality
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	4 December 2024

PURPOSE

[1] This report provides an annual update of water quality and ecosystem health monitoring results from the State of the Environment surface water monitoring network, for the period July 2023 to June 2024. This annual reporting is required by the National Policy Statement – Freshwater Management.

EXECUTIVE SUMMARY

[2] The Otago Regional Council (ORC) monitors the water quality and ecosystem health in selected Otago rivers, streams, and lakes through long-term State of the Environment (SoE) monitoring programmes.

[3] In recent years, the programmes have been expanded to implement the National Policy Statement – Freshwater Management (NPS-FM).[1] Surface water quality, and biological and physical habitat assessment data are now reported according to the National Objectives Framework (NOF) which identifies 'numeric attribute states' for attributes relating to the compulsory values 'ecosystem health' and 'human contact' (NPS-FM Appendix 2A and Appendix 2B).

[4] Current state results reflect the well documented variation in water quality across the Otago Region. Water quality is generally good particularly in headwater and upper catchment areas which comprise a significant proportion of the region. In lowland areas and in catchments where urban and intensive agricultural land uses predominate, water quality is poor; phosphorus, sediment and *E. coli* are among the poorest performing attributes. Components of ecosystem health can be influenced by both natural processes and conditions as well as human activities.

[5] Understanding current state of water quality and ecosystem health is required to inform future regional plan and action plan development.

RECOMMENDATION

That the Committee:

1) **Notes** this report.

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[1] Ministry for the Environment. 2020. National Policy Statement for Freshwater Management 2020.https://www.waterreform.mfe.govt.nz/publications/fresh-water/national-policy-statement-freshwatermanagement-2020

BACKGROUND

[6] Between July 2023 and June 2024, the Environmental Monitoring team completed monthly sampling for a suite of physio-chemical and microbiological water quality variables at 106 sites in 84 rivers and 14 sites in eight lakes. Monthly periphyton and deposited sediment assessments were completed at 32 river sites. Electrofishing surveys were conducted at 16 river sites and macroinvertebrate samples were collected at 100 river sites, during the summer months. Lake Submerged Plant Indicators (LakeSPI) surveys are undertaken across monitored lakes on a rotating basis. In the 2023-24 monitoring period NIWA divers completed surveys at three lakes. These results are discussed further in the Lakes Programme update report to this meeting.

[7] The attributes monitored include those in Appendix 2A and 2B of the NPS-FM. In accordance with the requirements of the NPS-FM, the results have been analysed and graded according to the relevant attribute table and guidance provided. Current state results are generally based on the latest five years of data. Sites with an insufficient data record are removed from analysis or may be assigned an interim grade.

[8] The NPS-FM defines the ranges for numeric attribute bands in the NOF. The attribute bands represent a graduated range of conditions supporting environmental values from high (water quality generally very good, similar to reference conditions/unimpacted - A band) to low (poor water quality, significantly impacted/degraded - D/E band). For some attributes, a 'national bottom line' has been defined (generally between the C and the D band) representing a minimum acceptable standard.

[9] The summary report presents a regional overview of the current state of 'ecosystem health' and 'human contact' values as defined by the NPS-FM based on five years of monitoring data (2019-2024).

DISCUSSION

[10] Spatial variation in Otago's water quality has been well described from previous reports.[2] Water quality is best at sites at higher elevations under predominately native vegetation or conservation land cover. These sites tend to be in the upper catchments of the large lakes (e.g. Hāwea, Whakatipu and Wānaka) and tributaries of the upper Clutha Mata-Au. The poorest water quality is found in urban streams and in the lowland rivers and stream of catchments where intensive agriculture is the predominant land use.

[2] Ozanne R, Levy A, Borges H. 2023. State and Trends of Rivers, Lakes, and Groundwater in Otago 2017 – 2022. Dunedin, NZ: ORC

[11] The report attached as Appendix 1 shows 98 % of monitored river sites are in the A or B band (above the national bottom line) for ammonia; two sites, Kaikorai Stream at Brighton Road and Horn Creek at Queenstown Bay are in the C band. Similarly for nitrate toxicity, the national bottom line was met for 98 % of sites; two sites, Lovells Creek at Station Road and Wairuna River at Millar Road are in the C band.

[12] Suspended fine sediment did not meet the national bottom line at a quarter of monitored river sites. Naturally occurring processes influence suspended fine sediment levels for some sites e.g., glacial four in the Clutha River and tannin-stained waters in the Taieri River.

[13] There is no defined national bottom line for dissolved reactive phosphorus however about 13 % of sites are in the D band indicating the levels are substantially elevated compared to reference conditions.

[14] For ecosystem metabolism 97 % of sites were in the A, B or C band. Blackcleugh Burn at Rongahere Road (Lower Clutha Rohe) was the only site in the D band. To date, this attribute has been measured using cotton-strip assay (CSA) to estimate organic matter processing, while staged deployment of dissolved oxygen sensors has been ongoing across the network. Results are assessed according to interim bands developed for the ORC by the Cawthron Institute.[3] With continuous dissolved oxygen measurement now available for 17 sites, further analysis is underway to assess ecosystem metabolism based on these data, in line with the guidance in the NPS-FM.

[3] Wagenhoff A, Clapcott J, Goodwin E 2021. Thresholds to inform the setting of numeric targets for managing ecosystem health of Otago streams and rivers. Prepared for Otago Regional Council. Cawthron Report No. 3626. 54 p. plus appendices.

[15] Water quality results for monitored lakes show about 75 % of sites are in the A band for all water quality attributes. Lake Tuakitoto is below the bottom line for all monitored attributes. This shallow lake is a remnant of a much larger wetland complex in the Lower Clutha catchment. It is classified as eutrophic and has been impacted by wetland drainage and intensification of land use in the surrounding catchment. Lakes Onslow, Waihola and Hayes are also affected by elevated nutrient levels and phytoplankton levels, reflecting a higher trophic state compared to the large Upper Clutha lakes. Lake Hayes does not meet the national bottom line for lake-bottom dissolved oxygen or mid-hypolimnetic dissolved oxygen.

[16] To assess the value 'human contact', faecal indicator bacteria *E. coli* are measured monthly, year-round at SoE monitoring sites and weekly at primary contact sites during the summer. For SoE river sites 37 % of sites are in the D/E band. For lakes 94 % of sites are in the A band with just one lake in the D band. For monitored freshwater primary contact sites 33 % of sites are graded 'poor' (D band) and do not meet the national bottom line.

[17] Monitoring results are reported in various ways which reflects the different purposes and end users of the data. A schedule of SoE reporting for water quality and ecosystem health data is provided in Table 1.

Table 1 State of the Environment surface water quality & ecosystem health reporting schedule

Frequency	Data reported	Format
Real time & Latest results	Data from continuous sensors and the latest water sampling results	ORC Environmental Data Portal
Annually	NPS-FM current state assessment	Regional summary report to Council
	National state and trends assessment	LAWA website
	Schedule 15 assessment	Regional summary report published to website
5-yearly	Regional trends assessment	Full technical report to Council

[18] Presenting an extensive regional SOE dataset with a large number of parameters within a mandated reporting framework is a challenge, and the science team continues to explore ways to make this data readily understandable and accessible. In addition to existing reporting formats, a series of interactive reports will be developed to present state and trend results by FMU/Rohe. These will include detail about results for individual sites and will aim to encourage greater engagement and further exploration of the data at a scale relevant to local communities.

[19] Land Air Water Aotearoa (LAWA) collate national water quality data annually and report state and trends nationally. There is a one-year lag in this reporting; current results include data up to June 2023. In the 2024 LAWA data update approximately 50 ORC sites

were added so that the complete surface water network is now available on the website https://www.lawa.org.nz/explore-data/otago-region.

[20] A report of water quality results assessed against Schedule 15 of the current Regional Plan: Water will continue to be published to the website annually until a new plan is operative.

[21] A comprehensive technical report of water quality state and trends for the Otago Region is prepared every five years. The next report is scheduled for 2028. This report provides detailed methodology and analysis of regional state and trends in river and lake health, performance against the NPS-FM, and the effectiveness of the Regional Plan. This report was last presented to Committee in June 2023 and is available on the ORC website Reports and publications – water quality.

[22] A review of the monitoring network is scheduled for the current financial year, although the pausing of the proposed Land and Water Regional Plan may require reassessment of what the monitoring network is being assessed against. Further work is required to implement assessment of attributes for further components of ecosystem health (i.e., water quantity), as well as the compulsory values 'threatened species' and 'mahinga kai' as outlined in the NPS-FM. In addition, the proposed update to the NPS-FM may result in changes to requirements and further adaptation may be required to ensure the monitoring network remains aligned with national direction.

OPTIONS

[23] N/A

CONSIDERATIONS

Strategic Framework and Policy Considerations

[24] This programme supports the enhancing environmental management and healthy water strategic priorities:

- Monitoring and investigating the health of Otago's fresh and coastal water
- Providing the best available information on Otago's water resources
- Enhancing access to and communication of data and knowledge

Financial Considerations

[25] This work is planned and funded through the annual work programme.

Significance and Engagement

[26] N/A

Legislative and Risk Considerations

[27] Monitoring networks must follow national legislation and effectively evaluate the objectives in regional plans. However, as policies can change rapidly, there is generally a lag for implementing network changes and then further delay until sufficient data is collected to enable analysis.

Climate Change Considerations

[28] Data from state of the environment monitoring may assist with understanding any environmental changes in response to climate change.

Communications Considerations

[29] This report will be published on the ORC website Reports and publications – water quality

NEXT STEPS

[30] The next annual report will incorporate results of the July 2024 to June 2025 monitoring period.

ATTACHMENTS

1. Annual water quality summary report 2024 [**9.2.1** - 5 pages]

Annual Summary Report 2024

Water Quality and Ecosystem System Health in Otago Rivers and Lakes

Otago Regional Council monitors surface water quality at over 100 river and lake sites across the Otago Region.

We use a combination of monthly water sample collection, continuous data sensors and annual surveys of stream life to assess the following components of ecosystem health:

WATER QUALITY

- **Nitrogen** and **Phosphorus** - are essential nutrients for plant growth. Increased levels of these nutrients can contribute to algal blooms and excessive growth of aquatic plants. In lakes, we measure **total nitrogen** (TN) and **total phosphorus** (TP). In rivers, we measure **dissolved reactive phosphorus** (DRP). We also measure forms that can be toxic to aquatic life - **ammoniacal nitrogen** and **nitrate nitrogen**.
- **Dissolved Oxygen** – the amount of oxygen dissolved in water. Low dissolved oxygen (DO) levels can affect fish and other aquatic organisms that require oxygen to breathe. Decaying organic matter (aquatic plants and algae) and high temperatures can reduce DO levels. In deep lakes which seasonally stratify into distinct layers, we measure DO at the lake bottom and in the mid-hypolimnion (bottom layer).
- **Suspended fine sediment** – fine particulate matter (sand, silt or clay) in the water column that can impact water clarity. Sediment naturally occurs in rivers due to processes like water movement, erosion and weathering of rocks. However, activities such as agriculture, horticulture, forestry and earthworks can increase fine sediment inputs.

PHYSICAL HABITAT

- **Deposited fine sediment** – fine particulate matter (sand, silt or clay) that settles on the bed of a river. It can fill spaces betweeen cobbles and reduce habitat for aquatic life.

Annual Summary Report 2024

Eagle Technology, Land Information New Zealand, GBBCO, Community maps contributors

Otago Regional Council

ECOYSTEM PROCESSES

- **Ecosystem metabolism** – the production of oxygen and carbon dioxide by all the organisms that make up the ecosystem. It represents how energy is created (primary production) and used (respiration) within an aquatic ecosystem and is a functional indicator of ecosystem health.

AQUATIC LIFE

The range and diversity of flora and fauna in our waterways are measured by the following indicator groups:

- **Macroinvertebrates** – freshwater invertebrates such as insects, worms and snails. These organisms are sensitive to changes in water quality and habitat. The **Macroinvertebrate Community Index** (MCI) is a measure based on the presence of these organisms.
- **Fish** – we use the **Fish Index of Biotic Integrity** (Fish IBI) to assess the richness of fish species by comparing the fish species present at a site to the expected species in the absence of human impacts.
- **Periphyton** – algae and slime that grows on the rocks and other stable substrates that make up the streambed, measured as chlorophyll a. Periphyton is an important food resource in the aquatic food webs but can proliferate and become a nuisance. Excess growth is related to nutrient levels, amount of shading, temperature, stream substrate and the number of flushing flows.
- **Phytoplankton** – algae that grows in the water column of lakes, measured as chlorophyll a. It is often closely linked to the amount of nutrient enrichment in a lake ecosystem.
- **Lake Submerged Plants** – aquatic plant communities in lakes. Community composition is measured by underwater divers using the **Lake Submerged Plant Indicators** (LakeSPI) method and reported as a **Native Condition Index** and an **Invasive Impact Index**.

We also monitor water quality properties important for human health:

HUMAN CONTACT

- ***E. coli*** – *Escherichia coli* are faecal indicator bacteria found in the gut of warm-blooded animals. We measure *E. coli* monthly throughout the year at our SOE monitoring sites and during the summer bathing season at popular primary contact recreation sites.

- **Cyanobacteria** – microscopic organisms that multiply and form blooms, which can be suspended in the water column (planktonic) or attached to rocks (benthic). Also known as toxic algae or blue/green algae, some species produce toxins that are harmful to animlas.

This summary report presents a regional overview of the current state of the ecosystem health and human contact values as described by the **National Policy Statement – Freshwater Management** (NPS-FM).
We use 5 years of data (2019-2024) to assess current state. For each indicator, results from each site are graded A-E according to the attribute bands of the National Objectives Framework in the NPS-FM.
For some attributes there is a defined 'national bottom line' indicating a minimum acceptable standard.

Learn more about these measures at **LAWA Glossary & Factsheets**

View our monitoirng sites and explore the data **LAWA – Otago Region**

RIVER ECOSYSTEM HEALTH

Attribute band:

A Excellent B Good C Fair D Poor

Water quality

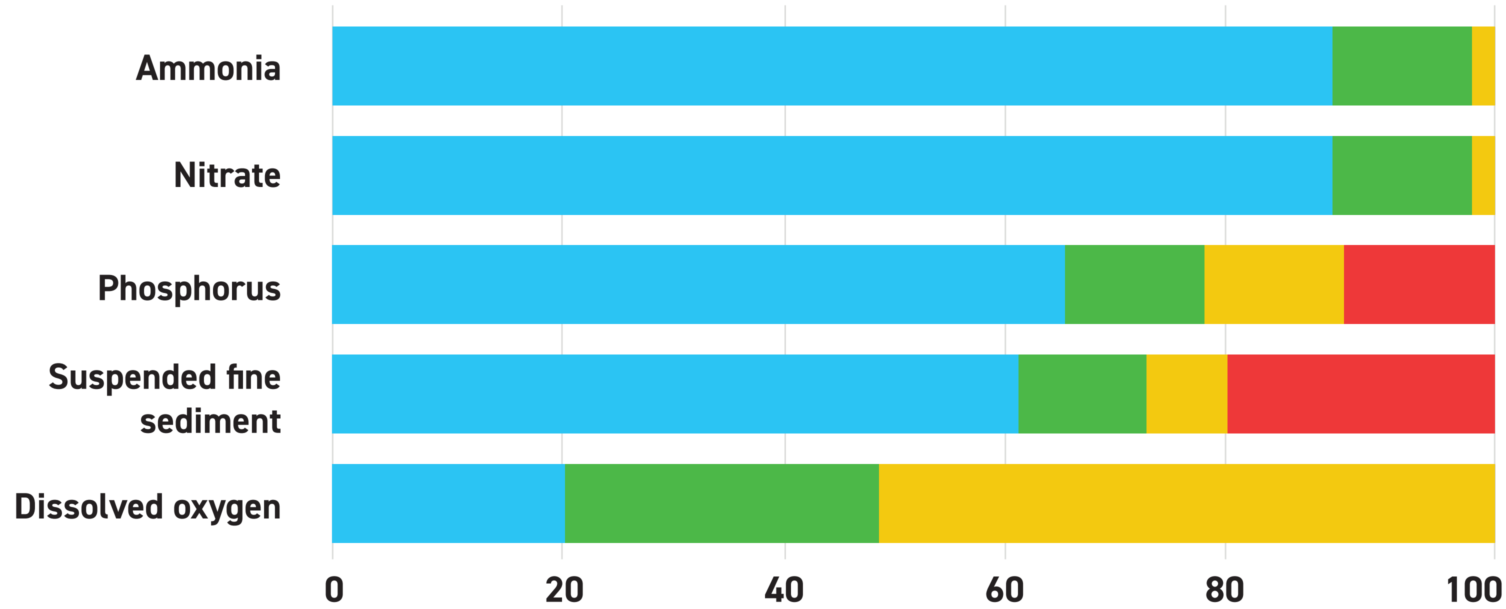


Figure 1 | Percentage of rivers sites graded as A, B,C or D for five water quality attributes

Otago's water quality is typically excellent at higher elevation sites under predominately native vegetation or conservation land cover. These sites tend to be in the upper catchments of the large lakes (e.g. Hāwea, Whakatipu and Wānaka) and tributaries of the upper Clutha Mata-Au. The poorest water quality is found in urban streams (e.g. Dunedin & Coast FMU) and in the lowland rivers and stream of catchments where intensive agriculture is the predominant land use (e.g., Manuherekia Rohe, Lower Clutha Rohe, North Otago FMU).

All sites are above the national bottom line for ammonia, nitrate, and dissolved oxygen. Grades for dissolved oxygen are interim and based on data for 15 sites only. We are continuing to deploy continuous monitoring sensors across the network and extend our data records.

About a quarter of sites do not meet the national bottom line for suspended fine sediment (graded D). Some sites have naturally elevated suspended sediment levels. Thirteen sites (13 %) are graded D for dissolved reactive phosphorus indicating that levels are higher than natural conditions.

Physical habitat

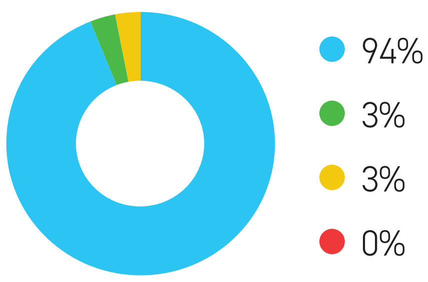


Figure 2 | Percentage of rivers sites graded A, B,C or D for deposited fine sediment.

All sites are above the national bottom line. Grades are interim as a 5-year data record is not yet available.

Ecosystem processes

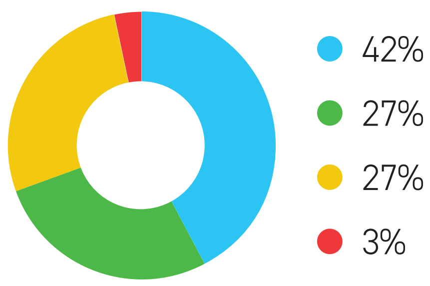


Figure 3 | Percentage of rivers sites graded A, B,C or D for ecosystem metabolism.

Grades are interim as a 5-year data record is not yet available and there is no national guidance on attribute grades within the NPS-FM.

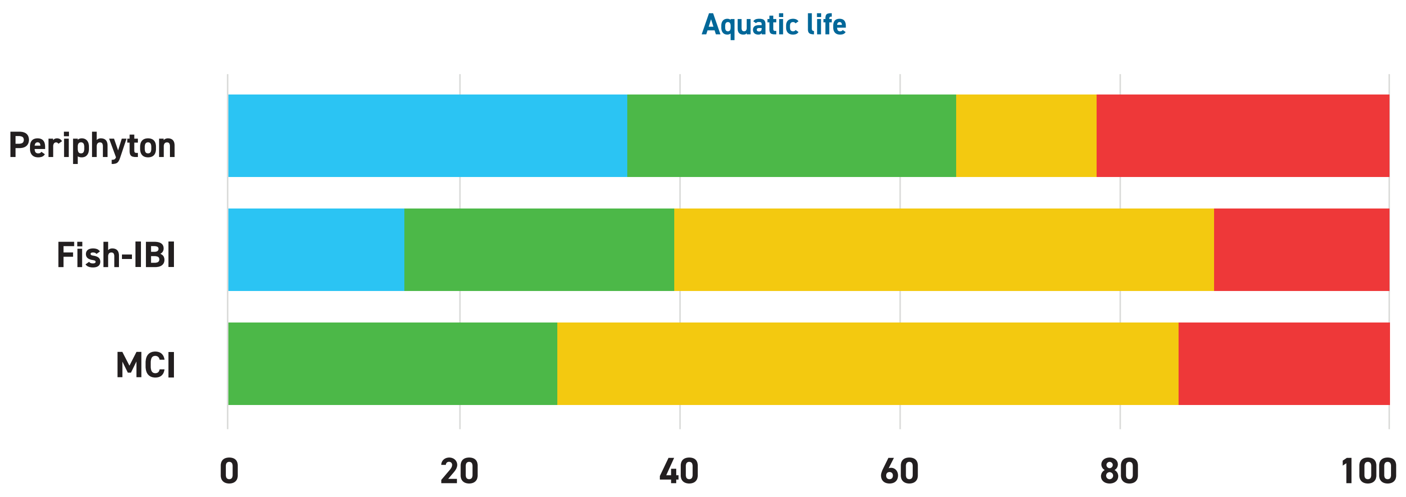


Figure 4 | Percentage of river sites graded A, B, C or D for aquatic life attributes

Eight of the 32 sites we monitored for periphyton are below the national bottom line. For the Macroinvertebrate Community Index (MCI), six of 32 sites are below the national bottom line. About 60 % of the 13 sites assessed for Fish-IBI are graded C or D, indicating that some habitat loss and/or migratory access has impacted fish communities at these locations.

LAKE ECOSYSTEM HEALTH

Attribute band:

A Excellent B Good C Fair D Poor

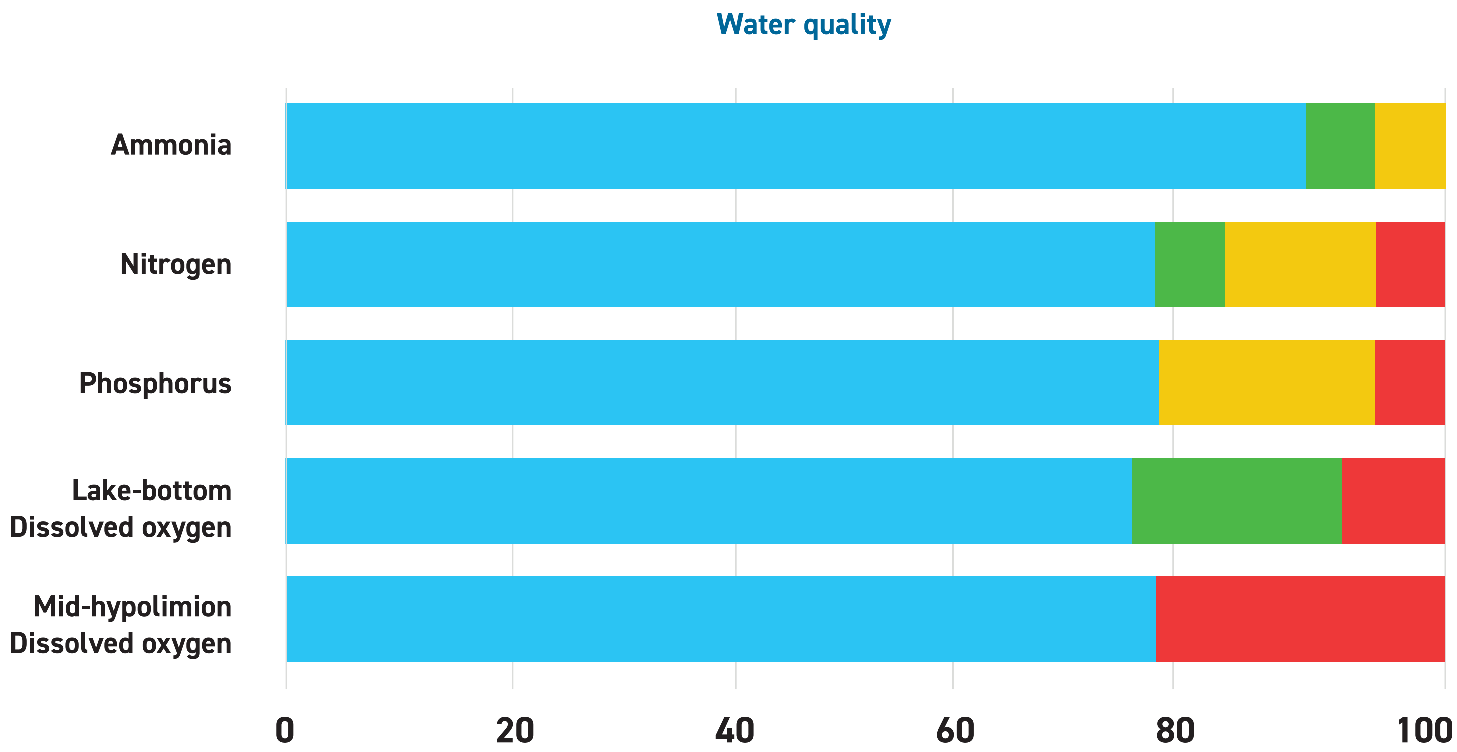


Figure 5 | Percentage of lake sites graded A, B,C or D for five water quality attributes.

We monitor eight lakes across Otago – the large lakes in the Upper Lakes and Dunstan Rohe (Lakes Whakatipu, Hāwea, Wānaka and Dunstan) have excellent water quality and low nutrient levels. Lake Tuakitoto is the only site not meeting the national bottom line for total nitrogen, phosphorus, and ammonia. Lakes Hayes, Waihola and Onslow are also impacted by elevated nutrient levels. Lake Hayes does not meet the national bottom line for lake-bottom dissolved oxygen or mid-hypolimnetic dissolved oxygen.

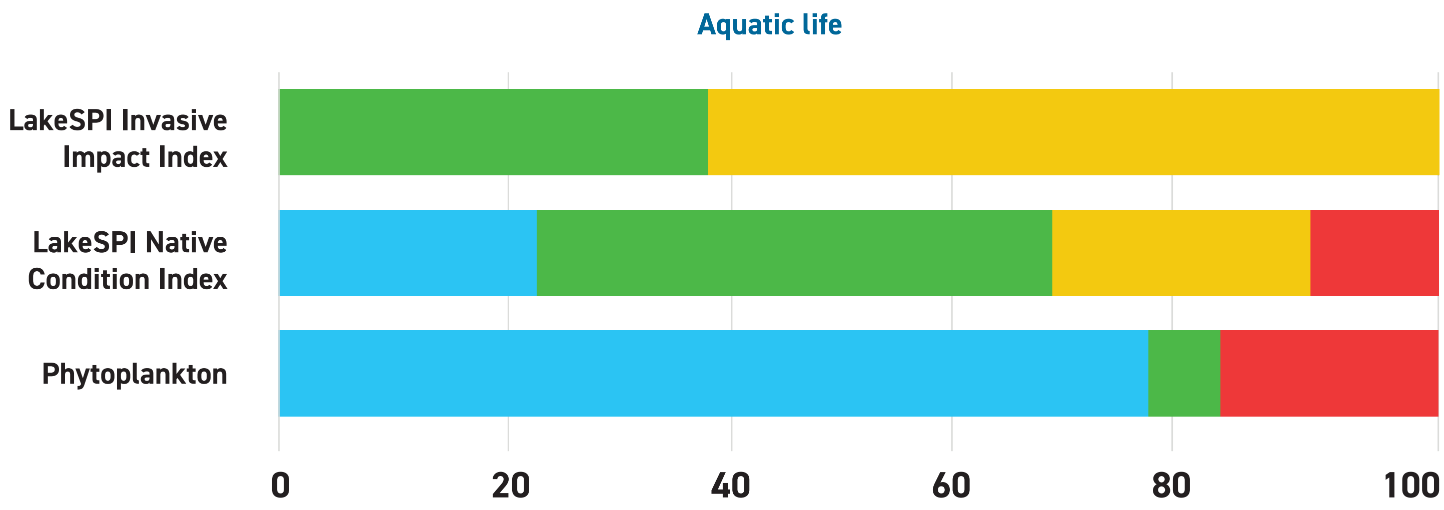


Figure 6 | Percentage of lake sites graded A, B, C or D for aquatic life attributes

Three lakes do not meet the national bottom line for phytoplankton – Lake Hayes, Lake Tuakitoto and Lake Waihola.

Results of the Lake SPI Invasive Impact Index reflect moderate impacts from invasive plants at five of eight monitored sites (band C). Lake Tuakitoto is the only site below the national bottom line for the Native Condition Index.

HUMAN CONTACT

Attribute band:

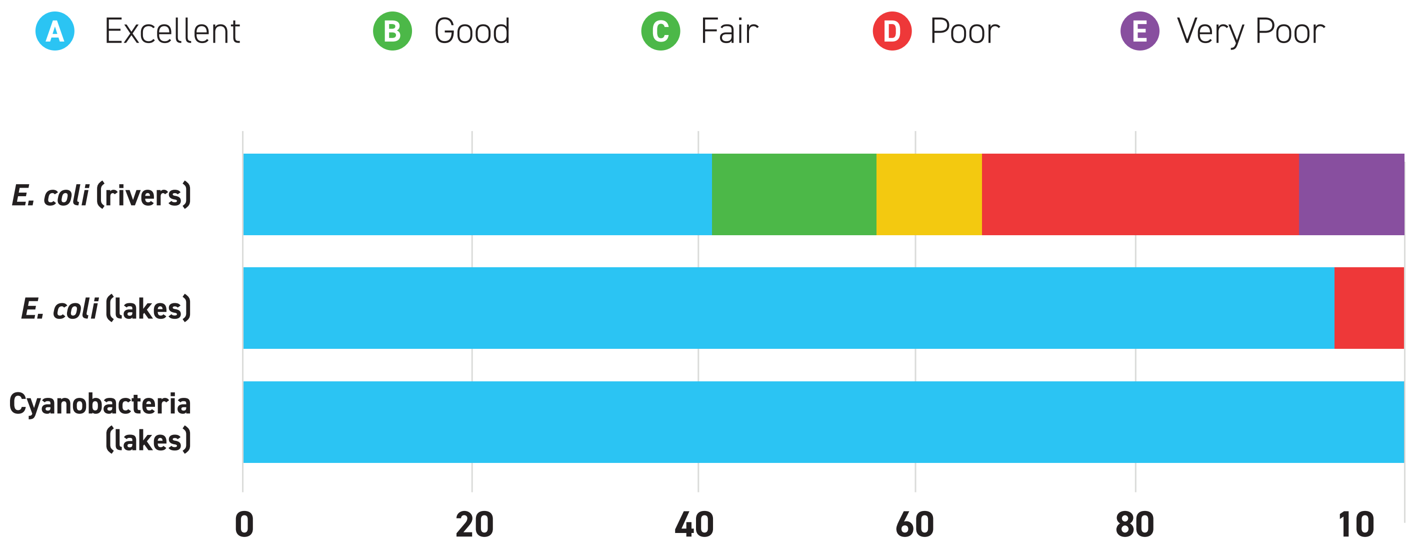
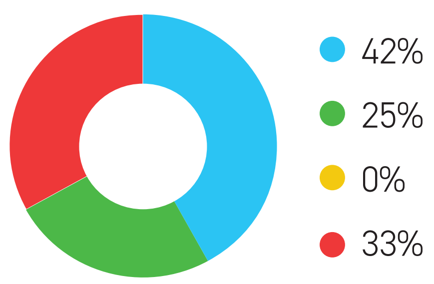


Figure 7 | Percentage of lake and river sites graded as A, B, C, D or E (E. coli only) for human health attributes. Data from year-round monthly monitoring.

All lake sites were in the A band for cyanobacteria, and 94% were in the A band for *E. coli* (Figure 7).

For *E. coli* in rivers, 27 % of sites are graded D, and 9 % are graded E. These tend to be lowland sites in catchments with larger areas of urban development and intensive agricultural land use (e.g., Lower Clutha Rohe, Manuherekia Rohe, Catlins FMU, Dunedin & Coast FMU, North Otago FMU). About 55 % of sites are in the A or B band; most are in the Upper Lakes and Dunstan Rohe or upper catchment areas with predominately native forest or conservation land cover.



During the summer we monitor 17 freshwater swimming sites weekly across Otago (Figure 8). Based on data for the last 5 summers, 67 % of sites are graded Excellent or Good. 33 % of sites are graded Poor (below the national bottom line).

Figure 8 | Percentage of sites grade Excellent, Good, Fair or Poor for E. coli at swimming sites (lakes and rivers). Data from weekly monitoring during the summer bathing season only.

For more information technical state and trend reports are available on our website **www.orc.govt.nz**

Contact us science.enquiries@orc.govt.nz

Otago Regional Council

9.6. Estuary SOE update for summer 2023 - 24 monitoring season

Prepared for:	Environmental Science and Policy Comm
Report No.	GOV2463
Activity:	Governance Report
Author:	Sam Thomas, Senior Coastal Scientist
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	4th December 2024

PURPOSE

[1] The purpose of this report is to provide the Committee with an annual update on the progress of the state of the environment estuary monitoring programme. The report outlines what monitoring has been completed over the summer monitoring season of 2023/24 and outlines the next steps in the monitoring programme, including the upcoming estuary programme review.

EXECUTIVE SUMMARY

[2] The state of the environment estuary monitoring programme was reviewed and expanded in 2020. Now after 5 years there are data and information about the state of every estuary in Otago. Data will be used to inform both regulatory plans and non-regulatory work such as catchment management planning. The revised programme uses a combination of monitoring techniques to provide information on estuary health.

[3] During the 2023/24 field and monitoring season a combination of broad scale and fine scale monitoring, in addition to sediment plate monitoring, was undertaken in estuaries across Otago

[4] The estuary programme is getting reviewed this financial year to look at current state of each estuary, and potential catchment risks, to provide information on a targeted estuary monitoring programme going forward. The aim of the review is to reduce monitoring costs through targeted monitoring, and to put more resources into improving estuarine health.

RECOMMENDATION

That the Committee:

a) ***Receives*** *this report.*

b) ***Notes*** *that the Estuary monitoring programme has been implemented according to the updated estuary monitoring programme plan in 2020 and now has obtained data for every estuary in Otago.*

c) ***Notes that next steps*** *include an estuary monitoring programme review this financial year to ensure the programme is delivering maximum value and to start prioritising areas for investigations and targeted management/restoration where needed.*

d) ***Notes*** *that an SOE report for the state of Otago's estuaries, pulling together current data will be presented to council before the end of FY in June 2025 after the final pieces of data are gathered this summer 2024/25 to inform this report.*

BACKGROUND

[5] Until 2020 there were only 5 estuaries in Otago that had some monitoring occurring. Otago's estuary monitoring programme was updated in 2020 to build a resilient monitoring network that can provide data and information needed to manage Otago's estuaries. The programme's aim was to gain an understanding of each estuarine environment within the Otago region and to then determine monitoring priorities once a current state was determined.

[6] The updated estuary monitoring programme has been designed to provide useful information to manage Otago's 16 estuaries. The programme provides data for regulatory and non-regulatory management such regional plans (regulatory) and catchment groups or environmental implementation to undertake projects to improve estuarine health (non-regulatory).

[7] All monitoring planned to date has been completed with a mixture of broad and fine scale monitoring and sediment plate monitoring. Broad scale habitat monitoring maps the current estuarine state based on habitat of the estuary and surrounding areas (out to 200m). Fine scale monitoring establishes monitoring sites in the intertidal areas of the estuary to monitor long terms trends in macrofauna and physical parameters such as mud content and heavy metals. Sediment plate monitoring is established to monitor erosion/deposition trends over the longer term.

DISCUSSION

2023/24 Field season update:

[8] A combination of monitoring methods was used over the 2023/24 field season including, broad scale mapping (see Figure 1, for an example of outputs), fine scale monitoring, and sediment plate monitoring. At the completion of the 2023/24 field season all the estuaries in Otago have a current state for estuarine health, and the Catlins, Waikouaiti and Shag estuaries have had a follow up broad scale and fine scale mapping undertaken. Sediment plate monitoring is established in all estuaries.

[9] Hoopers Inlet currently only has salt marsh mapped as the tide did not drain sufficiently for intertidal mapping to be undertaken. The lack of tide draining to this extent is an exception to the normal tidal processes for this system. When Hoopers Inlet fully drains it will then be mapped (likely in the 2025/26 season) as reconnaissance has shown the system is still not draining fully for the 2024/25 field season.

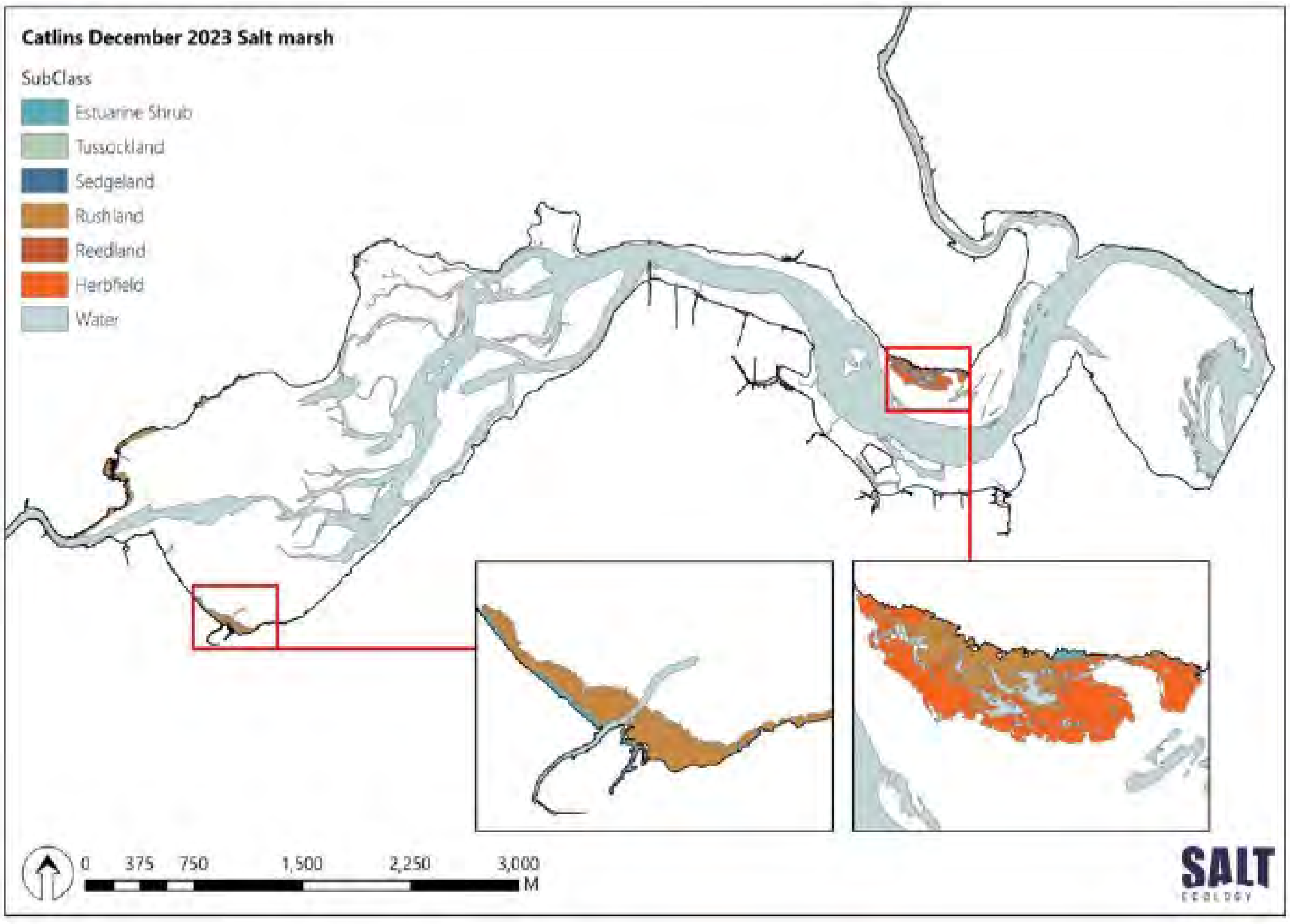


Figure 1: An example of broad scale habitat mapping in the Catlin's estuary, highlighting current extent of salt marsh (From Roberts et al., Attachment 14*)*

[10] Broad scale monitoring (habitat mapping) occurred in the Catlins, Shag River and Waikouaiti estuaries over the past summer. This was a follow up survey of these estuaries after the first broad scale survey occurred in 2016, eight years earlier. These are the first estuaries in Otago where comparisons can be made about estuarine state. Full details are in the attached reports (Attachments 3, 9 and 14). A more comprehensive report will be provided in an Otago estuary SOE report in June 2025 once summer work has gathered remaining data to inform the estuary programme review. However, a brief overview of the state of three estuaries which underwent broad scale monitoring this year is provided in the following paragraphs.

Shag River estuary

[11] The area of muddy sediment within the estuary has increased in the 8 years since habitat mapping was last undertaken. Equally the area of high enrichment conditions has increased from 0 to 5.3% of the available intertidal habitat to a fair condition. The rest of the indicators are all in a good or very good condition. The % of vegetated terrestrial margin has increased slightly but is still in a poor condition. For full details see the Broad scale report attached (Attachment 3).

Table 1: Broad scale indicator and condition ratings showing the results for the Shag River Estuary (see attachment 3).

Summary of broad scale indicator condition ratings. *Condition rating key:* Very Good | Good | Fair | Poor

Broad scale Indicators	Unit	December 2016	November 2023
200m terrestrial margin	% densely vegetated	26.1	33.8
Mud-elevated (≥25%-100%) substrate	% AIH[1] area	19.4	41.4
Macroalgae (OMBT[2])	Ecological Quality Rating (EQR)	0.982	0.665
Seagrass	% decrease from baseline	No seagrass present	
Salt marsh extent (current)	% of intertidal area	49.4	54.3
Historical salt marsh extent[3]	% of historical remaining	61.6	62.5
High Enrichment Conditions	ha	0.0	2.0
High Enrichment Conditions	% of AIH	0.0	5.3

[1]Available Intertidal Habitat (AIH; excluding salt march); [2]Opportunistic Macroalgal Blooming Tool (OMBT) scores have been updated following Stevens et al. (2022); [3]Estimated from historic aerial imagery. Data from 2016 revised following QAQC of GIS files.

Catlins Estuary

[12] The Catlins Estuary first had habitat mapping undertaken in 2006, however, this method was not the same as the current estuary monitoring protocol so not readily comparable. Mapping using current best practice occurred in 2016 and the current habitat mapping in 2023. The 200m terrestrial margin and area of mud elevated sediment have not changed greatly and are still in poor condition. The area of Macroalgae (OMBT index) has gone from good to poor and then back to Fair in rating over the last 5 years. Sea grass cover across the estuary has declined since 2016 to a poor condition. Area of Salt marsh surrounding the estuary has increased slightly in the last 5 years with historic salt marsh loss being high therefore in a poor condition. The area of high enrichment conditions and % of estuary of high enrichment conditions has gone from fair and good to poor in the last 5 years. The 2021 monitoring data is from a one off macroalgae mapping project. For full details please see attached broad scale report (Attachment 14).

Table 2: Broad scale indicators and condition ratings showing the results for the Catlins Estuary (see attachment 14).

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

Waikouaiti Estuary

[13] The area of terrestrial margin that is densely vegetated and the area of mud elevated sediment are both in a poor condition. However, there has been a slight increase in the area of densely vegetated margin and a reduction in areal extent of mud over the 8-year period since monitoring. The area of seagrass within the estuary has a poor rating, with a decline in seagrass area since 2016. The amount of salt marsh historically is in a fair condition, while all the other indicators range from good to very good condition. For full details please see attached broad scale report (Attachment 9).

Table 3: Broad scale indicators and condition ratings showing the results for the Waikouaiti Estuary (see attachment 9)

Summary of broad scale indicator condition ratings. *Condition rating key:* Very Good | Good | Fair | Poor

Broadscale Indicators	Unit	December 2016	December 2023
200m terrestrial margin	% densely vegetated	7.4	12.7
Mud-elevated (≥25%-100%) substrate	% AIH[1] area	35.6	33.6
Macroalgae (OMBT[2])	Ecological Quality Rating (EQR)	0.692	0.658
Seagrass (>50% cover)[3]	% decrease from baseline	87.0	96.4
Salt marsh extent (current)	% of intertidal area	45.4	49.0
Historical salt marsh extent[4]	% of historical remaining	47.0	55.2
High Enrichment Conditions	ha	0	2.9
High Enrichment Conditions	% of AIH	0	3.0

[1]Available Intertidal Habitat (AIH; excluding salt marsh); [2]Opportunistic Macroalgal Blooming Tool (OMBT) scores have been updated following Stevens et al. (2022); [3]Seagrass baseline 1958; [4]Estimated from historic aerial imagery. Data from 2016 revised following QA/QC of GIS files.

Fine Scale Monitoring

[14] During the 2023/24 field season, fine scale monitoring occurred in the Pleasant River, Tautuku, Catlins, Shag River and Waikouaiti estuaries. For the Catlins, Shag River and Waikouaiti estuaries this was the first comparison after the 3-year baseline surveys were undertaken starting in 2016. This is the first comparison of fine scale monitoring in the Otago region between a baseline survey and a follow up survey. For the Tautuku and Pleasant River Estuaries this was the 3rd year of the baseline survey's providing a current state over 3 years of monitoring. A full SOE report for these estuaries and the other estuaries in Otago will be presented in June next year once final data has been gathered over summer to inform this report. Data around catchment risk and extra sediment plate monitoring is needed to provide a more comprehensive picture of the fine scale monitoring to present an SOE report. Refer to reports attached for details of these monitoring results (Attachments 4, 5, 10, 15 and 17).

Figure 2: Macrofauna sediment washing during fine scale sampling, Blueskin Bay estuary.

Sediment Plate Monitoring

[15] Sediment plate monitoring involves measuring the accumulation or erosion of sediment, through taking measurements from the top of sediment plates buried to a known depth.

Long term measurements of sediment plates provide a trend of deposition or erosion of sediment within the estuary.

[16] Sediment plate monitoring occurred in the Shag River, Waikouaiti, Pleasant River, Blueskin Bay, Kaikorai, Tokomairiro, Catlins, Tautuku estuary, Waipati, Akatore and Purakaunui estuaries, see attached sediment plate summary reports (Attachments 1, 2, 6, 7, 8, 11, 12, 13 and 16).

Figure 3: Sediment Plate installation in Blueskin Bay during fine scale monitoring

2024/25 Field season work plan:

[17] The field work monitoring for the 2024/25 season is as follows: A synoptic survey (a comprehensive survey of habitats to provide a state overview) of the Tokomairiro estuary focusing on mapping macrophytes and subtidal water quality/macroalgae to better understand this system to provide information for the estuary monitoring review. Pilot sampling will occur in Papanui Inlet and Tautuku River estuaries to determine the best sites to serve as long term monitoring reference estuaries. Sediment plate measurements and monitoring will occur in all estuaries to track long term changes in sediment deposition or erosion.

[18] A new array of sediment plates will be established in the Akatore estuary as transects from where the river enters the estuary and more plates throughout the upper estuary. This is due to the increasing sediment issues detected through current monitoring. This new array of sediment plates will help to determine how much sediment is entering the estuary, and where it is settling, to inform management.

[19] An estuary monitoring programme review is occurring this financial year with the final report due in September 2025 which will provide options for the estuary monitoring programme for monitoring going forward. The review will pull together current data in the estuaries, look at land use change in each catchment, review any models for estuaries and assess the risk to each estuary from the catchment. This information will

then be used to determine a risk-based approach for how frequently the estuaries are monitored, with estuaries categorised into different tiers of monitoring from tier 1 to tier 3. For example, monitoring higher risk tier 1 estuaries could involve an annual macroalgae or mud content monitoring, whereas lower risk tier 3 estuaries could be an annual visit to determine if things have changed. The different tiers will have different timeframes of monitoring.

[20] This review purpose is to make the estuary SOE monitoring more streamlined and cost effective while providing the data needed to make management decisions to reduce impacts on Otago's estuaries. Equally it will allow for more structure in the monitoring programme, which up until now has been a programme that revolved around gathering data for each estuary as a baseline. It will also potentially allow more resources to be put into projects that improve estuarine health or provide information to undertake targeted management or restoration.

OPTIONS

[21] NIL

CONSIDERATIONS

Strategic Framework and Policy Considerations

[22] The state of the environment estuary monitoring programme will provide information and data needed for both regulatory and non-regulatory management needs.

[23] The estuarine programme review will look at both catchment risks and SOE data to optimise the estuary monitoring programme. The outcome will be a tiered framework for estuary monitoring with more focus on higher risk estuaries/catchments.

[24] The estuary programme will look to provide more refined guidance on restoration potential and areas requiring targeted investigations for management.

[25] The revised estuary programme will still deliver the data needed for input into freshwater and coastal plans.

Financial Considerations

[26] Budget is allocated to undertake this work in the long-term plan. However, the amount of work and monitoring will be determined by allocation of funding during the annual planning processes.

Significance and Engagement

[27] Engagement will be ongoing between stakeholders and iwi that operate in the estuarine space.

Legislative and Risk Considerations

[28] ORC needs to gather appropriate data to inform regulatory plans such as the Land and Water Plan and Regional Plan: Coast in order to meet its obligations

Climate Change Considerations

[29] Understanding the potential change in salt marsh habitat and estuarine state is important to manage challenges facing these ecosystems from sea level rise.

Communications Considerations

[30] Communication between iwi and key stakeholders will occur on a project-by-project basis.

NEXT STEPS

[31] To continue the current monitoring programme for the 2024/25 field season as planned.

[32] To review the current monitoring programme this financial year to make sure that it is fit for purpose to gather data needed to make informed management decisions and that monitoring network is optimised and targeted investigations/monitoring and restoration are prioritised.

[33] To introduce a new tiered monitoring programme for the 2025/26 field season and the next 10 years of estuary monitoring.

[34] To undertake targeted investigations and projects that improve estuarine health.

ATTACHMENTS

1. Attachment 1 - Pleasant River sedplate report 2023-24 FINAL [**9.6.1** - 2 pages]
2. Attachment 2 - Shag sedplate report 2023-24 FINAL [**9.6.2** - 2 pages]
3. Attachment 3 - Shag 2024 BS FINAL reduced [**9.6.3** - 73 pages]
4. Attachment 4 - Shag FS data summary FINAL [**9.6.4** - 18 pages]
5. Attachment 5 - Tautuku FS data summary FINAL [**9.6.5** - 20 pages]
6. Attachment 6 - Tautuku sedplate report 2023-24 FINAL [**9.6.6** - 2 pages]
7. Attachment 7 - Toko sedplate report 2023-24 FINAL [**9.6.7** - 2 pages]
8. Attachment 8 - Waikouaiti sedplate report 2023-24 FINAL [**9.6.8** - 2 pages]
9. Attachment 9 - Waikouaiti 2023 BS FINAL reduced [**9.6.9** - 89 pages]
10. Attachment 10 - Waikouaiti FS data summary FINAL [**9.6.10** - 21 pages]
11. Attachment 11 - Akatore sedplate report 2023-24 FINAL [**9.6.11** - 2 pages]
12. Attachment 12 - Blueskin sedplate report 2023-24 FINAL [**9.6.12** - 2 pages]
13. Attachment 13 - Catlins sedplate report 2023-24 FINAL [**9.6.13** - 2 pages]
14. Attachment 14 - Catlins 2024 BS FINAL reduced [**9.6.14** - 75 pages]
15. Attachment 15 - Catlins FS data summary FINAL [**9.6.15** - 20 pages]
16. Attachment 16 - Kaikorai sedplate report 2023-24 FINAL [**9.6.16** - 2 pages]
17. Attachment 17 - Pleasant River FS data summary FINAL [**9.6.17** - 20 pages]

PLEASANT RIVER (TE HAKAPUPU) ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 043. Prepared by Hayden Rabel for Otago Regional Council, May 2024

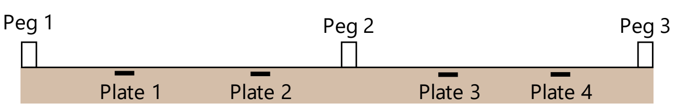
OVERVIEW

Since November 2021, Otago Regional Council has undertaken annual State of the Environment monitoring in Pleasant River (Te Hakapupu) Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 2 December 2023.

Fig. 1. Location of Pleasant River Estuary sites.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., Forrest et al. 2022). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness.

Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Annual results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2.

Table 2. Indicator summary and condition ratings from the November 2023 survey.

Indicator	A	B
Sedimentation (mm/yr)*	-1.1	1.4
Mud content (%)	53.1	50.4
aRPD (mm)	5	1

* Sedimentation is presented as the mean annual rate over the monitored period (n=2 yrs). Five years of data are recommended for a meaningful trend.

Sedimentation rate

Both sites received a condition rating of 'very good' in December 2023 with sedimentation rates less than 0.5mm/yr (Table 1, Table 3). With just two years of sedimentation results it is difficult to suggest any meaningful trends, however, the early patterns of accrual at Site B and erosion at Site A agree with previous studies that the estuary side-arms may be more susceptible to accumulating fine sediment from catchment run-off (Roberts et al. 2022).

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in Forrest et al. (2022).

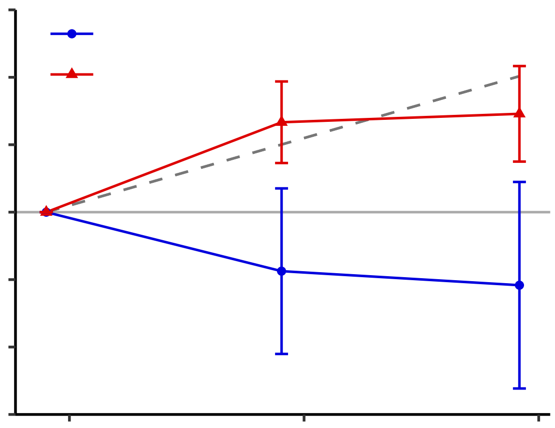


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

Sediment mud-content exceeded the biologically relevant limit of 25% for the third year running at both sites (rating 'poor'; Table 1, Table 3). These elevated fine sediments likely arise from land uses in the Pleasant River catchment known to generate high sediment loads (61.9% pasture, 31.1% exotic forest; Roberts et al. 2022).

Table 3. Annual sedimentation, grain size and aRPD results up to December 2023.

Site	Survey	Sed rate	Gravel	Sand	Mud	aRPD
		mm/yr	%	%	%	mm
A	Nov-2021	na	< 0.1	57.4	42.6	4
	Nov-2022	-1.7	< 0.1	59.4	40.5	12
	Dec-2023	-0.4	0.1	46.8	53.1	5
B	Nov-2021	na	2.3	51.6	46.1	2
	Nov-2022	2.7	1.2	52.9	45.9	3
	Dec-2023	0.2	2.8	46.8	50.4	1

< All values below lab detection limit

Muddy yet relatively firm sediments at Site A (left) and Site B (right) in December 2023.

Shallow sediment oxygenation (aRPD transition from brown to dark grey sediment) at Site A (left) and Site B (right) in December 2023.

The aRPD depths at both sites were rated 'poor' in December 2023 (Table 3), with the generally shallow depths in all surveys likely reflecting the muddy nature of the sediments, and the associated assemblage of small-bodied macrofauna (see Forrest et al. 2022), which are less efficient than larger organisms at turning over sediment and allowing oxygen to reach deeper layers.

CONCLUSIONS

Given the year-to-year variability often observed in estuary sedimentation, it is too early to gauge general trends of sedimentation rates in Pleasant River Estuary. However, consistently elevated mud-content and shallow aRPD depths provide a reasonable baseline assessment of degraded sediment conditions and reinforce previous recommendations to manage catchment sediment inputs to the estuary.

RECOMMENDED MONITORING

Continue annual monitoring and reporting of sedimentation rate, sediment grain size and aRPD depth.

REFERENCES

Forrest BM, Roberts KL, Stevens LM. 2022. Fine scale intertidal monitoring of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 093, prepared for Otago Regional Council, June 2022. 29p.

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, June 2022. 57p.

SHAG ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 044. Prepared by Hayden Rabel for Otago Regional Council, May 2024

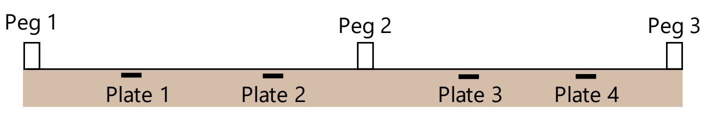
OVERVIEW

Since December 2016, Otago Regional Council has undertaken annual State of the Environment monitoring in Shag Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 30 November 2023.

Fig. 1. Location of Shag Estuary monitoring sites.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., O'Connell-Milne et al. 2023). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness. Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Annual results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2.

Table 2. Indicator summary and condition ratings from the November 2023 survey.

Indicator	A	B
Sedimentation (mm/yr)*	+2.6	1.1
Mud content (%)	29.4	29.8
aRPD (mm)	30	27

* Sedimentation is presented as the long-term mean annual rate over the monitored period (n=7 yrs).

Sedimentation rate

Estuary sedimentation has been highly variable at both sites since monitoring began, however, there has been slightly more accrual than erosion, with the long-term sedimentation rate at Site A exceeding the national guideline of 2mm/yr, rated 'poor', and a rate of 1.1mm/yr at Site B, rated 'fair' (Tables 1-3, Fig 2). The spatial variation suggests more deposition in the lower estuary with sediment build-up likely increased when the estuary mouth is restricted, while the temporal variation likely reflects the river dominated hydrological setting and large proportion of sediment generating catchment land uses (e.g., 71% pasture and 11% forestry; Stevens & Robertson 2017).

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in O'Connell-Milne et al. (2023).

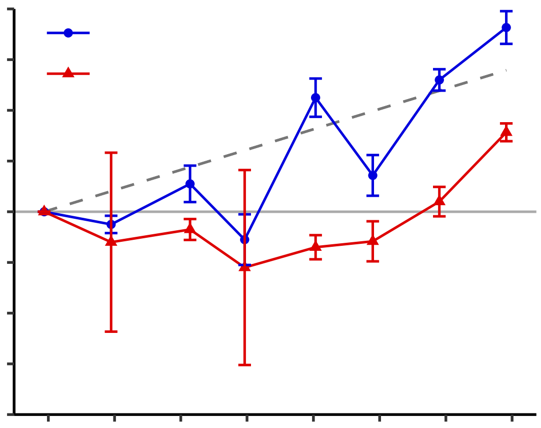


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

Since 2021, at both sites, sediment mud-content has exceeded the biologically relevant threshold of 25%, a condition rating of 'poor' (Table 3). This represents an increase in sediment muddiness since monitoring began.

Both sites consistently show aRPD depths greater than 20mm with a condition rating of 'good' (Table 3). Previous studies have identified high abundances of tube-building macrofauna (e.g., *Paracorophium excavatum*; Forrest 2023) that draw oxygen deeper into the sediment and likely explain the greater oxygenation observed in the sediments (see photo).

Table 3. Annual sedimentation, grain size and aRPD results up to November 2023.

Site	Survey	Sed rate mm/yr	Gravel %	Sand %	Mud %	aRPD mm
A	Dec-2016	na	3.5	77.4	19.1	30
	Dec-2017	-1.2	1.0	80.0	19.0	-
	Feb-2019	3.4	2.8	78.6	18.6	38
	Dec-2019	-6.7	3.0	79.5	17.5	45
	Jan-2021	13.1	0.7	44.0	55.3	45
	Nov-2021	-8.9	0.9	71.5	27.6	30
	Nov-2022	9.4	0.9	69.8	29.3	45
	Nov-2023	5.1	1.1	69.5	29.4	30
B	Dec-2016	na	25.1	51.9	23.0	30
	Dec-2017	-3.0	6.3	77.2	16.5	-
	Feb-2019	1.0	13.3	63.0	23.7	35
	Dec-2019	-4.5	9.2	69.8	21.0	35
	Jan-2021	1.9	6.4	70.2	23.4	45
	Nov-2021	0.7	2.9	71.5	25.7	30
	Nov-2022	3.9	7.0	64.1	28.9	50
	Nov-2023	6.8	3.7	66.4	29.8	27

November 2023 site photos. Top: Muddy sediment at Site A. Bottom: Macrofaunal sediment oxygenation at Site B.

CONCLUSIONS

Recent and long-term results show that Shag Estuary is under pressure from fine-sediment impacts. While it's river dominated nature has likely caused some variation in sedimentation rates over time, there is a general pattern of accretion and an increase in sediment muddiness. These results reinforce previous recommendations (e.g., Forrest 2023) to monitor and manage catchment sediment sources.

RECOMMENDED MONITORING

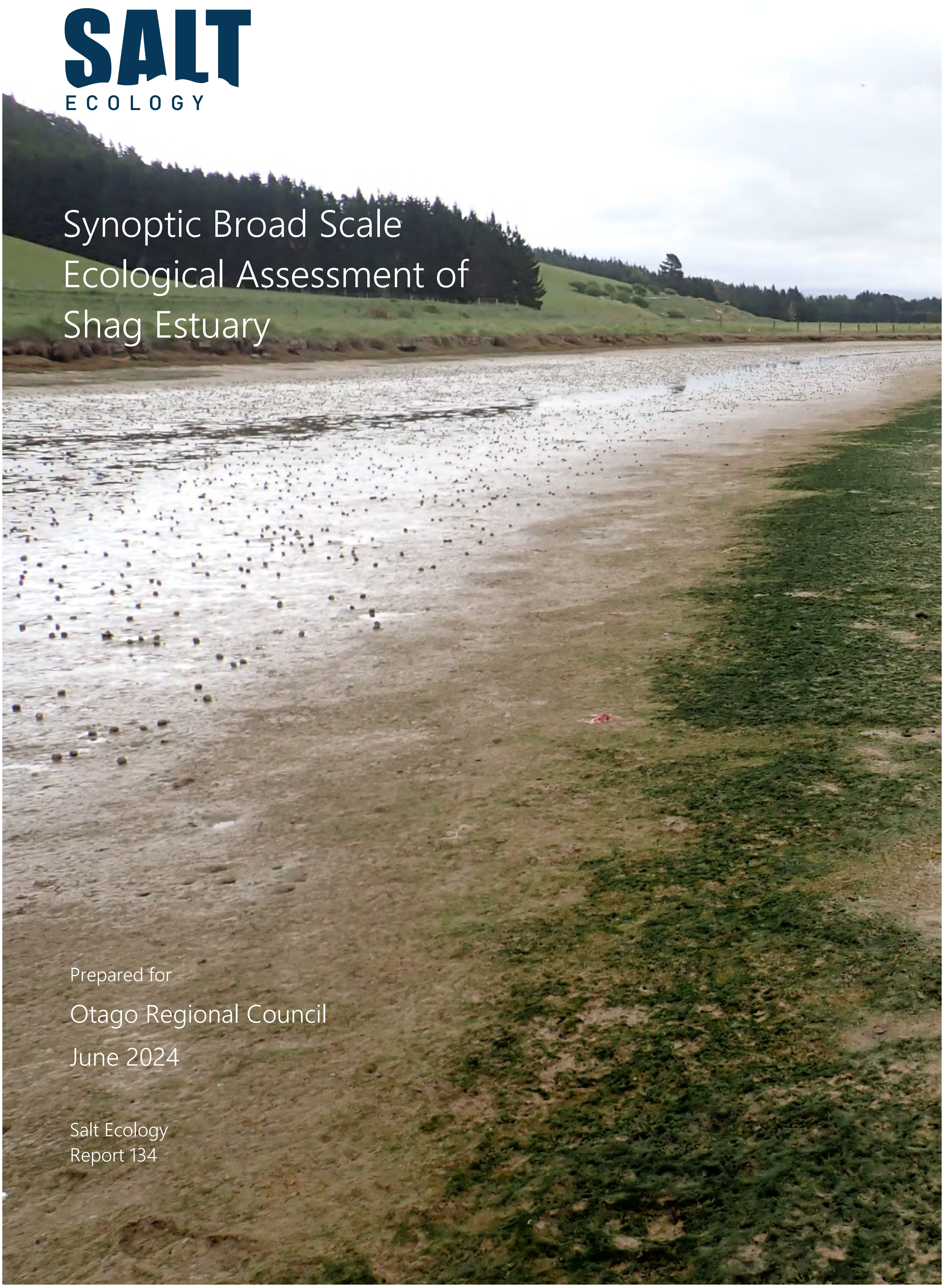
Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Consider site suitability and ongoing monitoring as part of a wider estuary programme review to be undertaken by ORC.

REFERENCES

Forrest BM. 2023. Shag Estuary Intertidal Fine-Scale Monitoring Data Summary. Salt Ecology Report 129, prepared for Otago Regional Council, November 2023. 11p.

O'Connell-Milne S, Forrest BM, Rabel H. 2023. Fine Scale Intertidal Monitoring of Blueskin Bay, Waitati Inlet. Salt Ecology Report 110, prepared for Otago Regional Council, July 2023. 40p.

Stevens LM, Robertson BM. 2017. Shag Estuary: Broad Scale Habitat Mapping 2016/17. Report prepared by Wriggle Coastal Management for Otago Regional Council. 26p.



Synoptic Broad Scale Ecological Assessment of Shag Estuary

Prepared for

Otago Regional Council

June 2024

Salt Ecology
Report 134

Cover and back photo: Shag Estuary mud flats with *Vaucheria* sp. on the edge of salt marsh habitat in the upper estuary, November 2023.

RECOMMENDED CITATION

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Synoptic Broad Scale Ecological Assessment of Shag Estuary

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for

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June 2024

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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
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 Sulfur
Zn	Zinc

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for reviewing the draft report. We are also grateful to Thomas Scott-Simmonds 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 the GIS data and produce summaries and maps were developed by Megan Southwick of Salt Ecology.

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SUMMARY

In November 2023, a synoptic broad scale ecological assessment was conducted in Shag Estuary, 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 (including associated biota) at discrete sites, and compares findings with a 2016 survey.

Monitoring results are summarised below, and assessed against preliminary condition rating criteria in the tables on the following page. Key findings are:

- Mud-elevated (≥25-100% mud) substrate covered 15.6ha (41%) of the Available Intertidal Habitat (AIH), a condition rating of 'poor'. Since the 2016 baseline, the extent of mud-elevated sediments has increased by ~7ha. Discrete sampling at mud-elevated sites showed a macrofaunal community dominated by hardy taxa that are resilient to elevated mud and most forms of disturbance. Macrofauna AMBI scores were rated 'fair' to 'poor'.
- Substrates had very low trace metal contaminant concentrations, indicating an absence of significant contaminant sources in the catchment (condition ratings of 'very good' or 'good').
- Salt marsh covered 45ha (54% of the intertidal area), a condition rating of 'very good'. The percentage of historic salt marsh remaining was 63%, a condition rating of 'good'. Historic salt marsh losses, attributed primarily to reclamation and drainage for pasture, are evident on the western and southern margins.
- Nuisance macroalgae cover was present across 3ha (8% of the AIH). The OMBT-EQR score was 0.665, a condition rating of 'good'. Since December 2016, the OMBT rating has declined from 'very good' to 'good'.
- High Enrichment Conditions (HEC) in the AIH were small (2ha, 5% of AIH), a condition rating of 'good'. Additional HEC from filamentous algae smothering affected 1ha of salt marsh, and 0.9ha of pooled water within salt marsh.
- The 200m terrestrial margin was dominated by pasture (63%). Areas classified as densely vegetated (predominantly exotic plantation forest on the northern margin) covered 34%, a condition rating of 'fair'.

RECOMMENDATIONS

Based on the 2023 survey, and changes recorded from 2016 to 2023, it is recommended ORC consider the following:

Monitoring

- Undertake broad scale monitoring ~5-yearly to track changes in the dominant features of the estuary.
- Synoptically assess macroalgae and HEC areas annually. Undertake targeted monitoring if expansion is observed.
- Utilise existing estuary monitoring data to review the SOE monitoring programme and assess monitoring needs in Shag Estuary alongside priorities for other estuaries regionally.

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 potentially impact the estuary.
- Improve estimates of sediment and nutrient loads to the estuary, determine potential sources, and investigate options for reducing inputs where loads exceed guidance thresholds, or adverse impacts are identified.
- Include Shag Estuary in 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 to identify and prioritise areas for ecological restoration, protection, and resilience to sea level rise. e.g., stock exclusion and weed control within salt marsh, replanting salt marsh, improving or reinstating tidal flushing, re-contouring shorelines, removing barriers to salt marsh expansion.

Overall, Shag Estuary is susceptible to, and affected by, fine sediment and (to a lesser extent) nutrient inputs. Estuary quality has declined since 2016. However, it retains extensive salt marsh, and has a high potential for ecological restoration, particularly through removing barriers to facilitate salt marsh migration in response to sea level rise.

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Summary of broad scale indicator condition ratings.

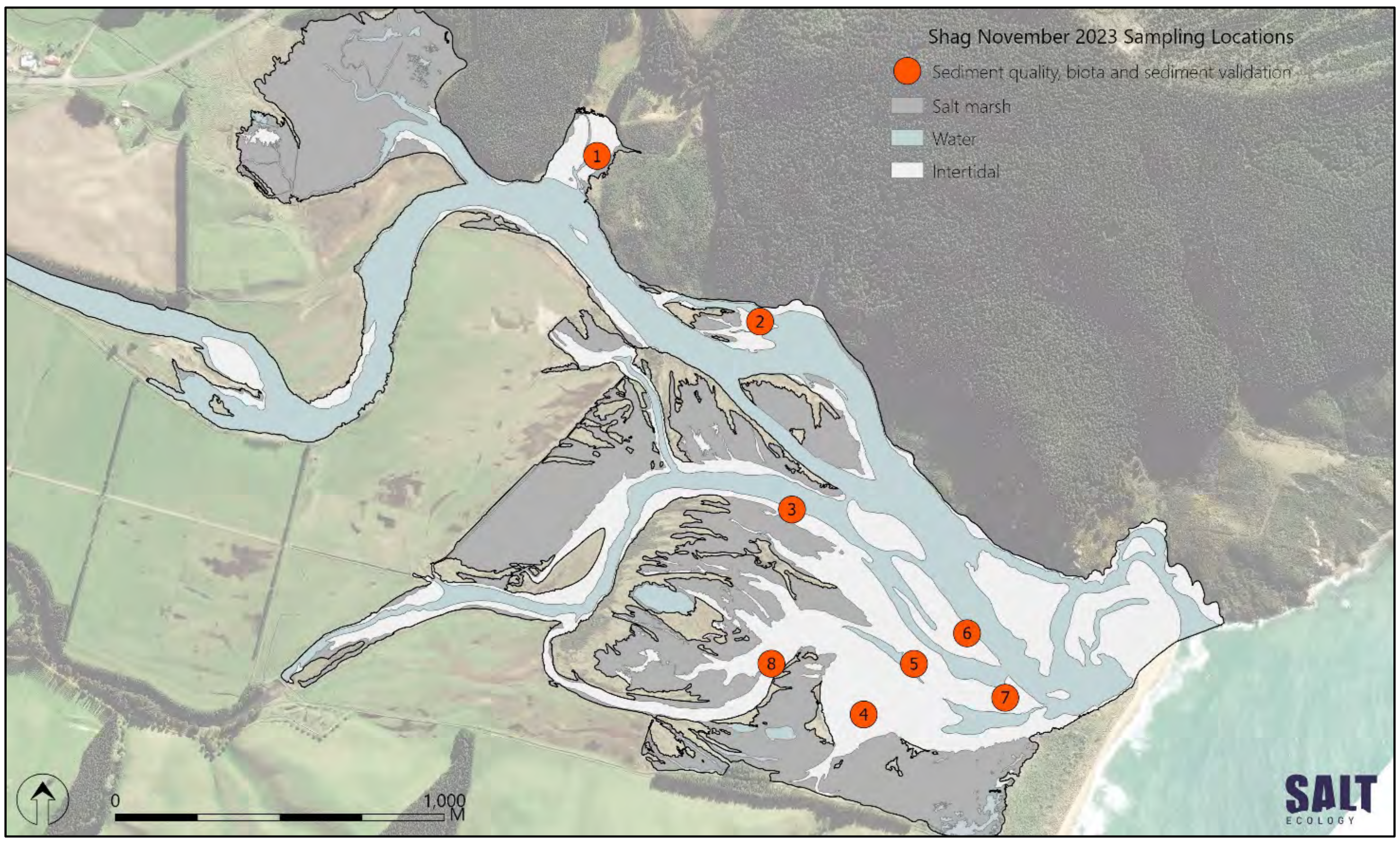
Condition rating key: Very Good | Good | Fair | Poor

Broad scale Indicators	Unit	December 2016	November 2023
200m terrestrial margin	% densely vegetated	26.1	33.8
Mud-elevated (≥25%-100%) substrate	% AIH[1] area	19.4	41.4
Macroalgae (OMBT[2])	Ecological Quality Rating (EQR)	0.982	0.665
Seagrass	% decrease from baseline	No seagrass present	
Salt marsh extent (current)	% of intertidal area	49.4	54.3
Historical salt marsh extent[3]	% of historical remaining	61.6	62.4
High Enrichment Conditions	ha	0.0	2.0
High Enrichment Conditions	% of AIH	0.0	5.3

[1]Available Intertidal Habitat (AIH; excluding salt marsh); [2]Opportunistic Macroalgal Blooming Tool (OMBT) scores have been updated following Stevens et al. (2022); [3]Estimated from historic aerial imagery. Data from 2016 revised following QAQC of GIS files.

Synoptic sampling sites (1-8) and indicator condition ratings for sediment quality and macrofauna AMBI.

Parameter	Unit	1	2	3	4	5	6	7	8
Mud	%	69.7	29.8	23.6	36.2	28.3	12.7	6.4	45.9
aRPD	mm	10	-	27	35	30	25	25	25
TN	mg/kg	600	800	400	300	500	300	< 200	400
TP	mg/kg	540	510	620	520	550	550	390	520
TOC	%	0.54	0.66	0.36	0.21	0.34	0.20	0.17	0.33
TS		0.07	0.08	0.04	0.03	0.03	0.03	0.03	0.04
As	mg/kg	8.0	12.1	13.9	7.4	10.6	9.8	10.1	9.7
Cd	mg/kg	0.03	0.05	0.03	0.01	0.02	0.02	0.02	0.02
Cr	mg/kg	7.2	9.6	9.6	6.8	9.6	8.5	6.1	8.6
Cu	mg/kg	3.9	6.7	4.6	2.1	3.8	3.1	2.0	3.9
Hg	mg/kg	0.03	0.05	0.03	<0.02	0.03	0.02	<0.02	0.02
Ni	mg/kg	5.1	9.8	7.5	3.6	5.9	5.8	4.0	5.9
Pb	mg/kg	5.3	7.2	5.8	3.7	5.4	4.2	2.7	5.5
Zn	mg/kg	33	45	37	23	33	28	18.3	32
AMBI	na	4.5	3.5	4.3	4.2	4.2	4.5	3.6	4.4



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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 mud extent), 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 extensions of that approach) with key locations being (from north to south) Kakanui, Shag, Pleasant River, Waikouaiti, Blueskin Bay, Hoopers Inlet, Kaikorai, Tokomairiro, Akatore, Catlins, Tahakopa (Papatowai), Tautuku and Waipati (Chaslands) estuaries. The current report describes the methods and results of a broad scale assessment undertaken on 30 November 2023 in Shag Estuary (hereafter Shag; 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 2006 and 2016.

2. OVERVIEW OF SHAG

Previous reports (Stewart 2007; Otago Regional Council 2010; Robertson et al. 2017 and references therein) present background information on Shag, which is paraphrased (and expanded in places) below.

Shag is a medium-sized (~120ha), shallow, intertidally dominated estuary (SIDE) situated at the mouth of the Shag (Waihemo) River on New Zealand's east coast. The estuary has a large central basin, two small side arm basins, and a 600m long sand spit on the eastern coastal margin. There is a single narrow opening at the

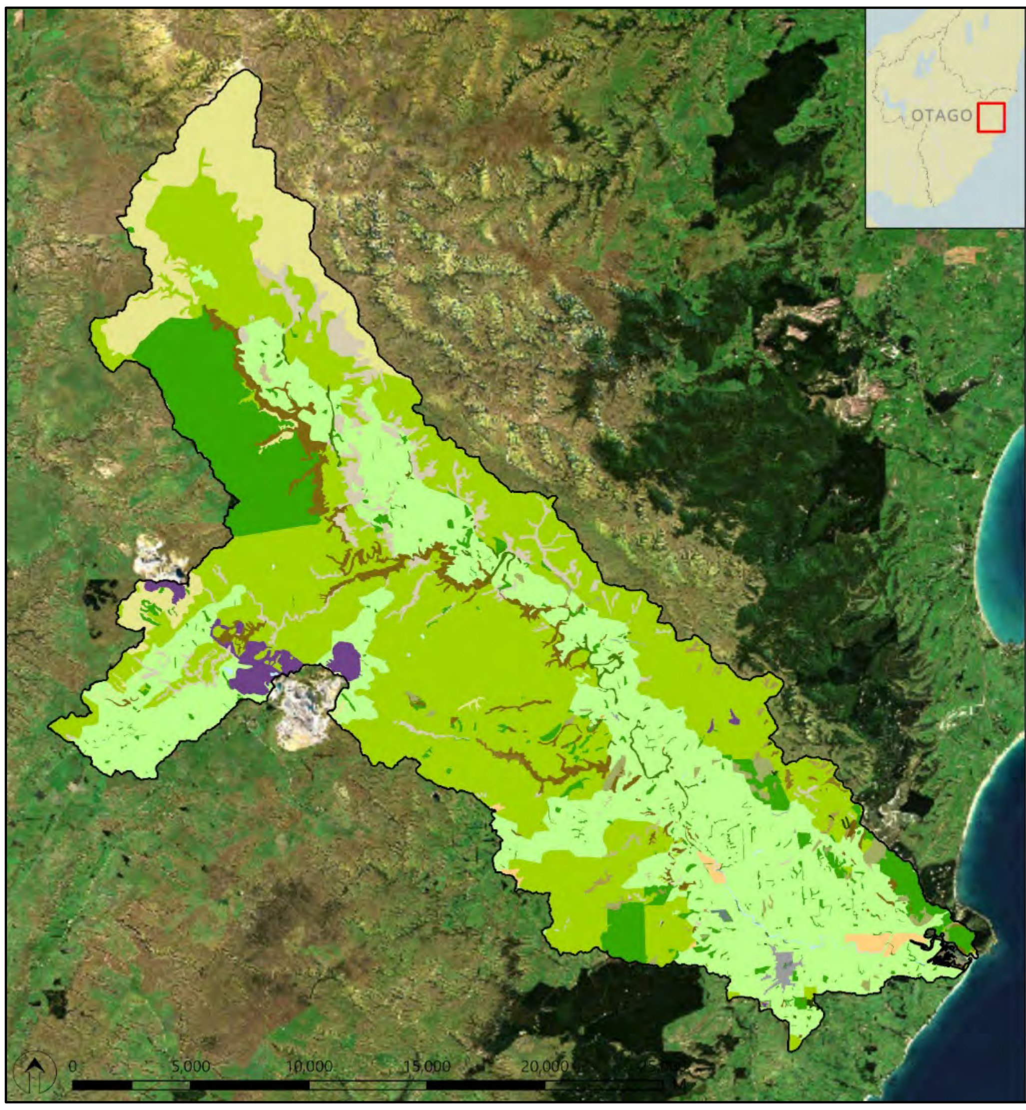
Fig. 1. Location of Shag Estuary, Otago.

north of the spit. The Shag (Waihemo) River is the dominant freshwater input to the estuary. Tidal flows extend ~3km inland with the estuary margins lined by salt marsh. Historically the estuary included large areas of estuary or flood plain which have subsequently been developed for farming, predominately on the western and southern sides.

The surrounding catchment (Fig. 2) is large (54,116km^2) and dominated by high- and low-producing exotic pasture (70%), with areas of exotic plantation forestry (10%). Macraes goldmine is located on the southwestern boundary of the mid catchment (~1%). The catchment contains very little native bush (<1%), although the headwaters comprise native tussock grassland (8%). Previous monitoring has identified Shag as being at risk from catchment land use inputs of sediment and nutrients (Stevens et al. 2017; Plew et al. 2018).

Salt marsh is relatively extensive (~54% of intertidal area) but much of this habitat type (~38%) has been lost historically through reclamation, drainage and conversion to pasture. These changes have greatly reduced the estuary's ability to filter, dilute, and assimilate catchment nutrient and sediment inputs. To date, no seagrass has been observed in the estuary, and macroalgal growth had not been widespread. However, in localised areas, the estuary is beginning to express symptoms of eutrophication characterised by low sediment oxygen and high cover (≥50%), high biomass growths of macroalgae, entrained in soft, muddy sediments. Background on the ecological significance of these different habitat features is provided in Table 1.

Shag has Kai Tahu cultural and spiritual values, and a significant settlement once existed at the river mouth (Ngāi Tahu Atlas). Shag (Waihemo) River and the estuary has been recorded as kāinga mahinga kai (food-gathering place) where tuna (eel), inaka (whitebait), pātiki (flounder), and pipi were gathered (Ngāi Tahu Atlas). The estuary is identified in the Otago Regional Plan: Water as a coastal protection area due to its estuarine values including large mudflats used as feeding and roosting areas for birds, fish nursery habitat, and whitebait spawning in the upper tidal reaches.



Catchment Land Use in 2018	ha	%
Artificial Surfaces		
Built-up Area (settlement)	128.4	0.2
Surface Mines and Dumps	707.3	1.3
Transport Infrastructure	0	0
Urban Parkland/Open Space	27.8	0.1
Bare or Lightly Vegetated Surfaces		
Sand and Gravel	2.1	0.0
Landslide	0	0
Alpine Grass/Herbfield	2.7	0.0
Gravel and Rock	18.9	0.0
Water Bodies		
River, Lake or Pond	53.3	0.1
Cropland		
Short-rotation Cropland	304.5	0.6
Orchard Vineyard and Other Perennial Crops	1.1	0.0
Grassland, Sedge and Saltmarsh		
High Producing Exotic Grassland	16,425.4	30.4
Low Producing Grassland	21,528.5	39.8
Tall Tussock Grassland	4,518.8	8.4
Depleted Grassland	24.7	0.0
Herbaceous Freshwater Vegetation	15.4	0.0
Herbaceous Saline Vegetation	6.6	0.0
Flaxland	0	0
Scrub and Shrubland		
Fernland	13.3	0.0
Gorse and/or Broom	1,688.6	3.1
Manuka and/or Kanuka	104.4	0.2
Broadleaved Indigenous Hardwoods	157.9	0.3
Sub Alpine Shrubland	0	0
Mixed Exotic Shrubland	74.1	0.1
Matagouri or Grey Scrub	1,863.7	3.4
Forest		
Forest Harvested	470.5	0.9
Deciduous Hardwoods	334.1	0.6
Indigenous Forest	33.6	0.1
Exotic Forest	5,599.0	10.3
	54,115.5	100.0

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

3. METHODS

3.1 OVERVIEW

The survey of Shag was carried out on 30 November 2023. It consisted of broad scale habitat mapping of substrates and vegetation, and targeted sampling of sediment quality and macrofauna in representative areas. Fig. 4 (next page) shows the estuary area surveyed and indicates where the sampling described below 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.

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 Shag was sourced from Apollo Mapping (Colorado) and consisted of 30cm/pixel colour satellite imagery captured 15 April 2023. QA/QC procedures, applied through the phases of field data collection, digitising, and GIS data collation and processing, are described in Appendix 1. GIS layers for 2006 and 2016 were run through the same QA/QC procedures. A large number of errors were identified in the 2006 dataset 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 12 representative locations (Fig. 4, next page) 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. 3. 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. 2022b). OMBT scores from previous monitoring years have been recalculated using the method in Stevens et al. (2022b).

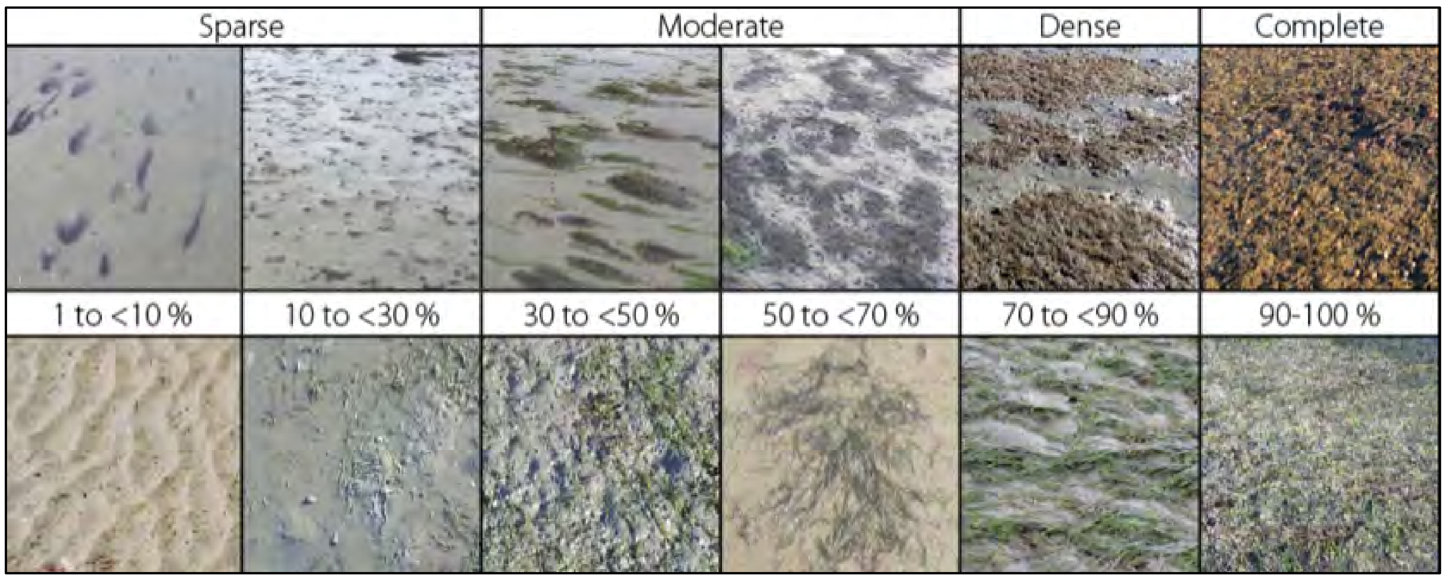


Fig. 3. Visual rating scale for % cover estimates of macroalgae and seagrass. Modified from FGDC (2012).

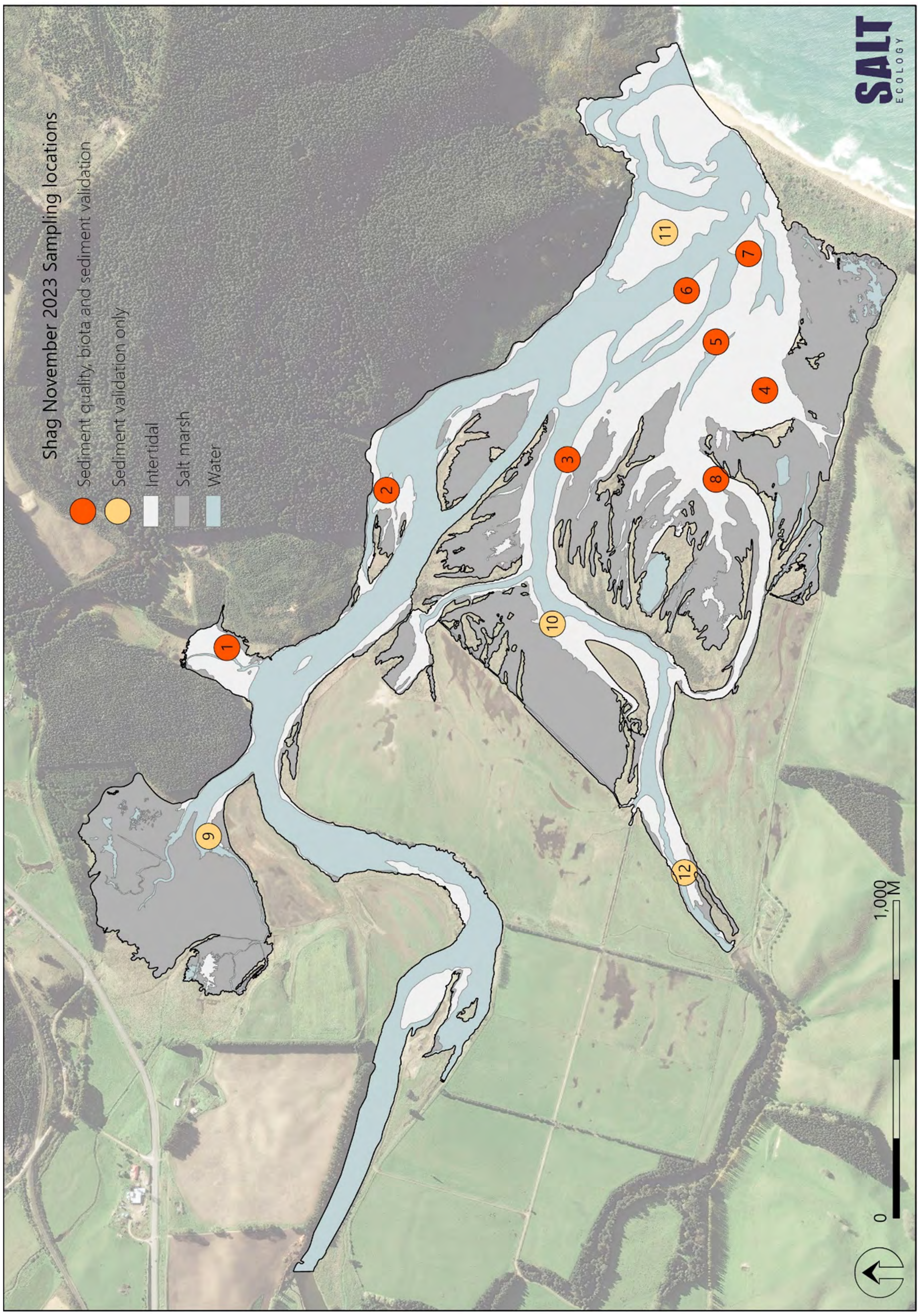


Fig. 4. Location of sites for sediment quality and biota samples (1-8) and sediment validation (1-12), Shag Estuary, November 2023.

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. (2022b).
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. 4). 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:

Broad scale mapping of the Shag, November 2023.

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.

Sediment sampling in Shag Estuary, 2023.

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).

Sediment core samples were split vertically to visually assess the depth of sediment oxygenation, as defined by the aRPD depth.

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.

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.

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. 2016a). 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.

There are two broad scale rating indicators (salt marsh and seagrass) that rely on assessment of differences between current state and historic or baseline state.

- To estimate historic salt marsh extent, we assessed LiDAR contours and historic aerial imagery captured from 1947, 1967, 1982 (source: retrolens.co.nz) and 2005 (data.linz.govt.nz). Where required, imagery was merged and georectified to digitise the salt marsh area and inform historic extent.
- For seagrass, we assessed aerial imagery from 1947, 1967, 1982 (retrolens.co.nz) and 2005 (data.linz.govt.nz), which showed no areas of distinguishable seagrass.

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[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. (2016a).
3. Mud-elevated substrate modified from Robertson et al. (2016a) 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. (2016a).
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 November 2023 mapping survey undertaken in Shag 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 exotic grassland (46%) and low producing grassland (17%). Pastoral grazing extends to the estuary edge along most of the southern and western margins.

Grazing to the fenced estuary margin.

Low producing grassland adjacent to fenced salt marsh, with high producing pasture and exotic forest in the background.

A total of 34% of the margin was categorised as densely vegetated, which corresponds to a condition rating of 'fair'. Dense vegetation on the estuary margin primarily comprised of exotic plantation forest (21%) and gorse/broom (5%). Other areas included small patches of broadleaved indigenous hardwoods (~3%), exotic shrubland (~2%), and flaxland (<1%).

Exotic plantation forestry transitioning to gorse on the northern margin of the lower estuary.

Table 4. Summary of 200m terrestrial margin land cover, Shag Estuary, November 2023.

	LCDB5 Class	ha	% Margin
1	Built-up Area (settlement)	0.2	0.1
5	Transport Infrastructure	1.5	0.7
20	Lake or Pond	0.4	0.2
21	River	1.5	0.7
40	High Producing Exotic Grassland	104.7	46.4
41	Low Producing Grassland	39.3	17.4
410	Duneland[1]	1.7	0.7
46	Herbaceous Saline Vegetation	5.7	2.5
47	Flaxland	0.1	0.1
51	Gorse and/or Broom	12.0	5.3
54	Broadleaved Indigenous Hardwoods	7.6	3.4
56	Mixed Exotic Shrubland	4.0	1.8
71	Exotic Forest	46.8	20.8
Grand Total		228.6	100
Total dense vegetated margin (LCDB5 classes 45-71)		76.3	33.8

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

Small areas (~2%) of herbaceous saline vegetation were present within the southern terrestrial margin of the mid estuary. These low-lying areas were historically salt marsh habitat before being drained to provide land for pasture. Many of these areas contain flap gates to restrict tidal inundation. Despite this these grazed areas still comprise salt-tolerant species. (see photo on following page).

Drainage pipe with flap gate blocking tidal inundation with herbaceous saline vegetation in the background.

Margin areas containing salt marsh species, and evidence of tidal flows extending into fenced paddocks, were common and highlights the potential impact of sea level rise around the edge of the estuary. Ideally from an ecological perspective, the estuary should be allowed to expand into these low lying areas to prevent the displacement and loss of high value salt marsh. (photo below).

Estuary extending into previously reclaimed and fenced area of grazed herbaceous saline vegetation.

Salt marsh species present in fenced areas.

Duneland (<1%) on the coastal sandspit was predominantly introduced marram grass (*Ammophila arenaria*). Marram grass transitioned to exotic shrubland with tree lupin (*Lupinus arboreus*), boxthorn (*Lycium ferocissimum*), and tall fescue (*Festuca arundinacea*) on the southeast estuary margin. It should be noted that broad scale mapping of the terrestrial margin recorded dominant cover only and does not represent a comprehensive survey of dune vegetation.

Coastal sandspit vegetated with marram grass.

Between 2016 and 2023 the area of densely vegetated margin has increased from 26% to 34%. However, a cursory assessment of aerial photographs indicates that changes can be attributed primarily to the reclassification of some features as opposed to any meaningful change. For example, some areas on the southern margin classified as grassland in 2016 were updated to herbaceous saline vegetation in 2023 following more extensive ground-truthing and access to higher resolution aerial photographs.

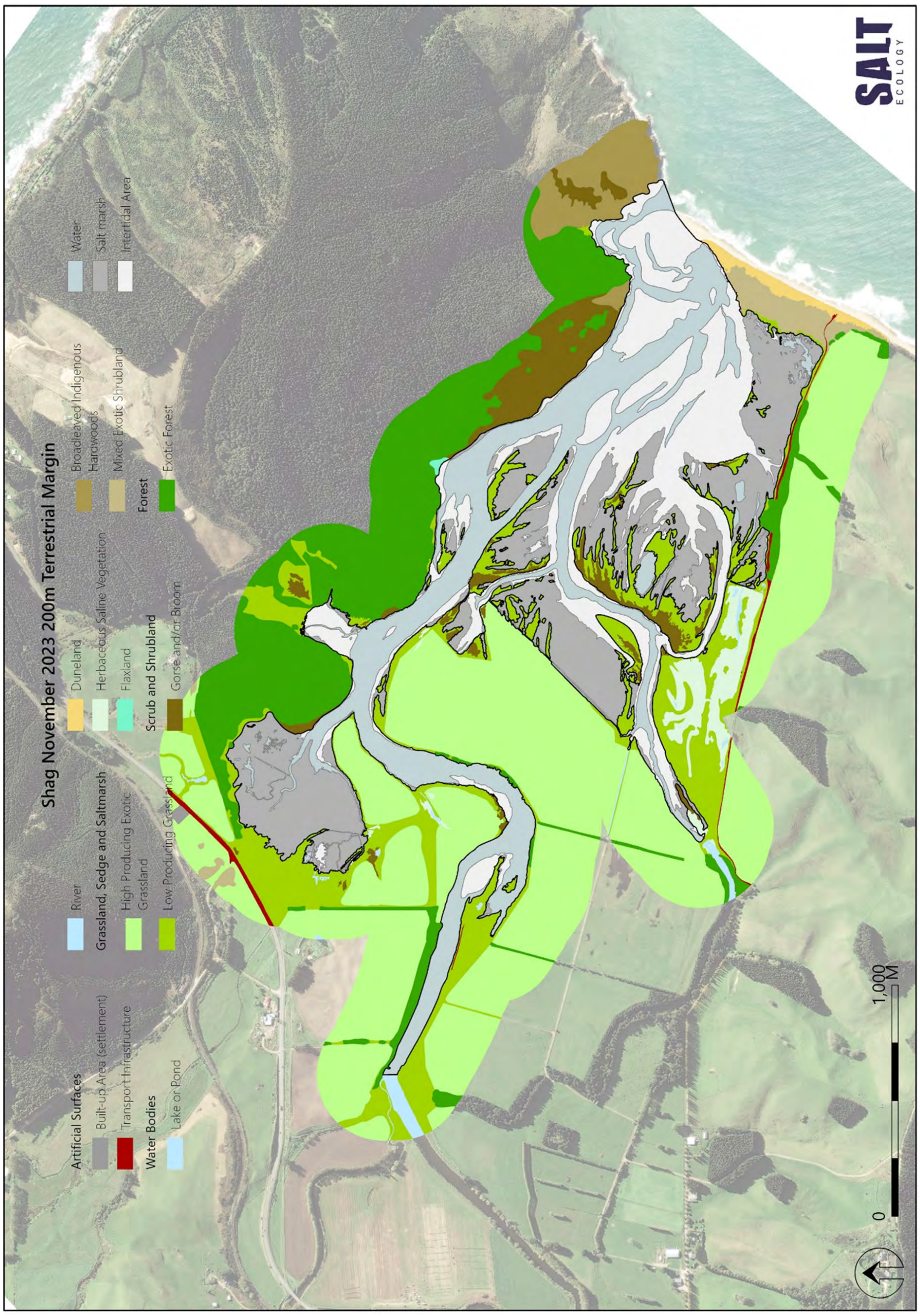


Fig. 5. Map of 200m terrestrial margin land cover, Shag Estuary, November 2023.

4.2 SALT MARSH

Shag had 45ha of salt marsh, comprising ~54% of the mapped intertidal area (83ha; Table 5, Fig. 7). Dominant species are noted in Table 5, while sub-dominant species are detailed in Appendix 3 and accompanying GIS files.

Salt marsh was predominantly located on the western and southern margin of the central estuary, on islands and peninsulas between the primary and secondary channels, and in an embayment north of the upper estuary (Fig. 7). Salt marsh was dominated (97%) by herbfield (~44ha), and primarily comprised of glasswort (*Sarcocornia quinqueflora*), primrose (*Samolus repens*) and remuremu (*Selliera radicans*). The estuary supported small areas of rushland (~1ha) dominated by jointed wirerush (*Apodasmia similis*). Tussockland and estuarine shrub each comprised less than 1% of the intertidal area.

The lobe of salt marsh northwest of the estuary is identified within Schedule 9 of the Regional Plan: Water for Otago as a Regionally Significant Wetland named Shag River Estuary Swamp (ORC 2004), and is also identified as an Area of Significant Indigenous Vegetation and Habitat for Indigenous Fauna within the Waitaki District Plan.

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

Salt Marsh Class	Dominant species*	ha	% Intertidal
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.1	0.1
Tussockland	*Puccinella stricta* (Salt grass)	0.1	0.1
Rushland	*Apodasmia similis* (Jointed wirerush)	1.1	1.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort) *Samolus repens* (Primrose) *Selliera radicans* (Remuremu)	43.8	52.8
Total		**45.0**	**54.3**

* See Appendix 3 for additional species in subclass.

There was active erosion along the steep banks of the channels in the upper estuary, likely driven by periods of high river flow. Wind and wave driven erosion was also occurring on the seaward edge of salt marsh on the main estuary flats. Further, physical damage to salt marsh habitat was observed from vehicle disturbance, with fresh tyre tracks cutting through herbfield (see photo lower right).

Herbfields dominated by glasswort, primrose and remuremu cover. Large, raised islands within the estuary (top); and fringing the estuary margin (bottom).

Erosion on the margin of the upper estuary channel.

Vehicle damage to herbfield in the southeast of the estuary toward the sand spit.

Similar to other estuaries in the region (e.g., Pleasant River), herbfield dieback caused by localised filamentous algae smothering was observed on the southern margin (see photo below) and within shallow pools in the herbfield (see Section 4.5).


Mats of filamentous algae smothering areas of herbfield.


Rushland with jointed wirerush within an embayment in the upper estuary, adjacent to herbfield comprised of glasswort, primrose, and remuremu.

Most (>99%) of the substrate within salt marsh habitat had an elevated mud content (≥25% mud) comprised of firm sandy mud (≥50-90% mud). Exceptions to this include a few small areas (<1%) where herbfield species were growing amongst cobble and gravel fields. Substrate details for salt marsh and other vegetated habitats are provided in Appendix 4. As salt marsh habitats play a vital role in retaining fine sediments, they commonly have a high mud content. Therefore, when assessing substrate metrics in Section 4.3, areas of salt marsh habitat are excluded.

Mapped salt marsh remained very similar from 2016 to 2023 (44.3ha in 2016; 45ha in 2023), however, the calculated percentage of salt marsh of the estuary increased from 49.4% to 54.3%. This increase was attributed to a larger subtidal area being mapped in 2023 compared to 2016. The current extent retains a condition rating of 'very good'.

The historic extent of salt marsh in the estuary was estimated to cover 72ha comprising 63% of the intertidal area (see Fig. 7; Appendix 5). Losses have occurred primarily in low-lying land to the west and southwest of the estuary (now pasture) with a cursory assessment of historic imagery dating back to 1947 indicating substantial losses had already occurred by this time. These appear to largely be a consequence of land drainage channels west of the estuary. In 2023, many of the drains around the estuary margin have outfalls fitted with flap gates to restrict tidal inundation of low lying areas (see photo). As discussed in Section 4.1, many of these areas retain salt-tolerant species with some fenced paddocks dominated by herbaceous salt marsh vegetation.

Despite past losses it is estimated that ~62% of historic salt marsh remains in the estuary, a condition rating of 'good'.


Flap gate preventing tidal inundation into low lying paddock.


Drainage channel through paddocks on the estuary margin dominated by salt tolerant species.

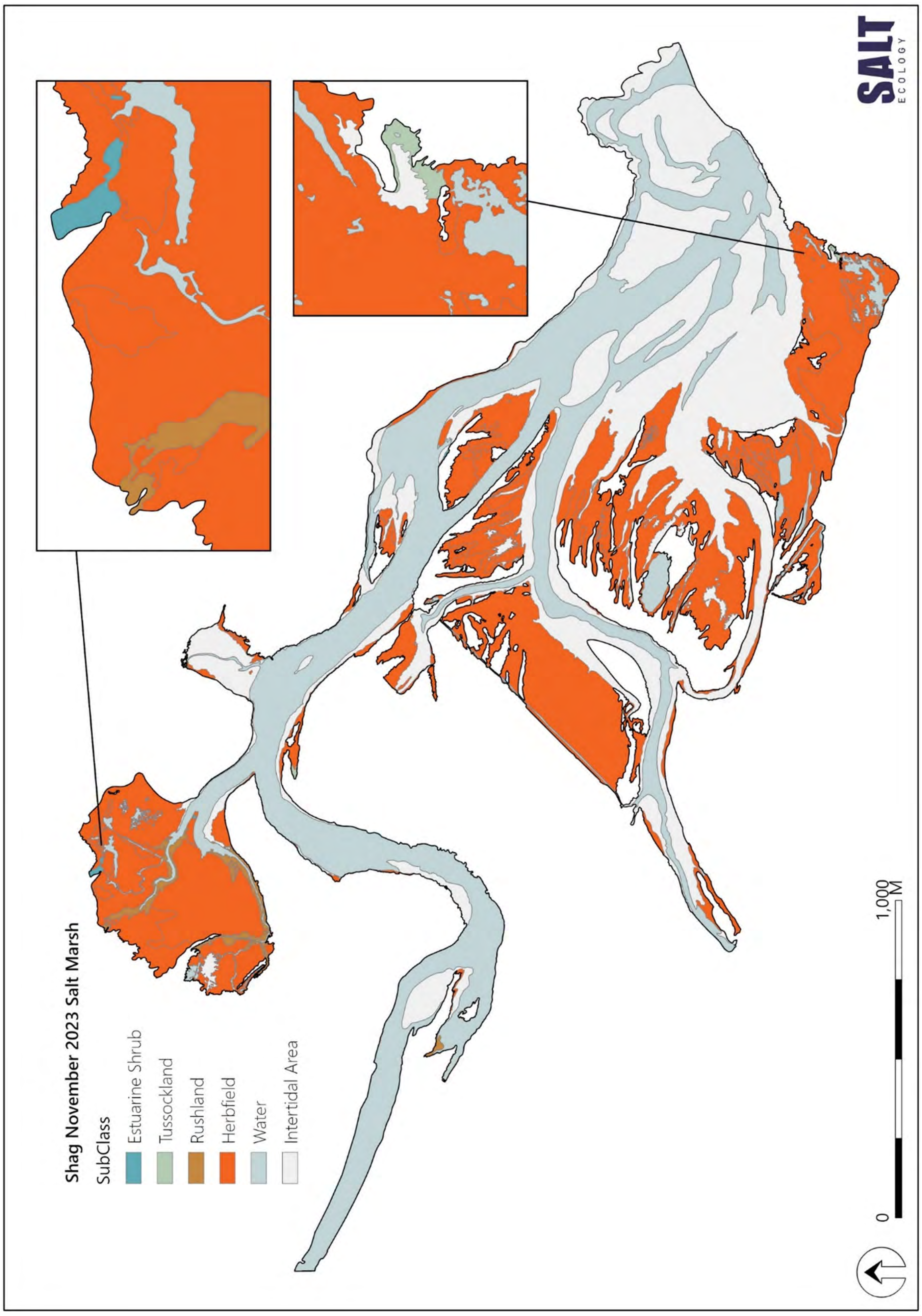


Fig. 6. Salt marsh sub-classes and their distribution, Shag Estuary, November 2023.

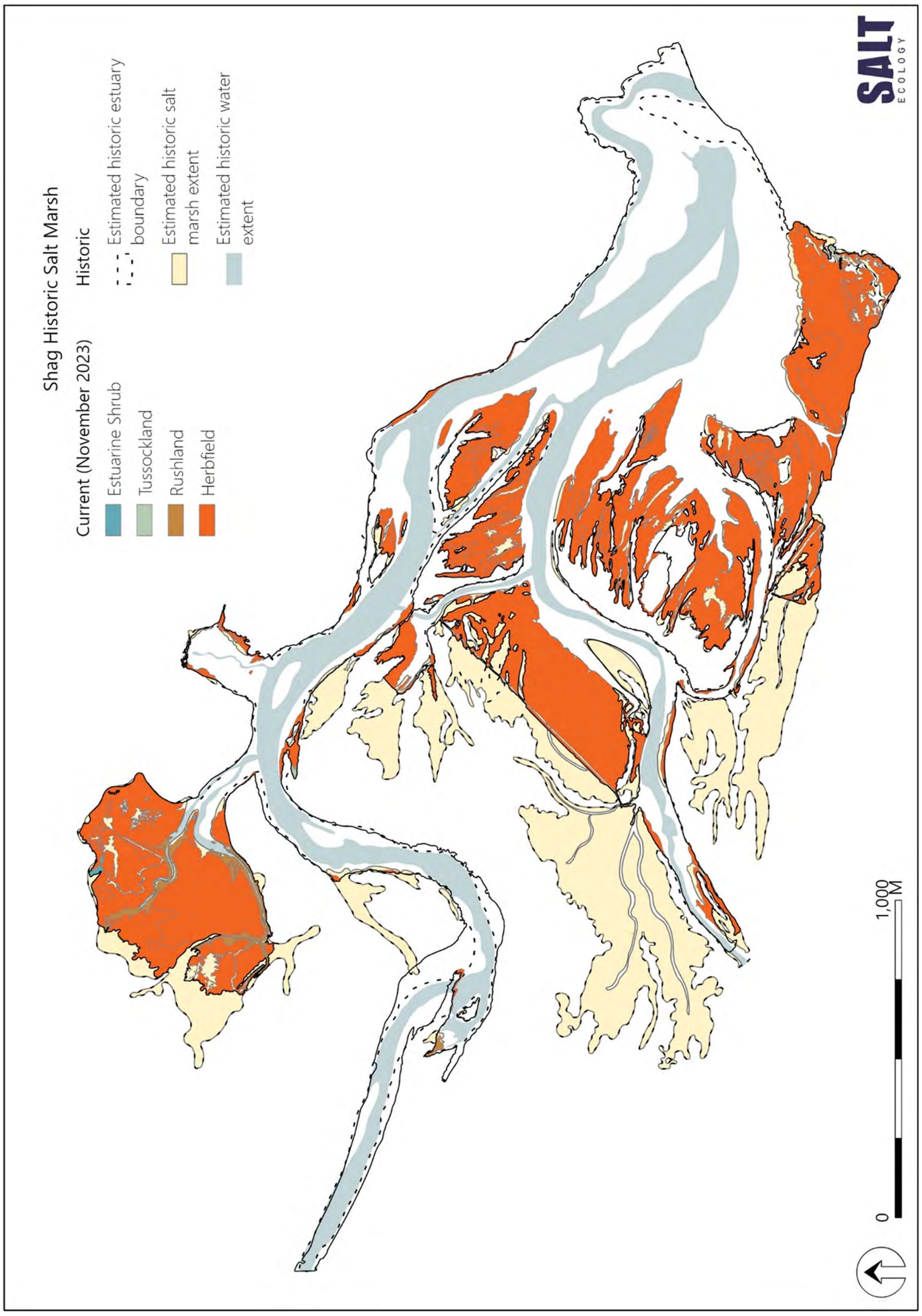
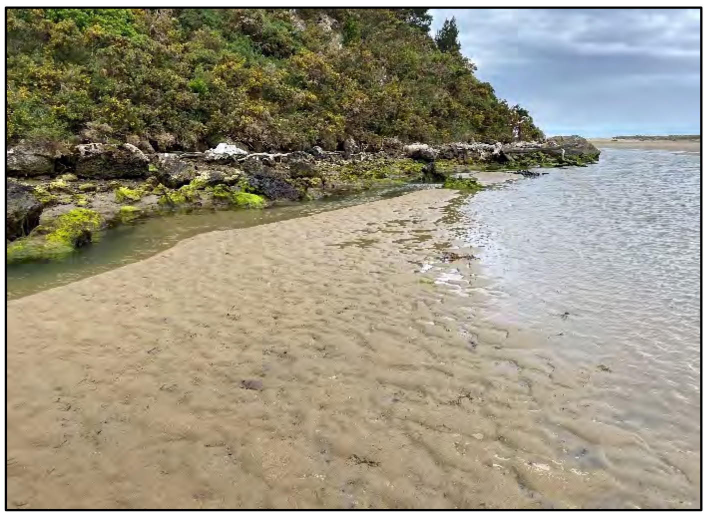


Fig. 7. The historic salt marsh extent (yellow) and historic estuary margin (dashed line) are overlaid with the current mapped salt marsh extent.

4.3 SUBSTRATE

Outside of salt marsh, ~38ha of intertidal substrate was mapped (Table 6, Fig. 8). There was generally a good agreement between the subjective sediment classifications applied during mapping and the sediment grain size validation measures (Appendix 6).

Hard substrates were limited in extent, with a small area of bedrock and boulders on the northern side of the entrance (0.4ha) and cobble at the base of rocky headlands on the north edge of the estuary (0.3ha). Gravel field was the predominant coarse substrate within the estuary, comprising ~9% (3ha) of the AIH, with patches primarily located adjacent to the main channel of the estuary on the inside curve of bends in the channel.



Rock fields and bedrock substrate at the base of the steep terrestrial margin on the northern boundary of Shag.

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

Substrate Class	Features	ha	% AIH
Bedrock	Rock field	0.4	1.1
Coarse substrate (>2mm)	Cobble field	0.3	0.9
	Gravel field	3.0	8.1
Sand (0-10% mud)	Mobile sand	3.4	9.0
	Firm sand	4.9	12.9
Muddy Sand (≥10-25% mud)	Firm muddy sand	10.1	26.5
Muddy Sand (≥25-50% mud)	Firm muddy sand	3.3	8.8
	Soft muddy sand	2.3	6.0
Sandy Mud (≥50-90% mud)	Firm sandy mud	5.6	14.8
	Soft sandy mud	3.2	8.5
	Very soft sandy mud	1.2	3.3
Total		37.9	100

Sand (≤10% mud) covered ~8ha (~22% of the AIH). within the lower and mid estuary. Sand was mainly firm in the mid estuary (~5ha, ~13% of the AIH) and mobile (~3ha, ~9% of the AIH) towards the estuary entrance and adjacent to the main channel.

Firm muddy sand (≥10-25% mud) was the most dominant substrate within Shag covering ~10ha (~27% of the AIH) across the eastern flats of the central estuary and on the edges of the secondary channel southwest of the central basin. Muddy sand (≥25-50% mud) covered ~6ha (~15% of the AIH) with firm substrates observed on the central estuary flats and soft substrates accumulating on the outer bend of the secondary channel and around salt marsh.

Sandy mud (≥50-90% mud) covered a total area of 10ha, comprising ~27% of the AIH. Firm sandy muds, were present in sheltered areas such as the upper reaches of the central flats, sheltered embayments on the northern extent of the estuary and outer bends of main channels. Soft to very soft sandy muds dominated the small connecting channel southwest of the central estuary. This area of very soft sandy mud was also associated with dense beds of entrained *Gracilaria* spp., a species which can promote settling of fine sediments by reducing water flow through the macroalgal bed.

Mobile sand (<10% mud) at the estuary entrance.

Sea lions haul out on firm sand in the lower estuary.

Muddy substrates accumulated in embayments sheltered by salt marsh.

As a general trend, the substrates become muddier closer to the riverine input and higher on the estuary flats. Embayments and small channels also have high mud content, likely attributed to limited water exchange and deposition of fine sediments. The Shag (Waihemo) River enters the estuary in a well-defined channel that follows the northern margin toward the estuary entrance, therefore on the outgoing tide nutrients and sediments likely bypass the central tidal flats.

Overall, mud-elevated (≥25-100% mud) sediments covered 15.6ha, comprising 41% of the AIH, a condition rating of 'poor'. The extent of mud-elevated substrates increased by ~7ha since 2016. The increase in muddiness is mainly associated with the tidal channel on the southern margin and east of the main salt marsh island.

Soft muddy sand (≥25-50% mud) west of the main channel in the upper estuary.

Firm muddy sand (≥10-25% mud) in the upper estuary.

Soft mud (≥50-90% mud) in the northwest of the upper estuary.

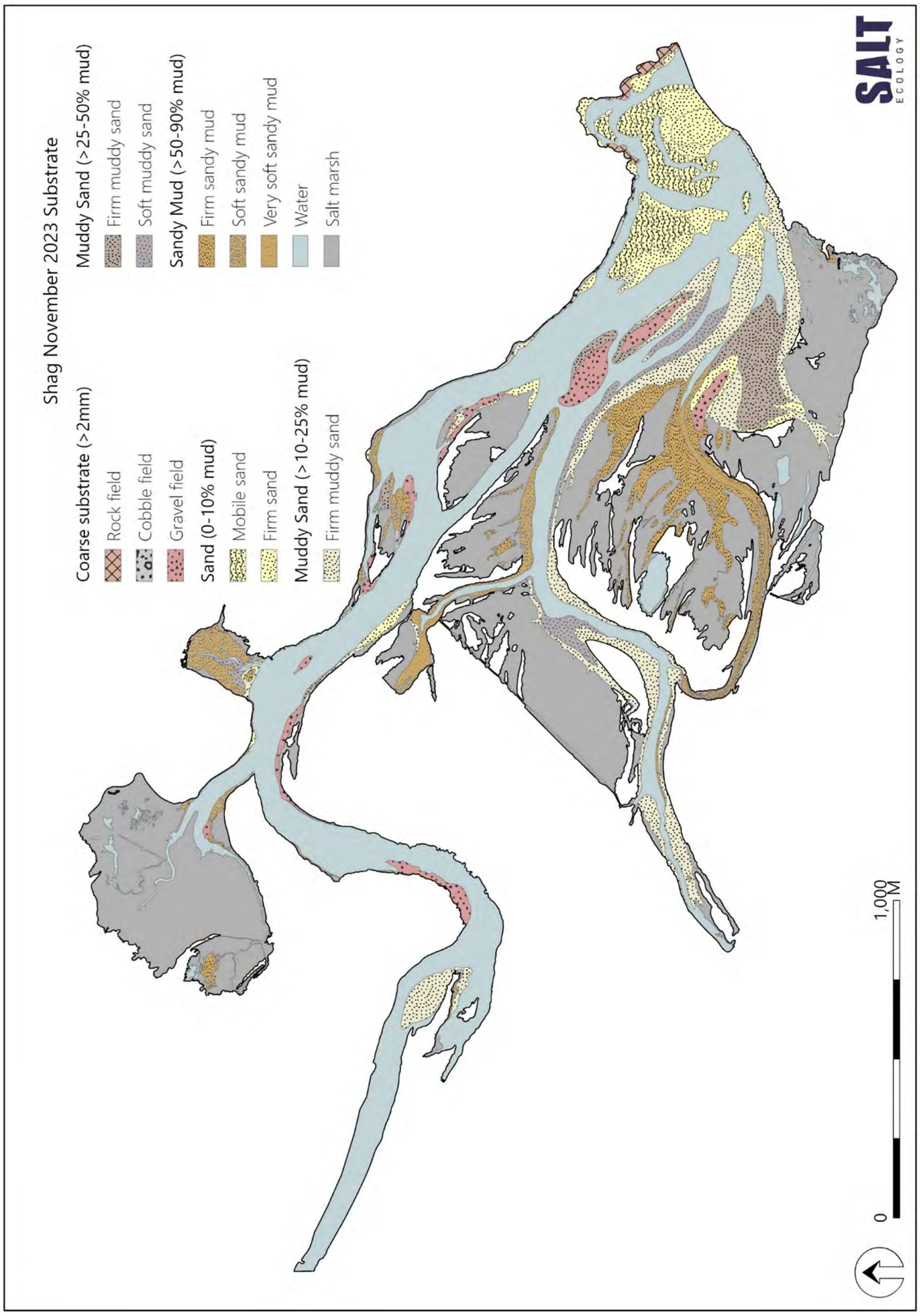


Fig. 8. Dominant intertidal substrate in the AIH (excluding salt marsh), Shag Estuary, November 2023.

4.4 SEAGRASS

Despite habitat conditions appearing largely suitable for growth, seagrass (*Zostera muelleri*) beds were not present in the intertidal estuary, consistent with previous surveys and analysis of historic imagery.

4.5 MACROALGAE

4.5.1 Opportunistic macroalgae

Opportunistic macroalgae species and biomass information is included in Appendix 7, with key results summarised in Table 7 and Fig. 9. Macroalgae comprised the green algae *Ulva* spp., the red algae *Gracilaria* spp., unidentified green filamentous algae, and a mat-forming yellow-green alga identified by NIWA as *Vaucheria* sp.

Macroalgae was mapped as absent or trace (<1% cover) across ~91% of the available intertidal habitat (AIH; excluding salt marsh). Very sparse to sparse macroalgae (1% to <30% cover) comprising *Gracilaria* spp. was observed on lower estuary flats (0.7% of the AIH).

Sparse *Gracilaria* spp. on firm muddy sand (>10-25% mud) in the lower estuary (Appendix 7: Patch ID 11).

Remaining beds of dense or complete macroalgal cover (2.1ha) comprised *Ulva* spp., *Gracilaria* spp. and filamentous green algae. *Ulva* spp. was localised to boulder habitat in the lower estuary and a discrete bed over firm muddy sand (≥10-25% mud) adjacent to the main channel in the upper estuary. Dense beds of *Gracilaria* spp. were predominantly located in exposed channels of soft to very soft sandy mud (≥50-90%) with high cover (>70% cover) and biomass entrained into the sediment. Long-stranded filamentous green algae formed mats of complete (≥90%) cover on the upper intertidal flats adjacent to salt marsh (0.9ha) and was also observed smothering an area of salt marsh southwest of the central estuary (~1ha).

Table 7. Summary of intertidal macroalgal cover (A) and biomass (B), in the available intertidal area (AIH), Shag Estuary, November 2023.

A. Percent cover

Percent cover category	ha	% AIH
Absent or trace (<1%)	34.5	91.1
Very sparse (1 to <10%)	0.1	0.4
Sparse (10 to <30%)	0.1	0.3
Low-Moderate (30 to <50%)	0.1	0.3
Moderate-High (50 to <70%)	0.1	0.2
Dense (70 to <90%)	1.9	4.9
Complete (≥90%)	1.1	2.8
Total	**37.9**	**100**

B. Biomass

Biomass category (g/m^2)	ha	% AIH
Absent or trace (<1)	34.5	91.1
Very low (1 - 100)	1.2	3.2
Low (101 - 200)	0.0	0.0
Moderate (201 - 500)	0.1	0.3
High (501 - 1450)	1.9	5.1
Very high (>1450)	0.1	0.4
Total	37.9	100

Ulva spp. growing on boulder field on the northern margin of the lower estuary (Appendix 7: Patch ID 16).

Dense *Gracilaria* spp. growing entrained in very soft sandy mud (≥50-90% mud) in an exposed channel (Appendix 7: Patch ID 18).

Vaucheria sp. formed thin mats with very low biomass (20-50g), generally on firm sandy mud (≥50-90% mud) in the upper tidal flats adjacent to salt marsh. Some patches had low to moderate cover (0.2ha), however, most (80%) *Vaucheria* sp. had dense (70 to <90%) or complete (≥90%) cover (0.9ha). Despite the low biomass, the substrates beneath mats of *Vaucheria* sp. were enriched and anoxic.

Dense cover of mat-forming yellow-green alga *Vaucheria* sp. and microalgae over sandy mud substrate in the upper estuary drives high enrichment conditions.

The OMBT-EQR score for Shag was 0.665, a condition rating of 'good'. Between 2016 and 2023 the OMBT-EQR has deteriorated from 'very good' to 'good' due to an increase in algal present. *Ulva* spp. was the only nuisance algae observed in 2016 and covered 0.2ha. Although spatial distribution of *Ulva* spp. remains low (~1ha in 2023), the development of *Gracilaria* spp. (0.4ha) growth, some of which is entrained in sediment, and high cover of *Vaucheria* sp. mats (~1ha) and filamentous green algae (0.9ha) result in a reduced OMBT score (Table 8; Appendix 7). Despite this, the area affected by entrained dense macroalgae remains small (~0.2ha, Appendix 7).

Table 8. Opportunistic Macroalgal Blooming Tool (OMBT) Ecological Quality Rating

Year	OMBT-EQR	Rating
2016	0.982	Very good
2023	0.665	Good

4.5.2 Other algae

In addition to opportunistic macroalgal species, other algae were also prolific in parts of the estuary (Fig. 10). These species included the following:

- Although microalgae were not widespread within the estuary (0.1ha, 0.3% of the AIH), a few patches of *Vaucheria* sp. with low to moderate cover (40% cover) had microalgae growing on adjacent substrate. In these areas substrate was depleted in oxygen (anoxic).
- Filamentous algae also formed abundant growth in ponds within herbfields (1.3ha; Fig. 10). Since these growths developed within ponded water and were likely influenced by shallow water temperatures and release of nutrients from salt marsh habitat, they were excluded from the OMBT calculation. The OMBT specifically targets opportunistic species on the main intertidal flats outside of salt marsh areas.

Dense filamentous green algae over firm muddy sand adjacent to salt marsh (Appendix 7: Patch ID 7).

Complete cover of filamentous green algae in ponded water within salt marsh on the southeast extent of the central estuary.

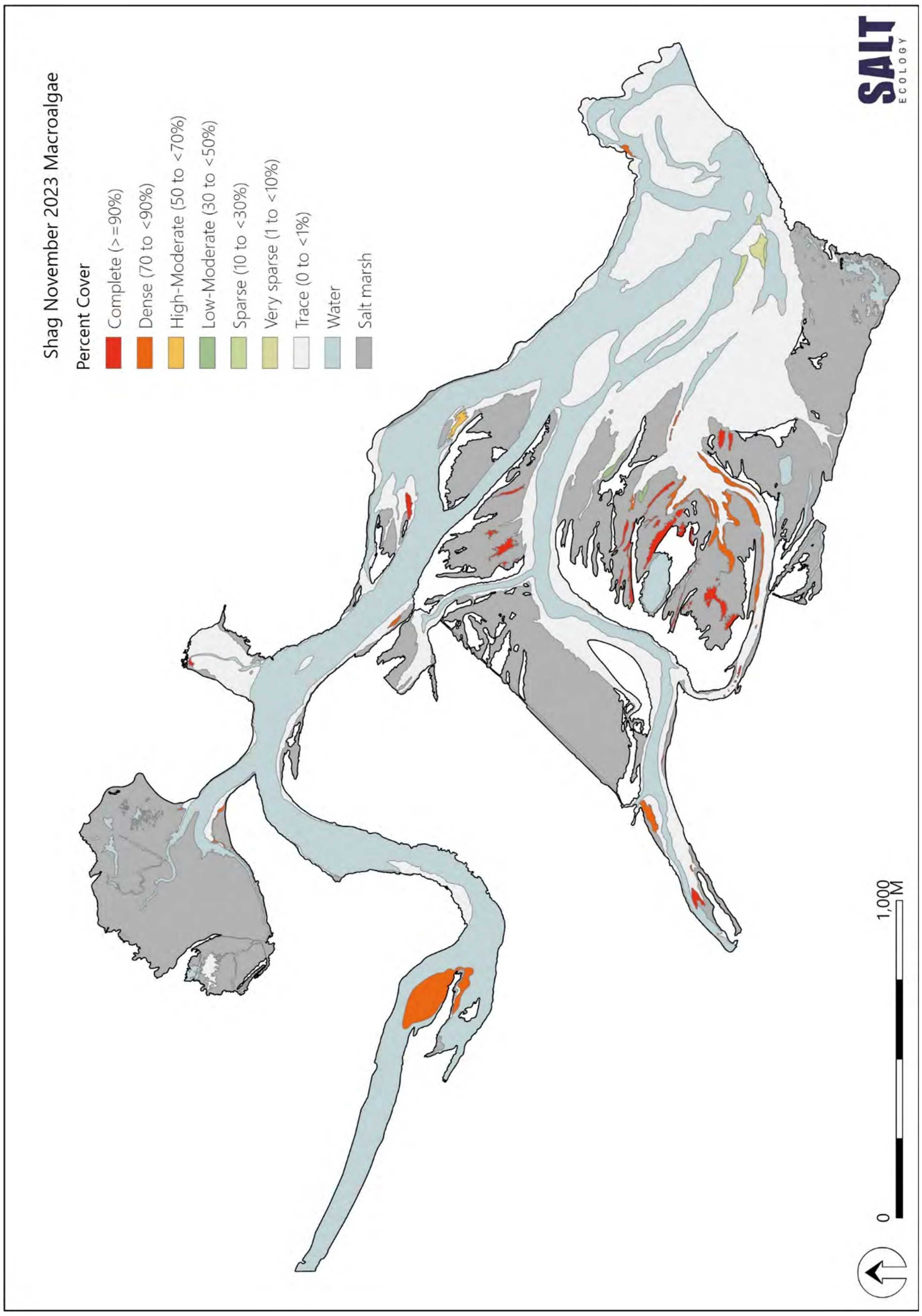


Fig. 9. Distribution and percent cover classes of macroalgae, Shag Estuary, November 2023.

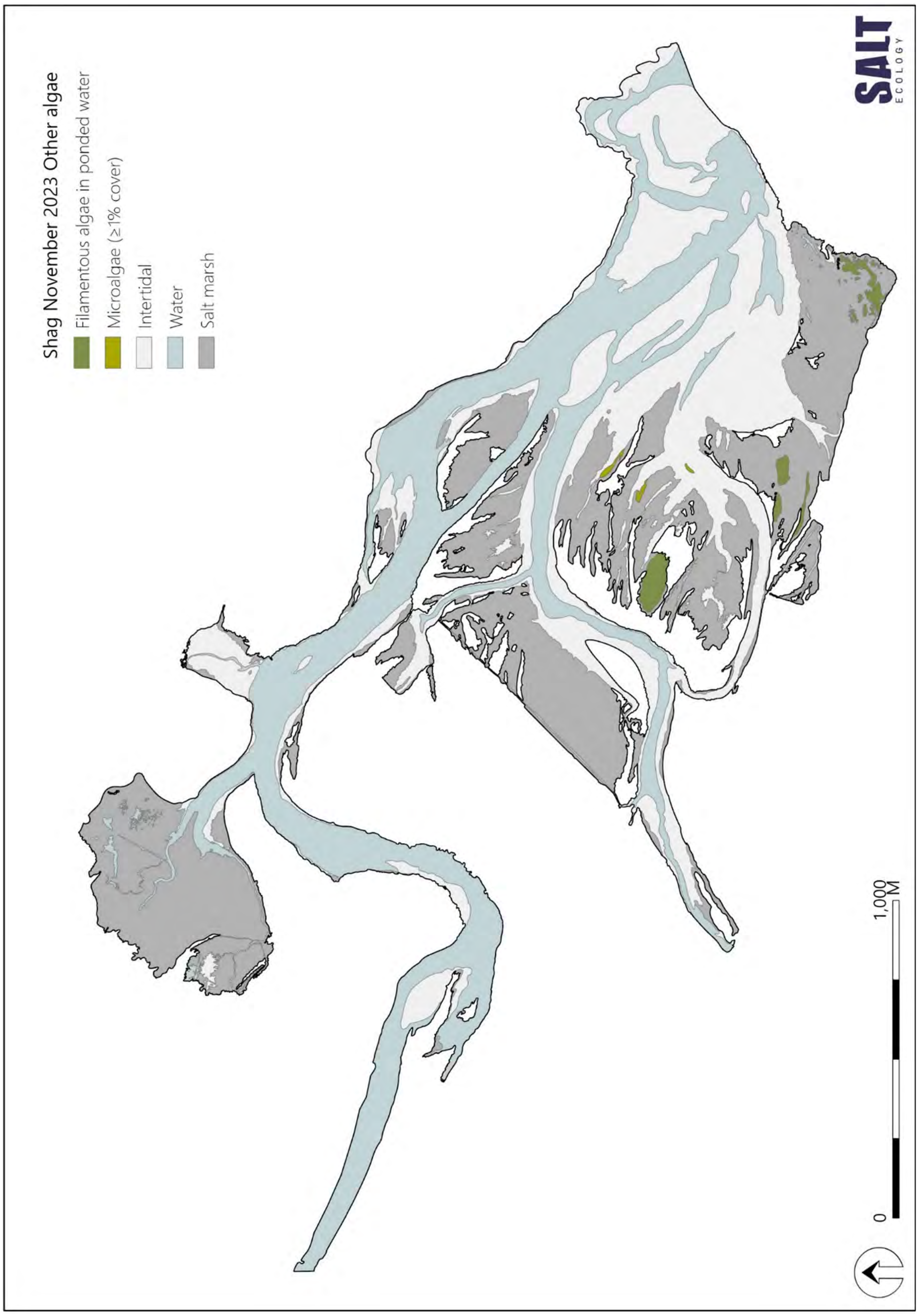


Fig. 10. Distribution of filamentous algae in water and microalgae, Shag Estuary, November 2023.

4.5.3 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., *Vaucheria* sp., and filamentous species) in areas of ≥50% mud and which are characterised by anoxic sediments with a strong sulfur smell and black colouration. However, the definition was broadened in the current report to include areas of blooming microalgal species where growth contributes to degradation of sediment oxygenation. HEC areas covered a total of ~2ha, ~5% of the AIH (Table 9; Fig. 11), comprising:

- 0.2ha of *Gracilaria* spp. entrained in sheltered mud-elevated (≥50% mud) channels;
- 0.8ha of filamentous green algae species; and
- 0.9ha of *Vaucheria* sp.
- Blooming microalgal species also contributed to sediment degradation over ~0.1ha in firm sandy muds (≥50-90% mud), often growing in mixed patches with *Vaucheria* sp.

While only small areas in the AIH were displaying HEC, a condition rating of 'good' (Table 9), this represents degradation of the estuary since 2016 when no areas of HEC were recorded (condition rating of 'very good').

Outside of the AIH, and hence excluded from the HEC metric, small areas within salt marsh habitat were smothered by filamentous algae (~1ha), and filamentous algae growth in pooled water (0.9ha).

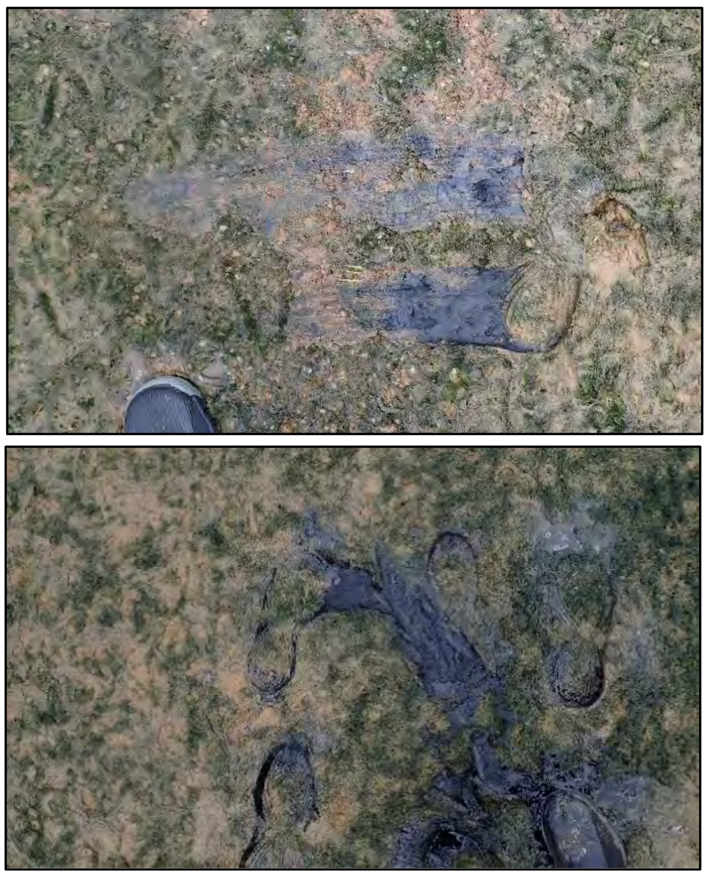
Table 9. Summary of High Enrichment Conditions (HEC) in available intertidal habitat (AIH).

Year	ha	% AIH
2016	0	0
2023	2	5.3

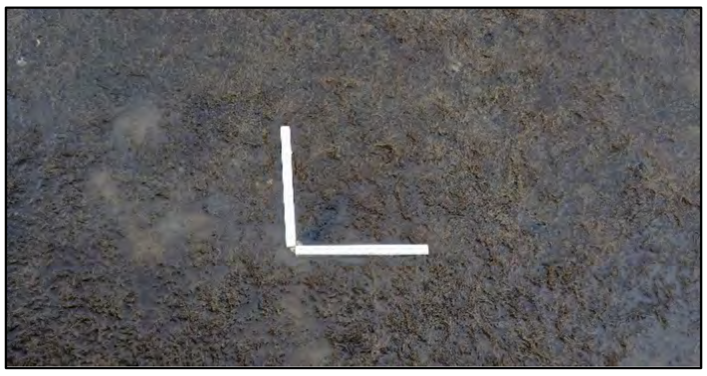
Condition rating key:

Very Good	Good	Fair	Poor

Complete cover of filamentous green algae with black anoxic sediment below.



Dense cover of mat-forming *Vaucheria* sp. with black anoxic sediment below.



Dense bed of *Gracilaria* sp. in the upper estuary

Microalgae over firm muddy sand with black anoxic sediment below.

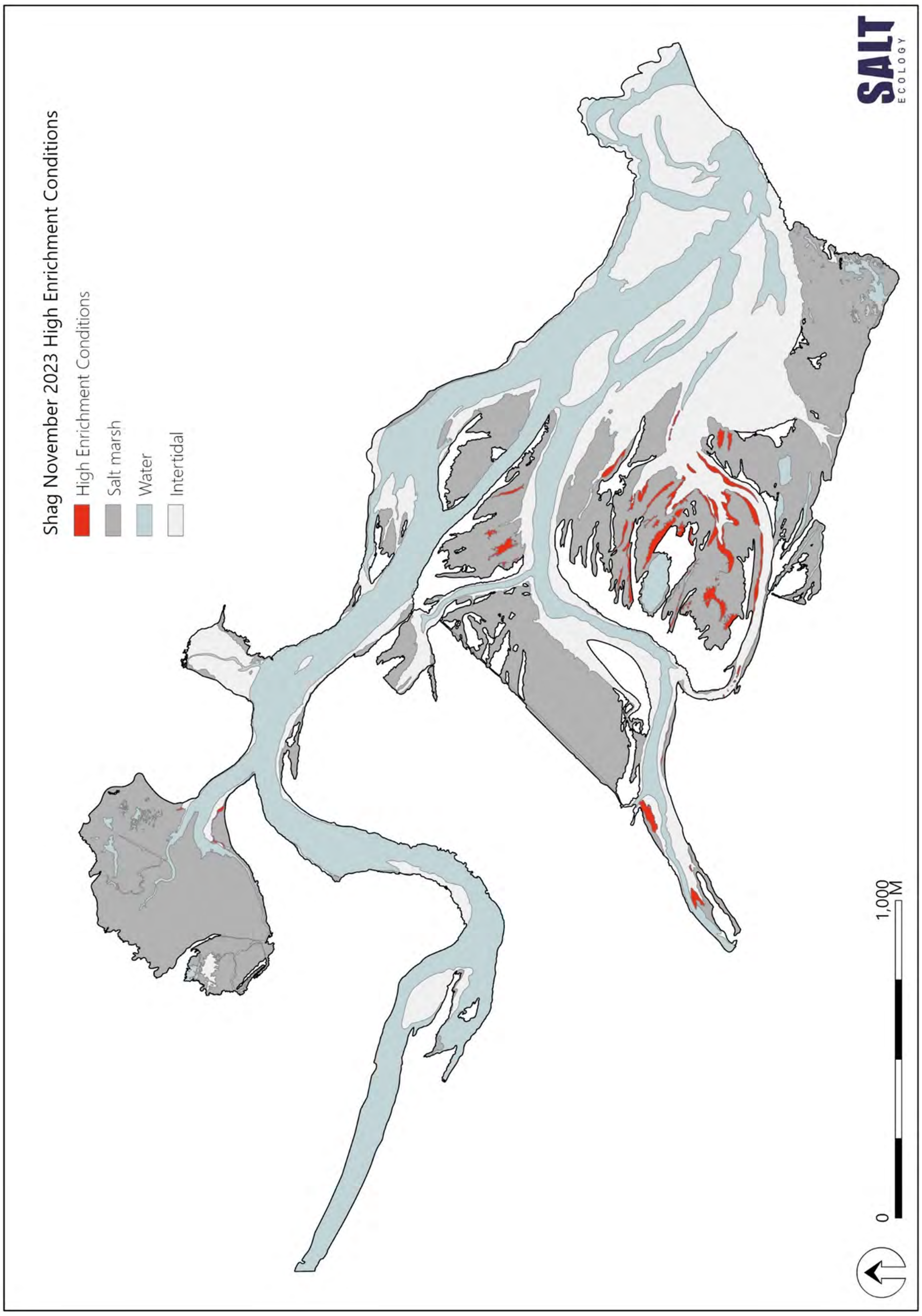


Fig. 11. Distribution of high enrichment conditions, Shag Estuary, November 2023.

5. SEDIMENT QUALITY AND BIOTA

Illustrative photos of Sites 1-8, where sediment quality and biota sampling were undertaken (see Fig. 4 for site locations), are provided on the next page. Sediment quality and biota sampling aimed to capture a broad range of representative habitat and substrate types, including upper-estuary sites strongly influenced by lower salinities and physical riverine processes. Upper estuary substrate grain size samples were also collected to inform substrate mapping validation as described in Appendix 1.

5.1 SEDIMENT QUALITY INDICATORS

Sediment sampling confirmed the general broad-scale mapping pattern of decreasing mud content moving toward the estuary entrance, with upper estuary sites (Sites 1, 2 & 8) having a higher mud content than lower estuary sites (Sites 6 & 7; Fig. 12). Strong riverine and tidal currents prevent fine sediment deposition, particularly near the channel edge and in the lower estuary toward the entrance (Sites 3, 6 & 7). Fine sediment deposition was evident on the main tidal flats where sediments comprised firm muddy sands (≥25-50% mud; Sites 4 & 5).

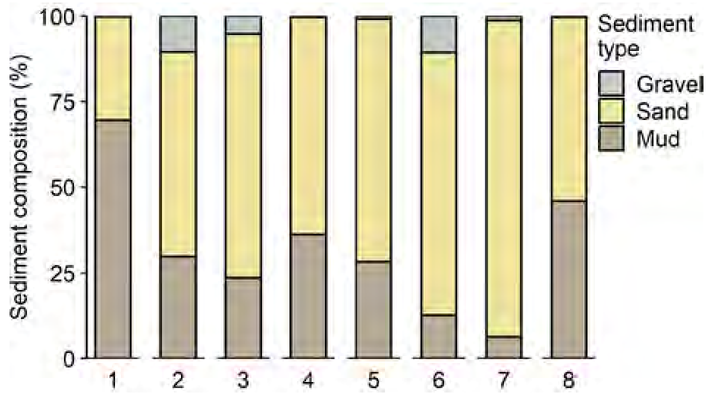


Fig. 12. Sediment grain size composition at sediment quality and biota sites. Size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

Key sediment quality indicators are presented relative to condition rating thresholds in Fig. 13. In summary:

- The mud contents of upper to mid estuary sites (1, 2, 4, 5 and 8) were >25% (range 28-70% mud), a condition rating of 'poor', and above ecological thresholds where significant biological changes due to elevated muddiness are expected. Sandier downstream sites (6 & 7) were rated 'very good'.
- There was a small decrease in both total nitrogen (TN) and total organic carbon (TOC) moving toward the estuary entrance. However, overall levels remained low and were rated 'good' or 'very good' indicating minimal enrichment. Total phosphorus (TP) showed a similar trend of decreasing values from the upper to lower estuary (690 to 320mg/kg, respectively; Appendix 4), however has no condition rating and thus is not included in Fig 13.
- In general, sediments were well-oxygenated (deep aRPD; see photos next page) and were rated 'good'. The exception was the muddiest site (Site 1), where a shallower aRPD was recorded, resulting in a condition rating of 'fair'. Overall, there were no signs of excessive sediment enrichment. This was further supported by very low levels of total sulphur (<0.1mg/kg) at all sites (Appendix 4).

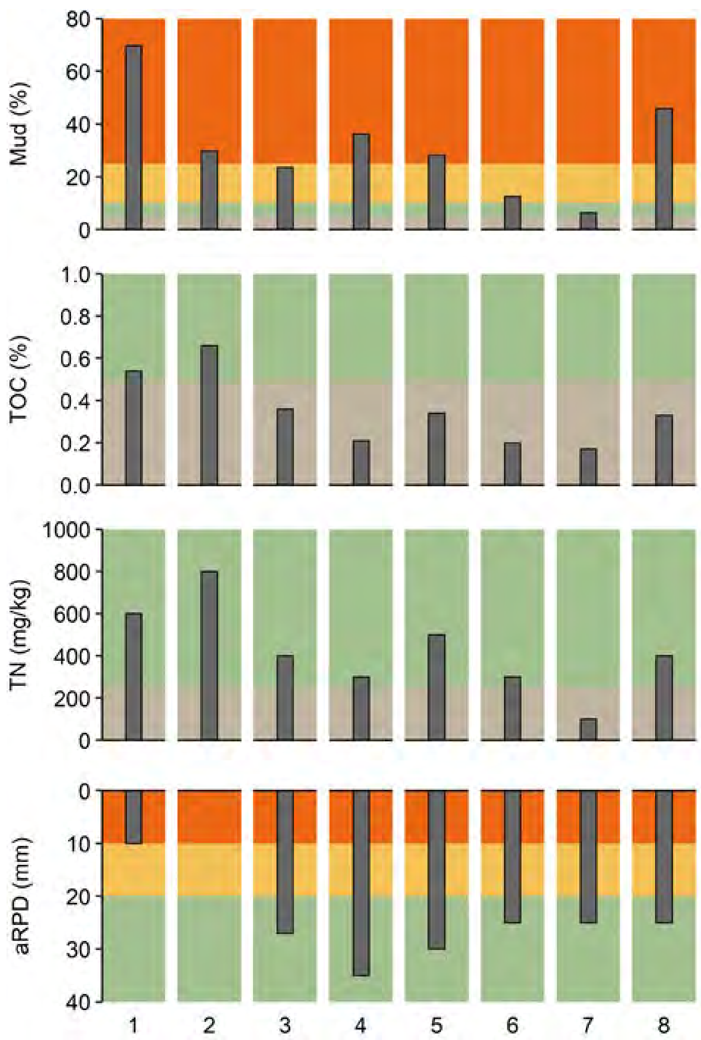


Fig. 13. Sediment %mud, total organic carbon (TOC), total nitrogen (TN) and aRPD at sediment quality and biota sites, relative to condition ratings.

TN at Site 7 was less than method detection limits (MDL), hence half of the MDL value is shown.

The aRPD was indeterminate at Site 2.

Condition rating key:

Very Good	Good	Fair	Poor

Photos of Sites 1-8 where sediment quality and biota sampling were undertaken (see Fig. 4 for site locations).

Trace metal concentrations were very low in all samples and rated 'very good', except for arsenic (Table 10). This rating represents metal concentrations that are less than half of ANZG (2018) Default Guideline Values (DGV). While arsenic was slightly elevated, it remained below DGV and was rated 'good' or 'very good'. These results are consistent with previous fine scale monitoring within the estuary and elevated arsenic levels likely reflect natural sources (Robertson et al. 2017; Blake et al. 2019; Forrest 2023).

Table 10. Trace metal concentrations (mg/kg) relative to ANZG (2018) Default Guideline Values (DGV).

Site	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
1	8.0	0.026	7.2	3.9	0.03	5.1	5.3	33.0
2	12.1	0.047	9.6	6.7	0.05	9.8	7.2	45.0
3	13.9	0.025	9.6	4.6	0.03	7.5	5.8	37.0
4	7.4	0.013	6.8	2.1	<0.02	3.6	3.7	23.0
5	10.6	0.022	9.6	3.8	0.03	5.9	5.4	33.0
6	9.8	0.021	8.5	3.1	0.02	5.8	4.2	28.0
7	10.1	0.017	6.1	2.0	<0.02	4.0	2.7	18.3
8	9.7	0.018	8.6	3.9	0.02	5.9	5.5	32.0
DGV	20	1.5	80	65	0.15	21	50	200

DGV indicates the concentrations below which there is a low risk of unacceptable effects occurring. Grey and green shading corresponds to a 'very good' (<0.5 x DGV) and a 'good' (0.5 x DGV to <DGV) condition rating respectively, as shown in Table 3.

5.2 BIOTA

At the sampling sites, minimal macroalgae or visible surface microalgae were noted. Sparse cover of *Vaucheria* sp. was observed adjacent to Site 1, and while Site 8 was bare it was in close proximity to a high biomass bed of *Gracilaria* sp.

Surface-dwelling epifauna were also sparse, with mud snails (*Amphibola crenata*) most abundant at Sites 1 & 8 (3-4/m^2), and occasional at Sites 3 & 4 (0.25-0.75/m^2). Cockles were observed at Sites 6 & 7 in the lower estuary.

Site 1 in the upper estuary had the highest mud content (70% mud) and highest abundance of mud snails *Amphibola crenata*.

By contrast, all sites had a suite of sediment-dwelling macrofauna in the core samples. A total of 32 species or higher taxa were recorded, representing 11 main organism groups (Appendix 8). Fig. 14 shows the average species richness per site was low-to-moderate, but organism abundances were generally high. Site 2, however, had very low relative abundance of *Paracorophium excavatum* (5 individuals) and very low abundances (1-2 individuals) of the other taxa present (nematoda, *Perinereis vallata*, and copepoda) across both replicate core samples. These differences, compared to other sites, may be attributed to extended tidal exposure, as this site was positioned 20cm higher on the tide relative to other upper estuary sites (see Appendix 6). Length of tidal inundation is a well-known driver of spatial variation in benthic communities (Edgar et al. 2002). Other factors potentially influencing this site include salinity, due to its close proximity to the river channel, or substrate composition of the core, which contained higher volumes of gravels deeper in the core than other samples (see photo previous page). Because Site 2 considerably deviates from the other sites, discussion of infauna community composition disregards this site.

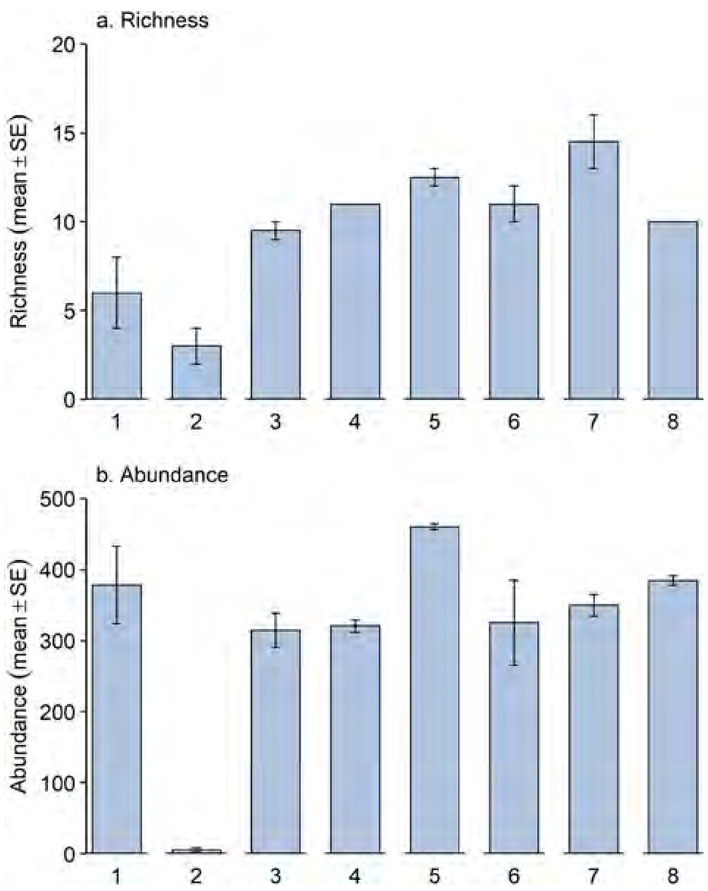


Fig. 14. Mean (±SE) taxon richness and abundance in duplicate core samples.

From a summary of the dominant macrofauna species in Table 11, high abundance at all sites was due to the dominance of the tube-building amphipod *P. excavatum*. This is a hardy species often found in river-dominated estuaries with low salinity water or subject to regular disturbance (e.g., mobile substrate). This was in line with previous fine scale monitoring carried out within the estuary (Robertson et al. 2017; Forrest 2023).

The tube-building amphipod *Paracorophium excavatum* drove much of the abundance captured within core samples (Photo courtesy of NIWA).

The polychaete *Paradoneis lyra* was most abundant in the lower estuary (Site 7) and moderately abundant on the mid estuary flats (Sites 4 & 5), with few specimens recorded at the upper estuary sites (Table 11). Several other polychaete species were ubiquitous across Sites 3-8 (mid-lower estuary) including *Capitella cf. capitata* and *Boccardia syrtis* and *Scolecolepides benhami*.

Core sampling found cockles (*Austrovenus stutchburyi*) were abundant in the lower well-flushed parts of the estuary (Sites 6 & 7) and present in low numbers on the mid estuary flats (Sites 4 & 5). *Macomona liliana* were present at Site 7 (lower estuary) only, while *Arthritica* sp.5 was absent from Site 7, but present at all other sites (excluding Site 2; Appendix 8).

Many of the dominant macrofauna species, described in Table 11, are either disturbance-tolerant or tolerant of low salinity conditions. As a result, most are in eco-groups (EG) III-V, representing a relatively hardy suite of species, and resulting in elevated AMBI scores (Fig. 15) that suggest 'fair' to 'poor' ecological conditions at all sites.

The comparatively low AMBI score at Site 7 (lower estuary) was driven by the relatively low number of *P. excavatum* (EG-IV) within the sample and relatively high numbers of *A. stutchburyi* and *B. syrtis*, both in EG-II. Additionally, the segmented worm Oligochaeta was absent from Site 7, yet ubiquitous at other sites and is generally considered pollution or disturbance tolerant (EG-IV).

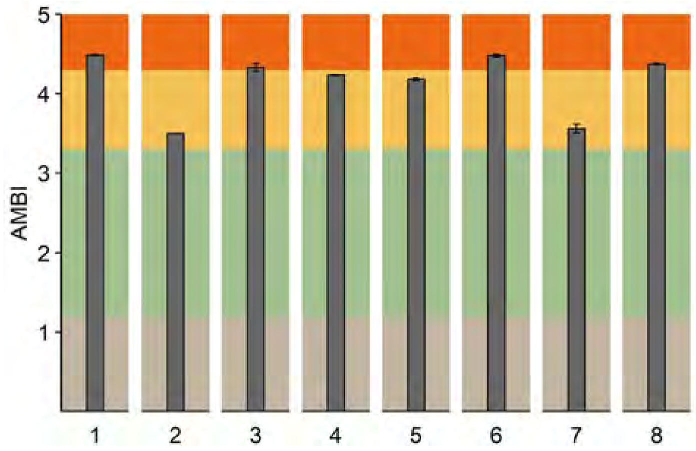


Fig. 15. Mean (±SE) macrofauna AMBI scores in duplicate cores at Site 1-8, relative to condition ratings.

Condition rating key:	Very Good	Good	Fair	Poor

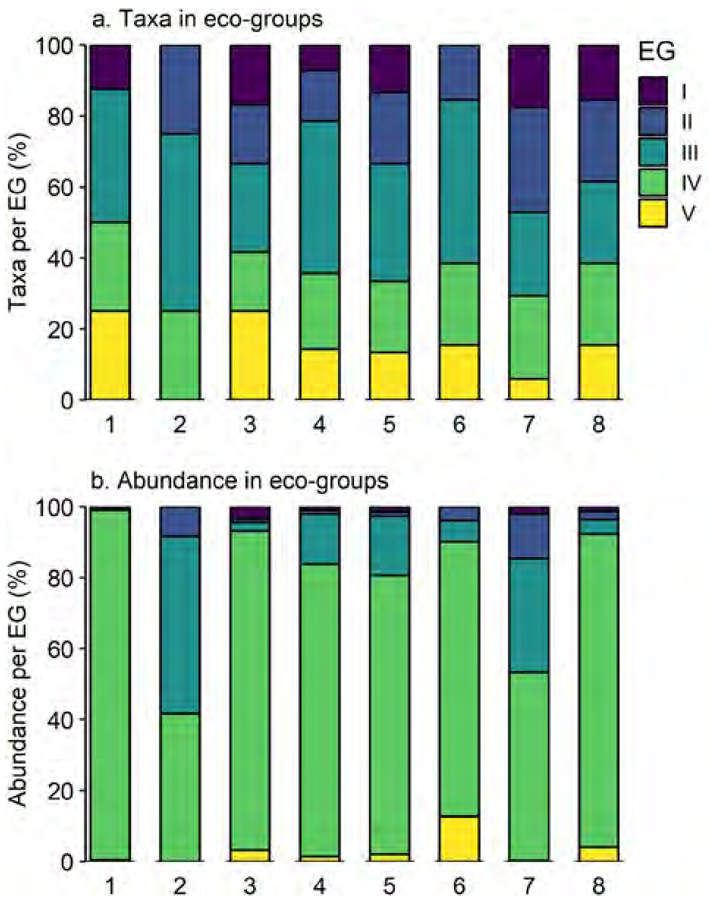


Fig. 16. Percentage of taxa within eco-groups ranging from sensitive (EG-I) to resilient (EG-V) at Site 1-8.

Polychaete visible in sediment core from lower estuary Site 7.

Table 11. Dominant macrofauna at the eight sites. Numbers are total abundances summed across duplicate cores.

Main group	Taxa	EG	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Description
Amphipoda	*Paracorophium excavatum*	IV	722	5	504	482	680	484	349	660	Corophioid amphipod that is an opportunistic tube-dweller, tolerant of muddy and low salinity conditions.
Polychaeta	*Scolecolepides benhami*	IV	24		62	44	36	18	16	17	A spionid, surface deposit feeder. It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark.
Nematoda	Nematoda	III		3	1	1	1	12			Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5mm mesh sieve. Generally reside in the upper 2.5cm of sediment. Intolerant of anoxic conditions.
Polychaeta	*Perinereis vallata*	III		3		3		21			An intertidal omnivorous nereid worm, associated with mud/sand sediments. Prey item for fish and birds. Considered sensitive to high sedimentation.
Amphipoda	*Paracalliope novizealandiae*	I	2		21	6	12		8	9	Amphipods are shrimp-like crustaceans. This species is common in New Zealand estuaries. It is considered to be indifferent to sedimentation and can tolerate muddy habitats to some extent.
Polychaeta	*Paradoneis lyra*	III			9	83	136	3	215	24	Common paraonid worm considered to be reasonably tolerant of muddy sediment and organic enrichment. Paraonids are considered to be deposit feeders, possibly selectively feeding on microscopic diatoms and protozoans.
Polychaeta	*Capitella cf. capitata*	V			18	3	13	68	2	7	Subsurface deposit feeder, occurs down to about 10 cm sediment depth. Common indicator of organic enrichment or other forms of disturbance. Is a dominant inhabitant of sediments polluted heavily with organic matter.
Bivalvia	*Austrovenus stutchburyi*	II				1	1	22	27		Cockles are suspension feeding bivalves, living near the sediment surface. They can improve sediment oxygenation, increasing nutrient fluxes and influencing the type of macrofauna present. Sensitive to organic enrichment. Important in diet of certain birds, rays and fish.
Polychaeta	*Boccardia syrtis*	II			5	6	10	4	54	15	A small surface deposit-feeding spionid. Found in a wide range of sand/mud habitats. Lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Sensitive to organic enrichment.
Oligochaeta	Oligochaeta	V	2		1	6	6	15		24	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered pollution or disturbance tolerant.

A multivariate analysis of macrofauna community composition is summarised in Fig. 17. Site 2 was excluded from multivariate analysis for the reasons described above.

Fig. 17 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. Community composition at Site 1 (upper estuary) and Site 7 (lower estuary) were the most different, reflecting both the presence of species not recorded at other sites, and the absence of certain species common at some or all of the other sites. The presence of *A. stutchburyi* and absence of *A. crenata* drive upper to lower (i.e., left-to-right in the Fig. 17 plot) estuary site differences, while the amphipod *P. excavatum* were highest at Site 1 and reduced down estuary. The vertical site separation (i.e., up-down in the Fig. 17 plot) was driven by relatively higher numbers of nematode worms and *Perinereis vallata* at Site 6, and low abundance and/or absence of these species at other sites.

Mud content was the sediment quality attribute which was most closely correlated with the changes in macrofauna community composition and most strongly explained the upper to lower estuary pattern of compositional change in the macrofauna. Total organic carbon (TOC) also contributed to this correlation, with sediment TOC highest at Site 1 (upper estuary) and lowest at Site 7 (lower estuary). Gravel was the only variable that had a reasonably strong association with the vertical site separation in Fig. 17, potentially reflecting the impact of substrate stability and homogeneity on abundance of disturbance tolerant species (i.e., Site 6), and may be related to higher riverine flow in this area which likely destabilises the substrate.

Other unmeasured factors are also likely to be important determinants of macrofauna composition differences, such as substrate stability and effects of wave action in the lower estuary, and the effects of pulses of low-salinity water during flood events, especially in the upper estuary.

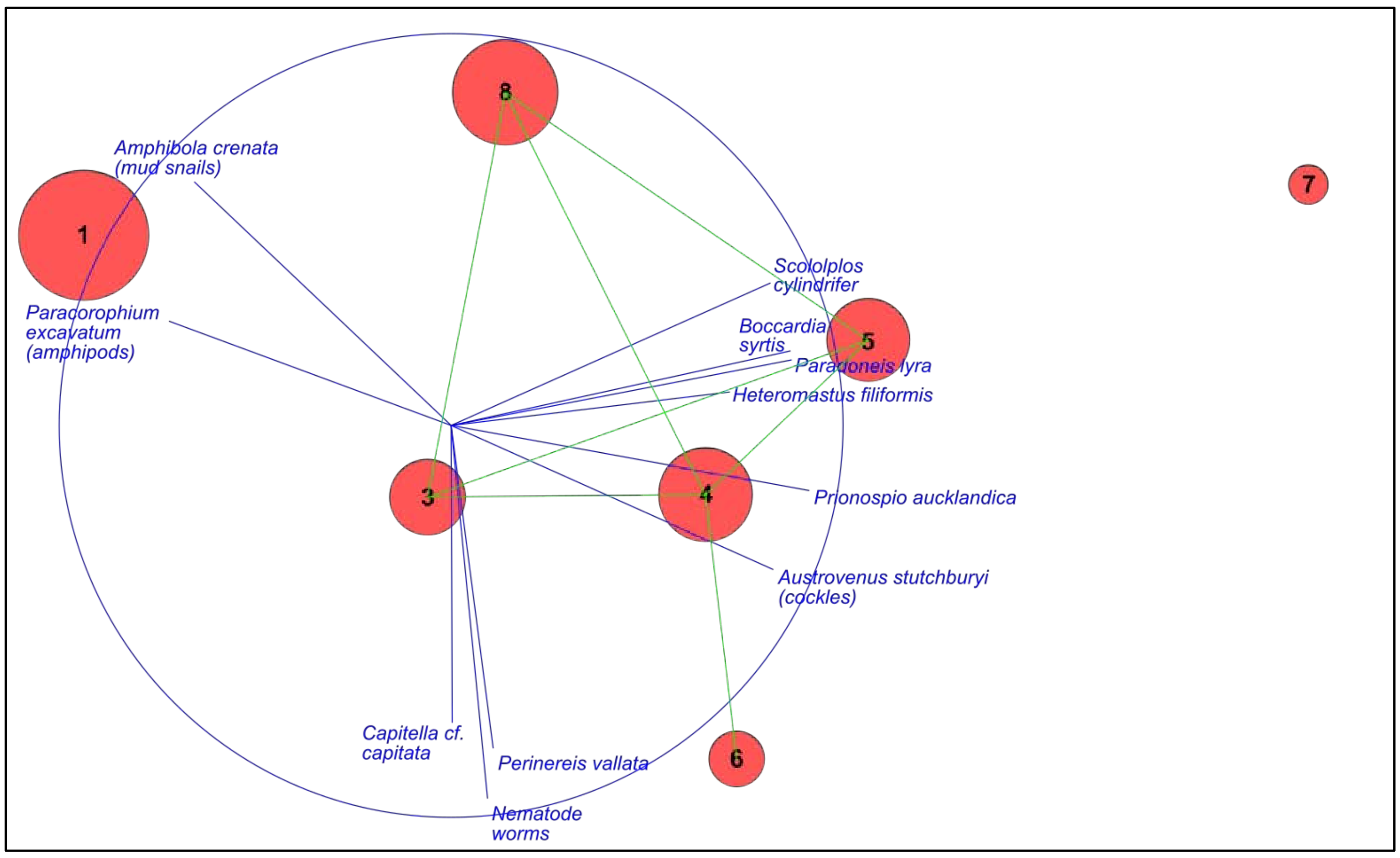


Fig. 17. Non-metric MDS ordination of macrofaunal core samples from each site.

Sites closer to each other are more similar than distant ones in terms of macrofauna composition. This plot has a 2D stress value of 0.02. A 'stress' value of zero indicates that a 2-dimensional plot provides a highly reliable representation of site differences. The blue vectors show the direction and strength of association (length of lines relative to circle) of grouping patterns for macrofauna species most correlated (>70%) with site differences. Green lines connect sites with a high similarity (70%) based on the Bray-Curtis measure. Red circles for each site are scaled to reflect sediment mud content, the variable most strongly correlated with macrofauna composition differences.

6. SYNTHESIS OF KEY FINDINGS

6.1 OVERVIEW

Summaries of key broad scale features and results relative to broad scale and fine scale condition ratings are provided in Tables 12, 13, and 14. Additional supporting indicators used to assess and interpret estuary condition were derived from catchment-scale nutrient and sediment models (e.g., CLUES; Hicks et al. 2019) and are presented in Table 15. The 2023 results indicate Shag Estuary is experiencing degradation as a consequence of catchment inputs of fine sediment and, to a lesser extent, nutrients.

Mud-elevated substrates in the upper estuary.

Opportunistic macroalgae growing in mud-elevated sediment.

Filamentous green algae growing in ponded water within salt marsh.

Table 13. Summary of key broad scale features as a percentage of total estuary, intertidal, available intertidal habitat (AIH) or margin area, Shag Estuary, November 2023.

a. Area summary	ha	% Estuary
Intertidal Area	82.9	66.7
Subtidal Area	41.3	33.3
Estuary Area	124.2	100.0
AIH Area	37.9	30.5
b. Key substrate features	**ha**	**% AIH**
Mud-enriched (25 to <50% mud)	5.6	14.8
Mud-dominated (≥50% mud)	10.1	26.6
c. Key habitat features	**ha**	**% Intertidal**
Salt marsh	45.0	54.3
		% AIH
Seagrass (≥50% cover)	0.0	0.0
Macroalgae (≥50% cover)	3.0	8.0
Microalgae (1-100% cover)	0.1	0.3
High Enrichment Conditions	2	5.3
d. Terrestrial margin (200m)	**ha**	**% Margin**
200m densely vegetated margin	76.2	33.8

Table 12. Summary of broad scale indicator condition ratings for Shag Estuary, 2023.

Broad Scale Indicators	Unit	2016	2023	2023 Rating
200m terrestrial margin	% densely vegetated	26.1	33.8	Fair
Mud-elevated substrate	% AIH[1] area (≥25% mud)	19.4	41.4	Poor
Macroalgae (OMBT-EQR[2])	Ecological Quality Rating (EQR)	0.982	0.665	Good
Seagrass	% decrease from baseline	No seagrass present		
Salt marsh extent (current)	% of intertidal area	49.4	54.3	Very good
Historical salt marsh extent[3]	% of historical remaining	61.6	62.4	Good
High Enrichment Conditions	ha	0.0	2.0	Good
High Enrichment Conditions	% of estuary	0.0	5.3	Fair
Estuary wide indicators				
Sedimentation rate	CSR:NSR[4] ratio	Na	1.7	Good
Sedimentation rate	mm/yr	Na	13.6	Poor

[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 from historic aerial imagery; [4]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling). na = not applicable. See Table 3 for colour bands and definitions.

Table 14. Summary of fine scale indicator condition ratings for sediment quality and macrofauna AMBI.

Fine Scale Indicators	Unit	Site 1	2	3	4	5	6	7	8
Mud	%	69.7	29.8	23.6	36.2	28.3	12.7	6.4	45.9
aRPD	mm	10	-	27	35	30	25	25	25
TN	mg/kg	600	800	400	300	500	300	< 200	400
TP	mg/kg	540	510	620	520	550	550	390	520
TOC	%	0.54	0.66	0.36	0.21	0.34	0.20	0.17	0.33
TS		0.07	0.08	0.04	0.03	0.03	0.03	0.03	0.04
As	mg/kg	8.0	12.1	13.9	7.4	10.6	9.8	10.1	9.7
Cd	mg/kg	0.03	0.05	0.03	0.01	0.02	0.02	0.02	0.02
Cr	mg/kg	7.2	9.6	9.6	6.8	9.6	8.5	6.1	8.6
Cu	mg/kg	3.9	6.7	4.6	2.1	3.8	3.1	2.0	3.9
Hg	mg/kg	0.03	0.05	0.03	<0.02	0.03	0.02	<0.02	0.02
Ni	mg/kg	5.1	9.8	7.5	3.6	5.9	5.8	4.0	5.9
Pb	mg/kg	5.3	7.2	5.8	3.7	5.4	4.2	2.7	5.5
Zn	mg/kg	33	45	37	23	33	28	18.3	32
AMBI	na	4.5	3.5	4.3	4.2	4.2	4.5	3.6	4.4

See Glossary for abbreviations. < Values below lab detection limit. See Table 3 for colour bands and definitions.

Table 15. Supporting data to assess estuary ecological condition in Shag Estuary, November 2023.

Supporting Condition Measure	Shag
Mean freshwater flow (m^3/s)[1]	4.1
Catchment Area (Ha)[1]	54,115
Catchment nitrogen load (TN-t/yr)[2]	107.3
Catchment phosphorus load (TP-t/yr)[2]	15.1
Catchment sediment load (KT/yr)[1]	33.5
Estimated N areal load in estuary ($mg/m^2/d$)[2]	236.7
Estimated P areal load in estuary ($mg/m^2/d$)[2]	33.4
CSR:NSR ratio[1]	1.7
Trap efficiency (sediment retained in estuary)[1]	76%
Estimated rate of sedimentation (mm/yr)[1]	13.6

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

6.2 VULNERABILITY TO MUDDY SEDIMENTS

In 2023, mud-elevated (≥25-100% mud) sediments continue to be the most significant pressure on estuary health in the Shag. Key results that support this conclusion are:

- Mud-elevated (≥25-100% mud) sediments covered 15.6ha (41% of the AIH), a condition rating of 'poor' and had expanded ~7ha between 2016 and 2023. The most significant area of increase occurred east of the secondary channel and on the seaward edge of salt marsh in the mid to lower estuary, an area that is relatively sheltered with low flows promoting settling of fine particles.
- Sites with mud-elevated sediments in the upper and mid estuary (Sites 1, 4, 5 & 8) were characterised by a macrofaunal community of hardy taxa that are resilient to elevated mud and most forms of disturbance. Accordingly, the macrofauna AMBI scores were rated 'fair' to 'poor' (Table 14).
- Sediment plate monitoring undertaken in parallel and reported on separately (Rabel 2024) highlighted a trend of fine sediment deposition at Sites 3 and 5 in the mid estuary. Sedimentation rates were 1.1 and 2.6mm/y (7-year trend), respectively, with deposition at Site 5 above the Townsend and Lohrer (2015) guideline value of 2mm/yr.
- Erosion was common on channel banks and margins of salt marsh habitat. In addition, there have been significant historic losses of salt marsh (~38% loss). The effect on muddiness is twofold, as losses reduce the capacity of the estuary to trap sediments, and erosion contributes to the release of previously trapped sediment.
- A high proportion of the catchment and margin is in land uses known to generate high sediment loads such as farming (70% of catchment area is pasture) and exotic forestry (10% of catchment area). Plantation forestry on the estuary margin (~20%) also presents a potential future sediment source directly to the estuary during harvest.

Mud-elevated sediments are likely attributable to a combination of historic land clearance, contemporary inputs from pasture and plantation forestry, and reduced trapping efficiency through the reduction of salt marsh through land conversion to pasture and drainage. Catchment modelling predicts a Current to Natural Sedimentation Rate (CSR:NSR) ratio of 1.7, a condition rating of 'good' (Table 15; Hicks et al. 2019). However, present-day loads are likely underestimated by Hicks et al. (2019) because land cover was based on LCDB3 (2008), the modelling does not account for variable intensification of land uses (e.g., intensive dairying or winter grazing), and erosion susceptibility is considered independently from land use (Hicks et al. 2019). More contemporary and refined estimates are needed to assess true sediment loads to the estuary.

Hicks et al. (2019) estimates estuary sediment retention to be 76% and the mean annual estuary-wide sedimentation rate to be 13.6mm/yr (Table 15), which is well above the 2mm/yr Townsend and Lohrer (2015) guideline value for New Zealand estuaries. However a recent study by Plew (2020) highlighted limitations of this approach whereby an overestimation of trapping efficiency is likely if net erosion from the estuary and other known processes that influence deposition are not accounted for. As such the modelled sedimentation rate should be used as a guide in conjunction with other sediment indicators such as in-situ sediment plate monitoring, which indicates mean annual fine-sediment deposition at monitored sites on the main estuary flats is ~1-2mm/yr.

ORC undertake water quality monitoring in the Shag River and results indicate improving trends for turbidity and clarity. These parameters rank in the best 25% of sites nationally (lawa.org.co.nz). While this is positive, high flow events are excluded from monitoring, and are when sediment is most likely mobilised down the catchment (Olsen 2014). This is supported by other New Zealand studies that have identified sediment deposition is most significant in estuaries during high rainfall and subsequent to high flow events (e.g., McKergow et al. 2010; Stevens et al. 2022)

The current extent of muddy sediments shows the estuary is vulnerable to catchment derived fine sediment inputs. Any increases in sediment loads, or further loss of salt marsh habitat, will likely result in expansion of mud-elevated sediments which are likely to have negative consequences for the overall health of the estuary. It will be particularly important to manage activities known to contribute elevated sediment losses from the catchment (i.e., intensive grazing, exotic forest harvesting, etc.). If sediment loads are likely to increase in future, enhancement of marginal habitat (e.g., salt marsh restoration; Section 6.4) and riparian planting should be considered to minimise or offset potential impacts on the estuary.

Erosion of salt marsh margins contributes an additional source of sediment to the estuary.

6.3 VULNERABILITY TO NUTRIENT ENRICHMENT AND EUTROPHICATION

In 2023, symptoms of eutrophication were limited in extent, with eutrophic indicators (i.e., macroalgae, HEC, aRPD, TN, TP, and TS) largely all rated 'good' to 'very good'. While these symptoms remain localised and are a minor feature, there has been an increase in areas of macroalgae and small patches of extreme enrichment (i.e., HEC) since 2016 (Table 13).

The current modelled nitrogen (N) areal load for Shag is 237mg/m^2/d (Table 15), which is above the ~100mgTN/m^2/d threshold at which nuisance macroalgae problems are predicted to occur in intertidally-dominated estuaries (Robertson et al. 2017).

Plew & Dudley (2018) assessed the eutrophication susceptibility of Shag using the principles in ETI Tool 1 (Robertson et al. 2016b). They estimated a lower areal load (145mgTN/m^2/d) and assessed Shag as having moderate physical susceptibility (i.e., high flushing potential, low dilution potential) to nutrient problems and, when combined with high present-day nutrient loads (i.e., high N-load susceptibility), it was considered to have a high combined physical and nutrient load susceptibility. These modelling results indicate that we would expect eutrophic symptoms such as macroalgal blooms to be occurring in Shag. However, while the OMBT score (Table 14) has shifted from 'very good' to 'good' since 2016, the extent of opportunistic macroalgae remains low.

In contrast to modelled nutrient loads, water quality monitoring in the Shag (Waihemo) River, the main freshwater input, indicates total nitrogen and total phosphorus concentrations are in the best 50% and 25%, respectively, when compared to sites nationally (lawa.org.co.nz). This provides a possible explanation for the lack of macroalgae growth predicted by modelled values, but could also reflect limited sampling during episodic flood events which may deliver large proportions of the predicted nutrient load. In addition, the estuary's high flushing potential, indicated by a freshwater inflow to estuary volume ratio of 0.16, resembles that of a river-dominated system (e.g., short residence time tidal river estuary). Further to this, the channelised hydrodynamics of the estuary (i.e., the main channel bypasses north of the main tidal flats) suggest nutrients coming into the estuary could be rapidly washed out to sea on the outgoing tide. The physical aspects of the estuary may therefore further minimise the impact of nutrients.

The hydrodynamics of the estuary are likely to also limit phytoplankton growth. Estuaries with a flushing time of ~4 days or less have a low susceptibility to phytoplankton growth in response to increasing concentrations of nitrogen (Plew et al. 2020). Modelling indicating Shag has an estimated flushing time of ~1.9 days. which is therefore considered too short to support regular phytoplankton growth. However, it is noted that one-off water column measurements collected in December 2016 (Robertson et al. 2017) identified phytoplankton blooms in deeper bottom waters of the main river channel. This indicates that stratification of the water column may, at times, result in phytoplankton blooms in parts of the estuary.

Another factor that may explain the lack of widespread eutrophic symptoms is the extensive areas of salt marsh habitat (~54% intertidal area). Salt marsh is an important feature of estuaries because, in addition to providing habitat for birds and insects, it traps sediments and assimilates nutrients. Studies have shown that salt marsh can use and store nutrients in their above and below ground biomass, potentially mitigating the effects of increased nutrient loads to the estuary (Vernberg 1993; Sousa et al. 2010). This emphasises the importance of salt marsh habitat in regulating estuary condition. Given significant historic losses (~38%) salt marsh, prioritising salt marsh protection and enhancement is essential, especially with the imminent threat of further losses with sea level rise (SLR).

While eutrophic symptoms were not widespread, there has been a small decline in estuary health since 2016 with an increase in opportunistic macroalgae and areas of HEC in 2023. Macroalgae species included *Gracilaria* spp., *Ulva* spp., filamentous green algae, and the less common species *Vaucheria*. *Vaucheria* sp. has been observed in other Otago estuaries (i.e., Pleasant River; Roberts et al. 2022a). Similar to *Gracilaria* spp., extensive mats of *Vaucheria* sp. are associated with enriched, anoxic, and sulfidic sediments (e.g., Simons 1974; Reise et al. 2022). A high cover of filamentous algae was also observed growing in several small shallow ponds within the herbfield. Additionally, localised areas of the herbfield were being smothered by filamentous green algae (see photos).

While these areas of algal growth were not widespread, the high combined physical and nutrient load susceptibility (Plew et al. 2018) combined with an increase in localised patches of eutrophic symptoms, and potential episodic phytoplankton blooms, suggest that Shag may be at risk of further nutrient-driven degradation. Although a specific tipping point beyond which rapid and difficult to reverse change is uncertain, maintaining or reducing current catchment nutrient inputs is recommended to ensure that the health of the estuary is maintained and/or improved.

Vaucheria sp. growing on the tidal flats adjacent to salt marsh.

Filamentous green growing in shallow ponds.

Filamentous green algae smothering salt marsh habitat.

6.4 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 Shag, 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

The 2023 results show that Shag is expressing ongoing problems from catchment derived sediments, and to a lesser extent nutrients. As discussed in Section 6.2, a large percentage (80%) of the Shag catchment is in land uses (e.g., pasture, plantation forestry) known to generate high rates of sediment and nutrient run-off to waterways. Without management actions to reduce loads, further expansion of mud-elevated sediments can be expected, alongside an increase in eutrophic symptoms (e.g., nuisance macroalgal blooms, sediment degradation). These issues will be exacerbated by any further losses of salt marsh habitat.

It has been estimated that 44% of the soil that enters New Zealand rivers is from pasture, and these sediments are deposited in estuaries or the marine environment (MfE 2019). Plantation forestry is also recognised as a significant source of sediment with disproportionately high sediment loss during harvest and in the post-harvest period before replanted forest reaches a closed canopy state (e.g., Gibbs et al. 2019). Lags in sediment inputs post-harvest are also likely as disturbed sediment can continue to be mobilised and flushed through the catchment in ongoing pulses. In a management context it would be prudent to assess erosion susceptibility in the Shag catchment and consider this when consenting land use activities (e.g., conversion of pasture to plantation forestry, increasing stock numbers or forest harvesting). Further, non-regulatory options could be considered such as larger grazing buffer zones on river margins and riparian planting, examples of which are already occurring within the catchment (e.g., the Halo Project)

Salt marsh protection and enhancement also presents an opportunity to increase the natural ability of the estuary to assimilate catchment derived sediments and nutrients, in addition to other benefits such as enhanced biodiversity, erosion control, carbon sequestration, flood and storm surge buffering, and cultural and recreational services.

Simple management practices, such as stock exclusion and weed control, are cost-effective measures that can improve salt marsh condition. Identifying and removing barriers, such as tidal flap gates, to allow tidal flushing in low-lying areas susceptible to tidal inundation in response to sea level rise (SLR), will facilitate the migration of estuarine species and allow for future salt marsh expansion while restoring connectivity between land and estuary. Salt marsh expansion would be most effective in areas of historic salt marsh loss where saline species persist within low-lying land identified through SLR inundation modelling (Stevens 2023).

Given the current state of Shag, and the above factors, it is recommended ORC consider targeted management of sediment and, to a lesser extent, nutrient sources in the catchment via both regulatory (e.g. ORC objective setting process) and non-regulatory pathways (e.g., riparian planting and salt marsh restoration).

Salt marsh herbfield margin with dried mat forming *Vaucheria* sp. over intertidal substrate.

Flap gate preventing tidal inundation into low lying paddock on the estuary margin containing salt tolerant species.

7. RECOMMENDATIONS

Based on the 2023 survey, it is recommended ORC consider the following recommendations:

Monitoring

- Undertake broad scale monitoring ~5-yearly 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.
- When undertaking annual sediment plate monitoring (see Rabel 2024), keep a watching brief on areas of macroalgae and HEC. If expansion is observed undertake targeted nuisance macroalgae monitoring to facilitate timely management actions and track long-term changes.
- Utilise estuary monitoring data to review the SOE programme and assess monitoring needs in Shag alongside priorities for other estuaries regionally.

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.
- Characterise 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 (e.g., Plew & Dudley 2018).
- 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., stock exclusion and weed control within salt marsh, replanting salt marsh, improving tidal flushing, re-contouring shorelines, removing barriers to salt marsh expansion) that builds on previous work by Stevens (2023).

Restoration planting bordering the salt marsh on the northern margin of the estuary.

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.

Blake F, Grant K, MacKenzie D, Scott J, Craw D 2019. Surficial arsenic redistribution above gold-mineralised zones in East Otago, New Zealand. New Zealand Journal of Geology and Geophysics 62(4): 573-587.

Edgar GJ, Barrett NS 2002. Benthic macrofauna in Tasmanian estuaries: scales of distribution and relationships with environmental variables. Journal of Experimental Marine Biology and Ecology 270(1): 24.

Forrest BM 2023. Shag Estuary Intertidal Fine-Scale Monitoring Data Summary. Salt Ecology Report 129, prepared for Otago Regional Council, November 2023. 11p.

Gibbs M, Swales A 2019. Historical sediment source apportionment in the Waimea Estuary: Continuation of the Waimea and Moutere River study. Prepared for TDC by NIWA. Report number: 2002012HN. 44p.

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.

McKergow LA, Pritchard M, Elliott AH, Duncan MJ, Senior AK 2010. Storm fine sediment flux from catchment to estuary, Waitetuna-Raglan Harbour, New Zealand. New Zealand Journal of Marine and Freshwater Research, 44 (1), 53–76. https://doi.org/10.1080/00288331003721471.

Ministry for the Environment & Stats NZ 2019. New Zealand's Environmental Reporting Series: Environment Aotearoa 2019.

Olsen D 2014. Shag River/Waihemo catchment: water quality and ecosystem. 76p.

Otago Regional Council 2004. Otago Regional Council (2004)Regional Plan: Water for Otago.

Otago Regional Council 2010. Otago estuaries state of environment report 2010.

Plew D 2020. Models for evaluating impacts of nutrient and sediment loads to Southland Estuaries. NIWA Client Report 2020216CH. Prepared for Environment Southland. 57p.

Plew D, Dudley B 2018. Eutrophication susceptibility assessment of Pounawea (Catlins) Estuary and Shag River Estuary. NIWA client report No: 2018133CH prepared for Otago Regional Council. 32p.

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.

Rabel H 2024. Shag Estuary: 2023/2024 Intertidal Sediment Monitoring Summary. Salt Ecology Short Report 044 prepared for Otago Regional Council, May 2024. 2p.

Reise K, Michaelis M, Rybalka N 2022. Invading grass-like alga transforms rippled sand bars into bumpy muddy flats: arrival of a game changer in the Wadden Sea? Aquatic Invasions 17(1): 120.

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 L, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016a. NZ Estuary Trophic Index Screening Tool 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, Robertson BP, Stevens LM 2017. Shag Estuary: Fine Scale Monitoring 2016/17. Prepared for Otago Regional Council. 31p.

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

Simons J 1974. Vaucheria compacta: A euryhaline estuarine algal species. Acta Botanica Neerlandica 23(5-6): 613 – 626.

Sousa AI, Lillebo AI, Pardal MA, Cacador I 2010. Productivity and nutrient cycling in salt marshes: Contribution to ecosystem health. Estuarine, Coastal and Shelf Science. 87(4): 640-646.

Stevens LM 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. Shag Estuary: Broad Scale Habitat Mapping 2016/17. Report prepared by Wriggle Coastal Management for Otago Regional Council. 26p.

Stevens LM, Roberts KL 2022a. Synoptic Assessment of August 2022 Sediment Flood Deposition in Wakapuaka/Delaware Inlet and Paruparuroa/Nelson Haven. Salt Ecology Report 103, prepared for Nelson City Council, October 2022. 14p.

Stevens LM, Forrest BM, Dudley BD, Plew DR, Zeldis JR, Shankar U, Haddadchi A, Roberts KL 2022b. 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 2007. Mapping of the Waikouaiti and Shag River Estuaries: Otago Regional Council State of the Environment Report. Prepared for the ORC by Ryder Consulting Ltd. 55p.

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

Vernberg FJ 1993. Salt-marsh processes: a review. Environmental Toxicology and Chemistry: An International Journal 12(12): 2167-2195.

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 1. SAMPLING METHODS, SHAG ESTUARY, NOVEMBER 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 (0-10%), firm shell/sand (0-10%), firm sand (0-10%).
Bottom row (L to R); firm muddy sand (≥10-25%), soft muddy sand (≥25-50%), very soft sandy mud (≥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:

- Forest (woody plants >10 cm density at breast height - dbh) and scrub (woody plants <10cm dbh) are considered terrestrial and mapped using LCDB codes as outlined in Table A1.
- Introduced weeds: Weeds are a common margin feature occasionally extending into upper intertidal areas and have been added to broad salt marsh structural classes.
- Estuarine shrubland: 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 in ArcMap (currently v10.8) 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

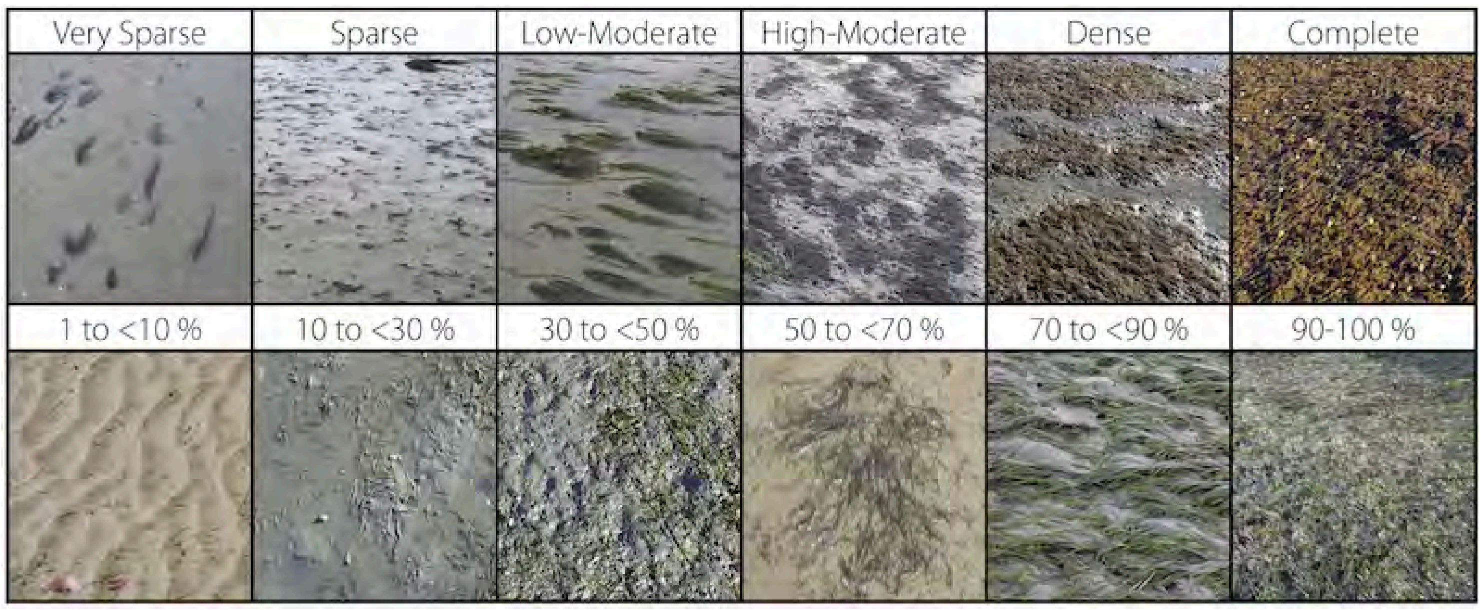


Fig. A1. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

broad scale surveys, historic imagery, supported by anecdotal reports of seagrass presence, can be georeferenced in ArcMap (v10.8) 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 ArcMAP (v10.8) 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 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 ArcMap (v10.8) 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 ArcMap, 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 ArcMap 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 RJ Hill Laboratories 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.

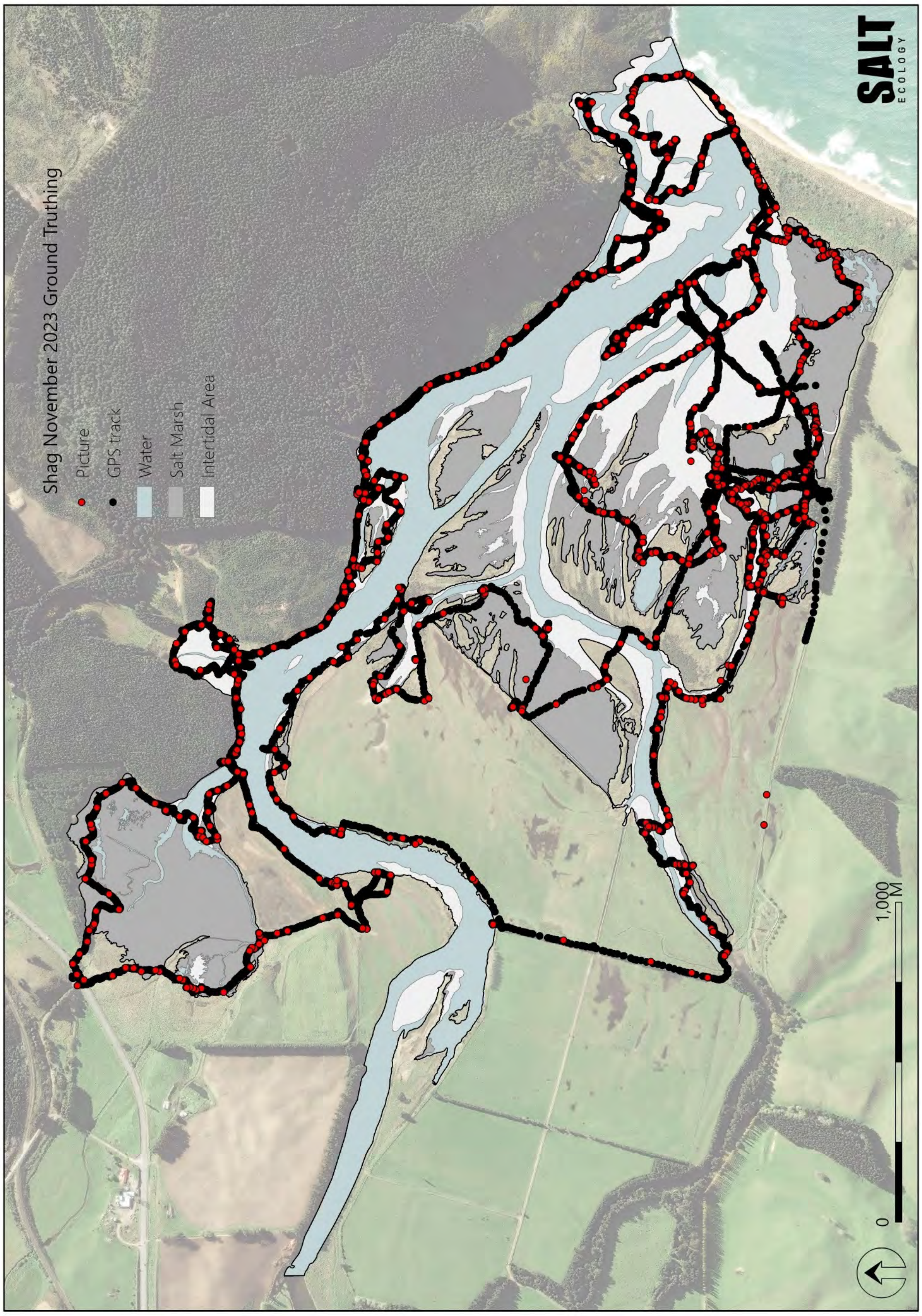
Stevens LM, Robertson BM 2014. Havelock Estuary 2014: Broad scale habitat mapping. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

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

SubClass	Dominant Species	Sub-dominant species	Sub-dominant species 2	Area (ha)	% Salt marsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)			0.1	0.2
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)		0.1	0.1
Tussockland	*Puccinella stricta* (Salt grass)			0.03	0.06
Tussockland	*Puccinella stricta* (Salt grass)	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	0.03	0.08
Tussockland	*Stipa stipoides*			0.01	0.02
Rushland	*Apodasmia similis* (Jointed wirerush)			0.1	0.1
Rushland	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		1.0	2.2
Herbfield	*Cotula coronopifolia* (Bachelor's button)			0.2	0.5
Herbfield	*Cotula coronopifolia* (Bachelor's button)	*Thyridia repens* (New Zealand musk)		0.1	0.1
Herbfield	*Leptinella dioica*			0.1	0.1
Herbfield	*Samolus repens* (Primrose)	*Leptinella dioica*	*Sarcocornia quinqueflora* (Glasswort)	0.003	0.007
Herbfield	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)		0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)			1.7	3.7
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Apium prostratum* (Native celery)	*Suaeda novaezelandiae* (Sea blite)	0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Atriplex prostrata (Orache)*		0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)		1.3	3.0
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)	*Puccinella stricta* (Salt grass)	0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Leptinella dioica*	*Atriplex prostrata (Orache)*	0.02	0.05
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Leptinella dioica*	*Selliera radicans* (Remuremu)	0.4	0.9
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)		0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Cotula coronopifolia* (Bachelor's button)	0.02	0.04
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Selliera radicans* (Remuremu)	0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)		0.4	0.9
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Apium prostratum* (Native celery)	0.2	0.5
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	0.6	1.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	0.3	0.6
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)		11.9	26.5
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Atriplex prostrata (Orache)*	8.1	17.9
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	0.9	2.0
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Leptinella dioica*	0.1	0.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	1.2	2.6
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	2.3	5.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Stipa stipoides*	0.1	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Suaeda novaezelandiae* (Sea blite)	8.5	18.8
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Thyridia repens* (New Zealand musk)	1.6	3.6
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Cotula coronopifolia* (Bachelor's button)	0.1	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Puccinella stricta* (Salt grass)	0.04	0.10
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Samolus repens* (Primrose)	0.4	0.9
Herbfield	*Selliera radicans* (Remuremu)			0.7	1.6
Herbfield	*Selliera radicans* (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	*Sarcocornia quinqueflora* (Glasswort)	0.1	0.2
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)		0.4	0.9
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Atriplex prostrata (Orache)*	0.2	0.4
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Festuca arundinacea* (Tall fescue)	0.1	0.2
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	1.1	2.4
Herbfield	*Selliera radicans* (Remuremu)	*Schoenoplectus pungens* (Three square)	*Thyridia repens* (New Zealand musk)	0.03	0.06
Herbfield	*Suaeda novaezelandiae* (Sea blite)			0.01	0.03
Herbfield	*Thyridia repens* (New Zealand musk)	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)	0.3	0.7
Total				45.1	100

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		Macroalgae		Microalgae	
SubClass	Feature	ha	%	ha	%	ha	%	ha	%	ha	%
Bedrock	Rock field	0.4	0.5	0.4	1.1	0.0	0.0	0.03	0.7	0.0	0.0
Coarse substrate (>2mm)	Cobble field	0.5	0.6	0.3	0.9	0.2	0.3	0.0	0.0	0.0	0.0
	Gravel field	3.1	3.7	3.1	8.1	0.02	0.1	0.0	0.0	0.0	0.0
Sand (0-10% mud)	Mobile sand	3.4	4.1	3.4	9.0	0.0	0.0	0.0	0.0	0.0	0.0
	Firm sand	4.9	5.9	4.9	12.9	0.0	0.0	0.2	4.2	0.0	0.0
Muddy Sand (>10-25% mud)	Firm muddy sand	10.1	12.1	10.1	26.5	0.0	0.0	1.3	29.7	0.0	0.0
Muddy Sand (>25-50% mud)	Firm muddy sand	3.3	4.0	3.3	8.8	0.0	0.0	0.0	0.0	0.0	0.0
	Soft muddy sand	2.3	2.7	2.3	6.0	0.0	0.0	0.0	0.0	0.0	0.0
Sandy Mud (>50-90% mud)	Firm sandy mud	50.4	60.8	5.6	14.8	44.8	99.6	2.6	60.9	0.1	100
	Soft sandy mud	3.2	3.9	3.2	8.5	0.0	0.0	0.1	1.3	0.0	0.0
	Very soft sandy mud	1.2	1.5	1.2	3.3	0.0	0.0	0.1	3.3	0.0	0.0
Total		82.9	100	37.9	100	45.0	100	4.3	100	0.1	100

Hills Laboratories sediment analytical results from Site 1 – 8.

	Sample Name:	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Dry Matter of Sieved Sample	g/100g as rcvd	72	72	81	80	80	81	81	78
Total Recoverable Phosphorus	mg/kg dry wt	540	510	620	520	550	550	390	520
Total Sulphur	g/100g dry wt	0.07	0.08	0.04	0.03	0.03	0.03	0.03	0.04
Total Nitrogen	g/100g dry wt	0.06	0.08	0.04	0.03	0.05	0.03	< 0.02	0.04
Total Organic Carbon	g/100g dry wt	0.54	0.66	0.36	0.21	0.34	0.2	0.17	0.33
Total Recoverable Arsenic	mg/kg dry wt	8	12.1	13.9	7.4	10.6	9.8	10.1	9.7
Total Recoverable Cadmium	mg/kg dry wt	0.026	0.047	0.025	0.013	0.022	0.021	0.017	0.018
Total Recoverable Chromium	mg/kg dry wt	7.2	9.6	9.6	6.8	9.6	8.5	6.1	8.6
Total Recoverable Copper	mg/kg dry wt	3.9	6.7	4.6	2.1	3.8	3.1	2	3.9
Total Recoverable Lead	mg/kg dry wt	5.3	7.2	5.8	3.7	5.4	4.2	2.7	5.5
Total Recoverable Mercury	mg/kg dry wt	0.03	0.05	0.03	< 0.02	0.03	0.02	< 0.02	0.02
Total Recoverable Nickel	mg/kg dry wt	5.1	9.8	7.5	3.6	5.9	5.8	4	5.9
Total Recoverable Zinc	mg/kg dry wt	33	45	37	23	33	28	18.3	32

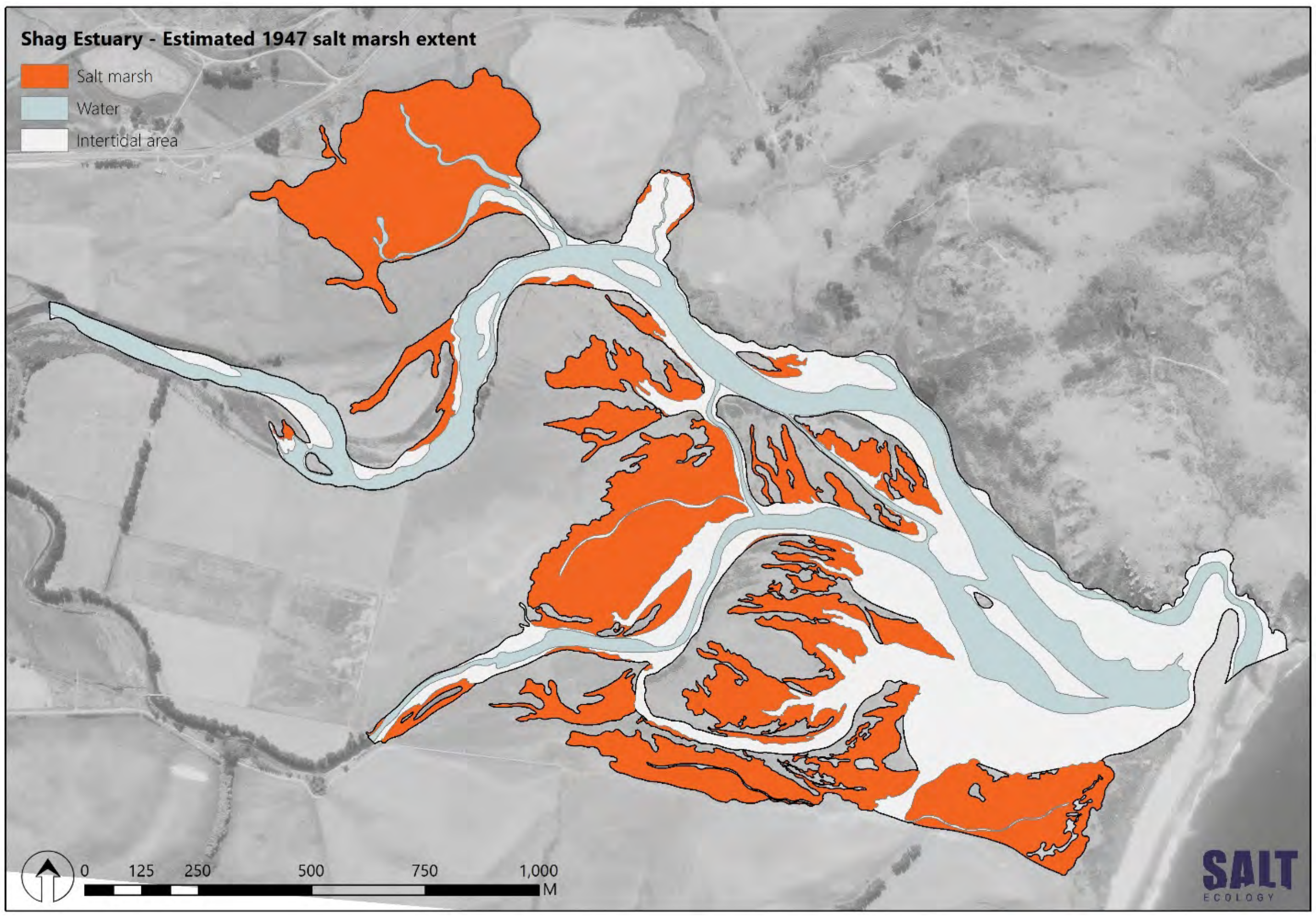
APPENDIX 5. ESTIMATED HISTORIC SALT MARSH EXTENT

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. 7.

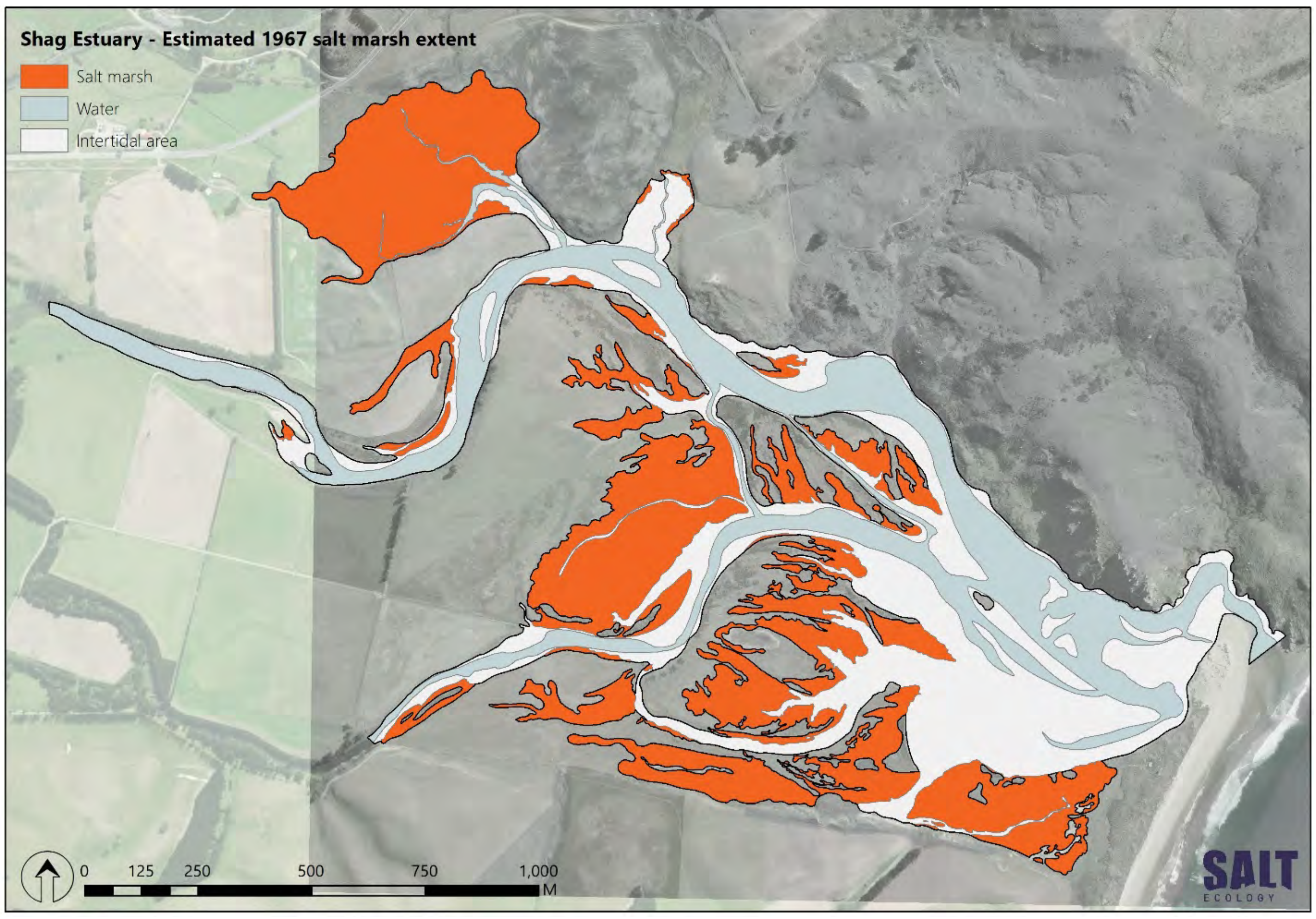
Year	Intertidal (ha)	Subtidal (ha)	Estuary (ha)	AIH* (ha)	Salt marsh (ha)	% Intertidal
Estimated natural	115.2	29.9	145.1	43.1	72.1	62.6
1947	100.2	30.4	130.6	41.9	58.3	58.2
1967	95.1	31.2	126.2	39.7	55.3	58.1
1982	88.8	29.5	118.2	42.7	46.1	51.9
2005	87.0	30.9	117.9	42.0	45.0	51.7
2016	89.8	27.9	117.7	45.5	44.3	49.4
2023	82.9	41.3	124.2	37.9	45.0	54.3

*Available intertidal habitat

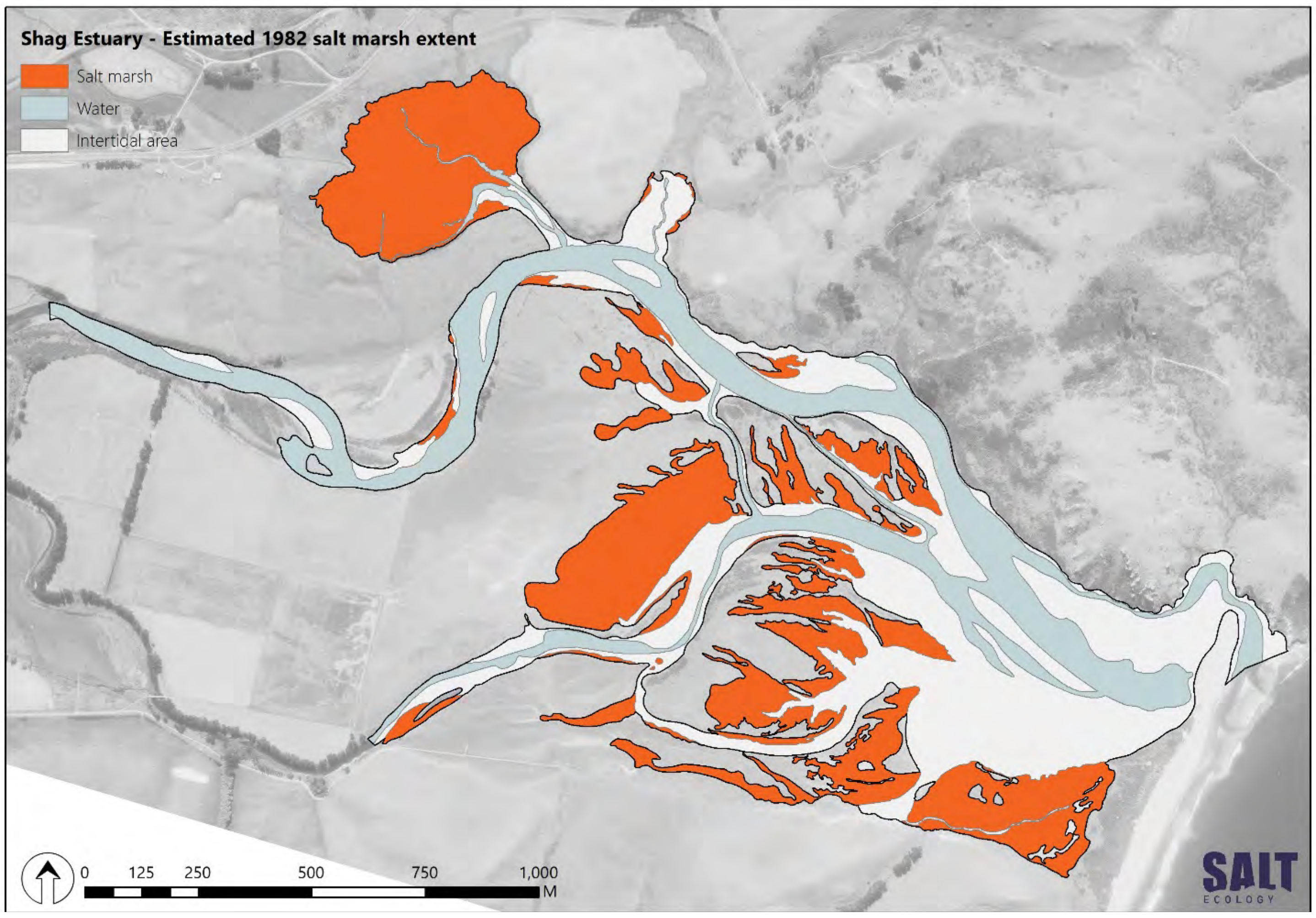
1947 salt marsh extent – based on 1947 imagery.



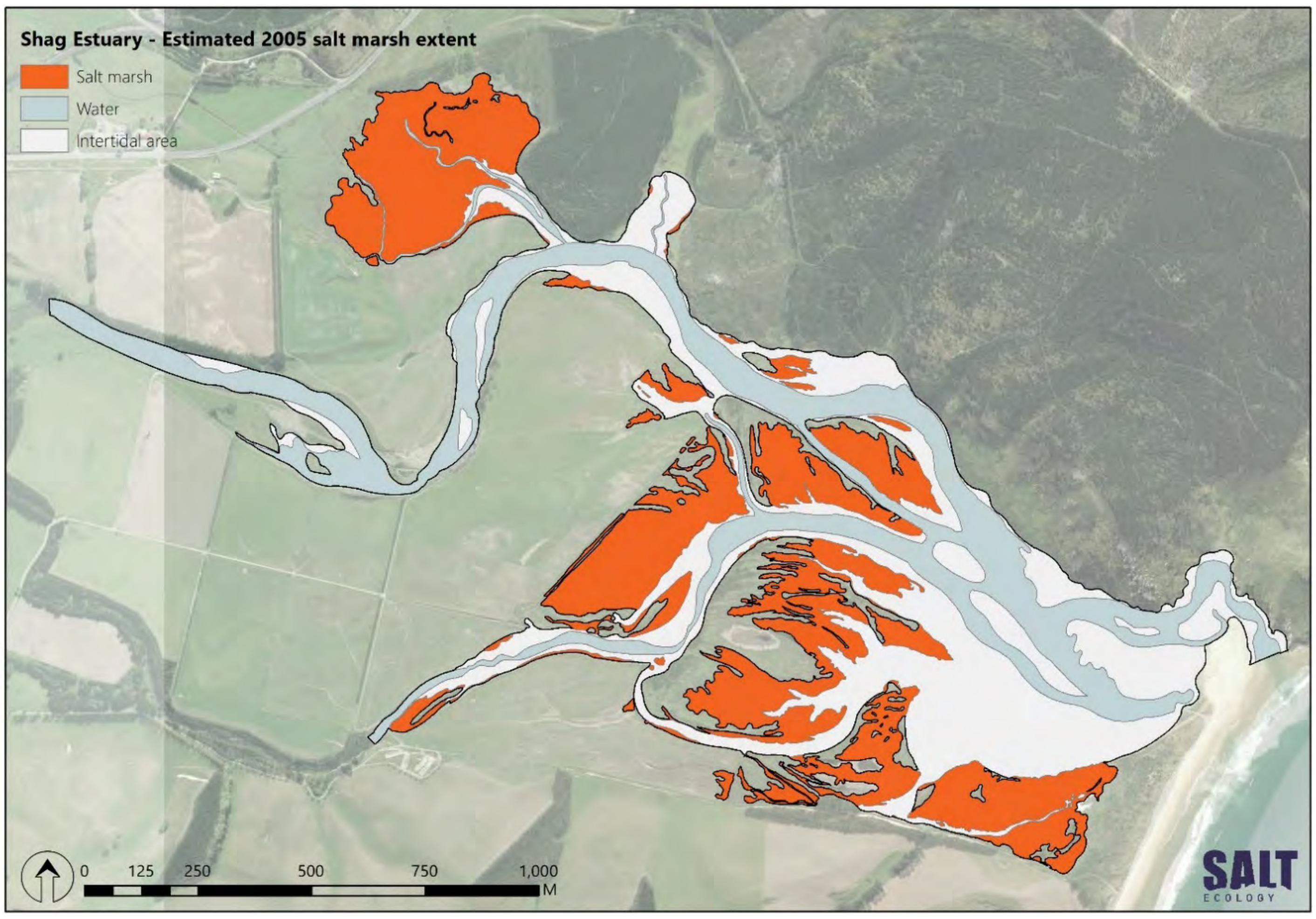
1967 salt marsh extent – based on 1967 imagery.



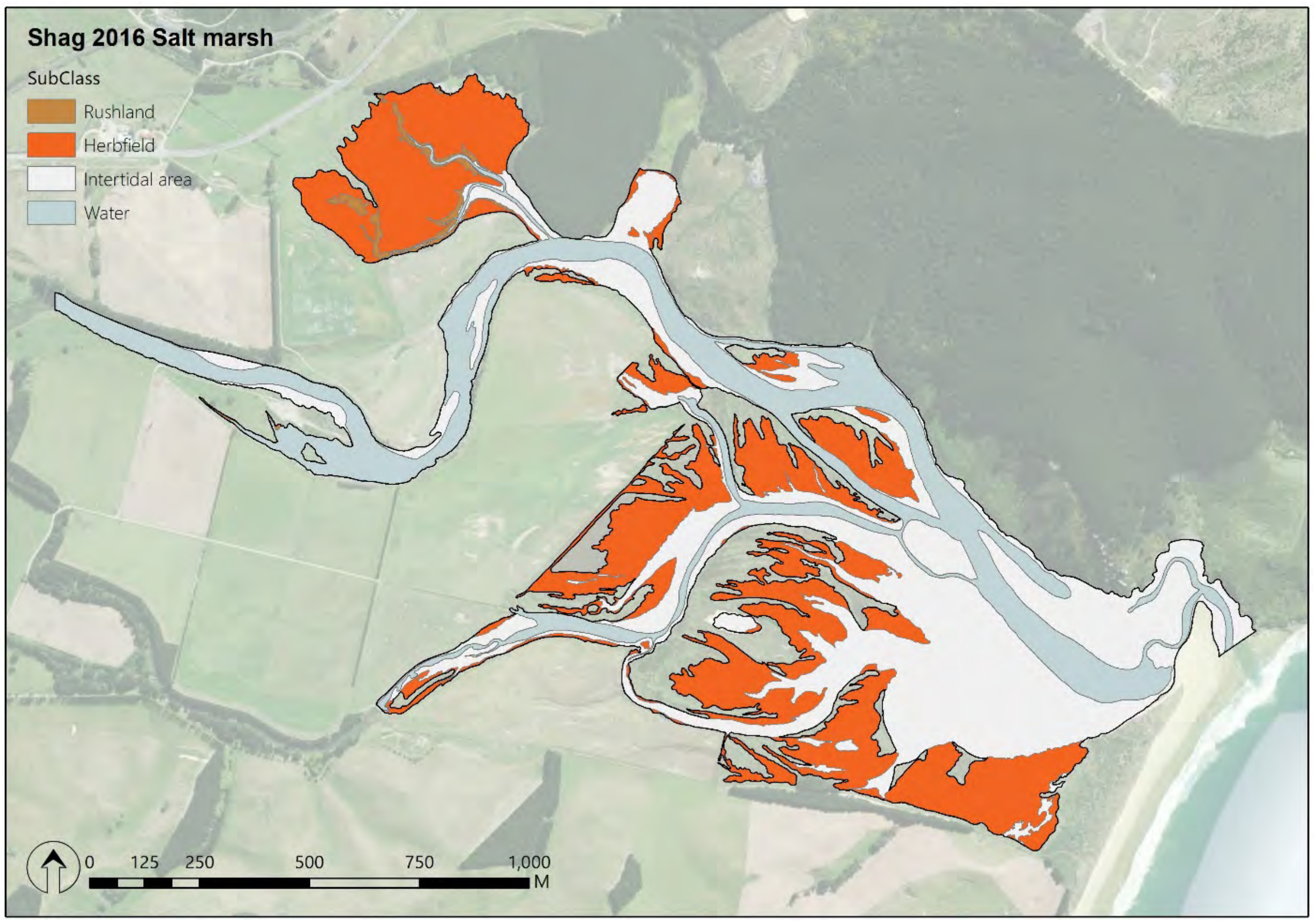
1982 salt marsh extent – based on 1975 and 1982 imagery.



<u>2005 salt marsh extent – based on 2005 imagery.</u>



<u>2016 salt marsh extent – based on 2016 broad-scale survey.</u>



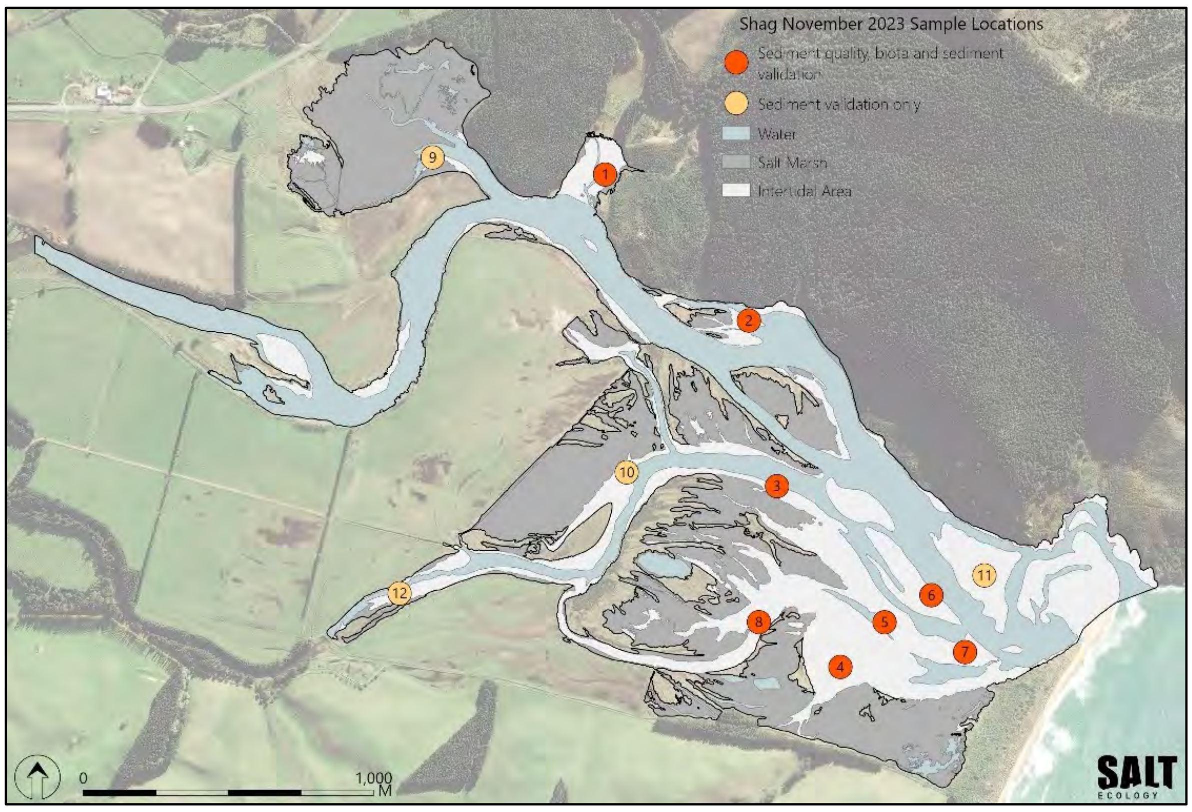
APPENDIX 6. SEDIMENT VALIDATION

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 eight of the twelve 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 4 was adjusted up, with the likely cause for the difference due to an underestimation based on the firm sediment texture.

Site	NZTM Easting	NZTM Northing	Sediment firmness	Field code	Subjective % mud	Mud (%)	Sand (%)	Gravel (%)	aRPD (mm)	Updated classification*	Estimated elevation[1] (m)
1	1428215.87	4962425.07	very soft	SM50_90	50 to <90%	69.7	30.1	0.2	10	-	-0.14
2	1428573.27	4962082.27	firm	MS25_50	25 to <50%	29.8	59.8	10.4	na	-	0.05
3	1428652.1	4961685	soft	MS25_50	25 to <50%	23.6	71.3	5.2	27	-	-0.38
4	1428817.21	4961253.36	firm	MS10_25	10 to <25%	36.2	63.5	0.2	35	MS25_50	-0.23
5	1428921.38	4961364.06	firm	MS10_25	10 to <25%	28.3	70.9	0.8	30	No change	-0.30
6	1429032.93	4961432.11	firm	S0_10	<10%	12.7	76.8	10.5	25	No change	-0.18
7	1429118.19	4961297.37	firm	S0_10	<10%	6.4	92.4	1.2	25	-	-0.20
8	1428617.41	4961356	very soft	SM50_90	50 to <90%	45.9	53.8	0.3	25	No change	-0.13
9	1427797.28	4962454.51	soft	SM50_90	50 to <90%	58.2	39.5	2.3	7	-	-
10	1428287.78	4961708.4	soft	MS25_50	25 to <50%	29.5	68.4	2.2	15	-	-
11	1427745.94	4961401.67	firm	MS10_25	10 to <25%	13.2	83.7	3	>200	-	-
12	1429159.99	4961483.54	mobile	S0_10	<10%	0.7	99.3	< 0.1	na	-	-

*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. 1. Elevation estimated from LiDAR 10cm contours with correction of -0.3 to calculate height relative to mean sea level.



Photos of sediment quality and biota sampling sites and representative aRPD (see p63 for site locations).

Site 1

Site 1 - aRPD

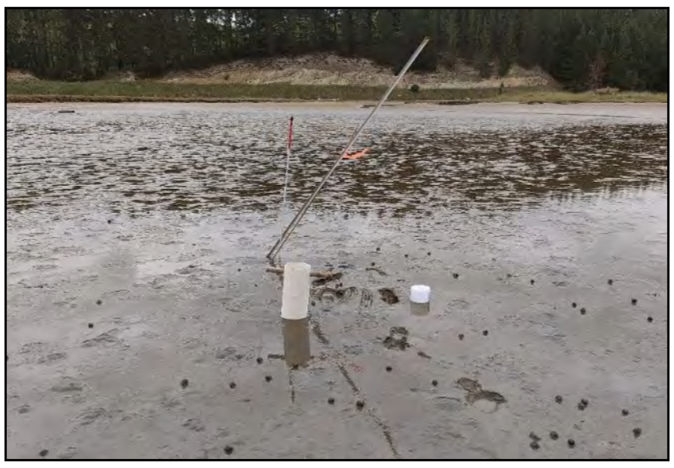
Site 2

Site 2 - aRPD

Site 3

Site 3 - aRPD

Site 4



Site 4 - aRPD

Site 5

Site 5 - aRPD

Site 6

Site 6 - aRPD

Site 7

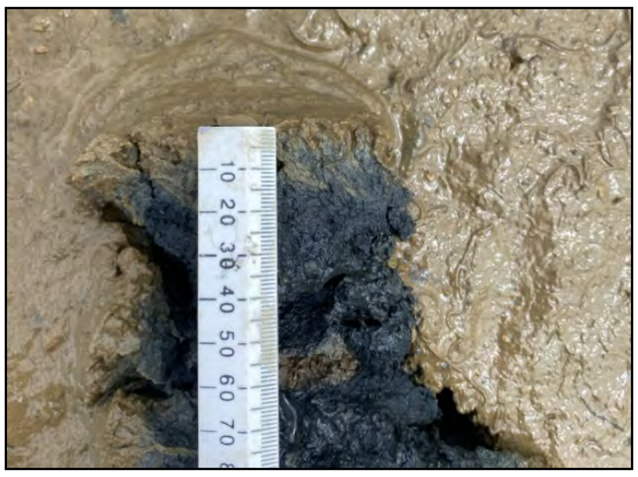
Site 7 - aRPD

Site 8

Site 8 - aRPD

Site 9

Site 9 - aRPD



Site 10

Site 10 - aRPD

Site 11

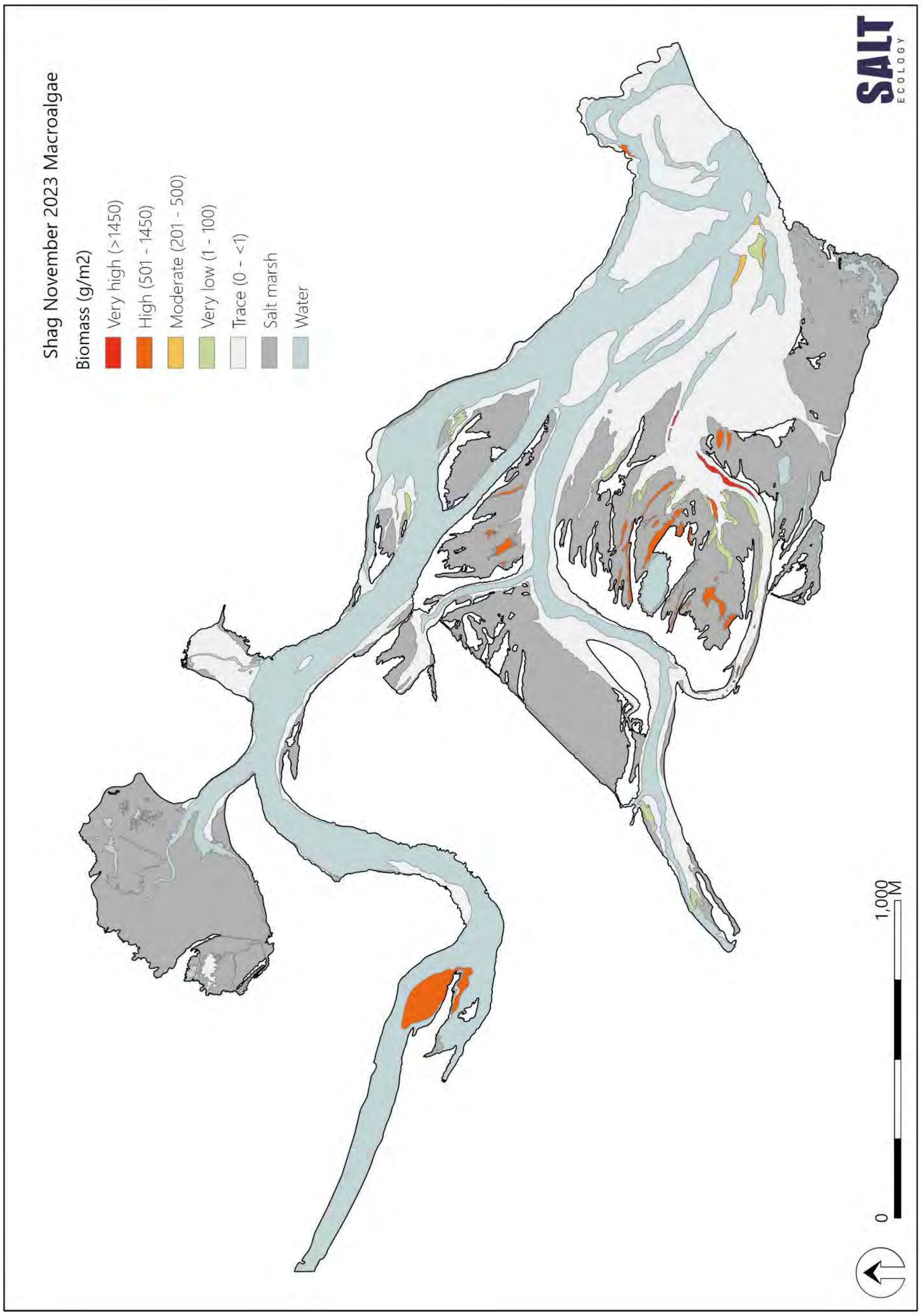
Site 11 - aRPD

Site 12

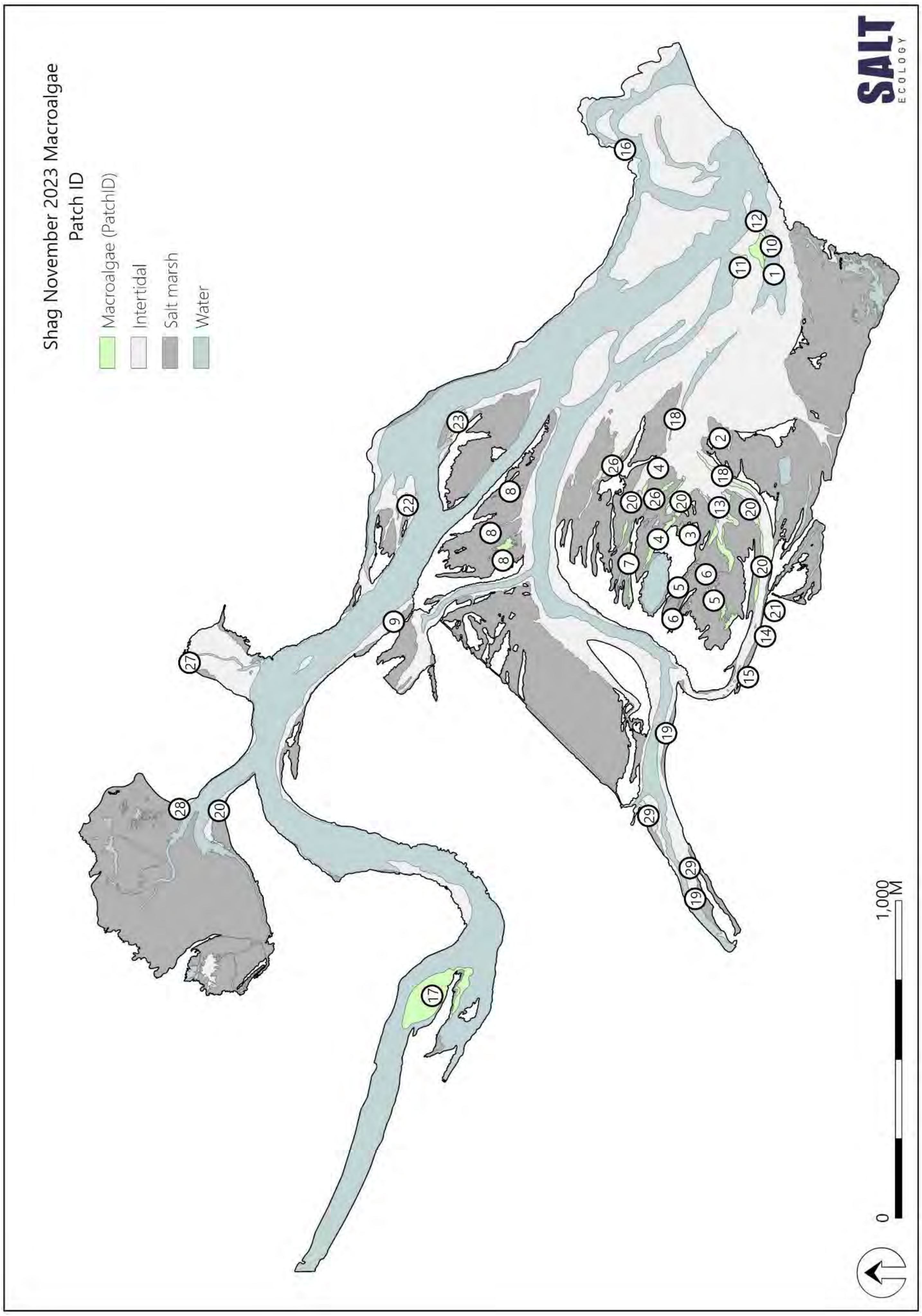
Site 12 – aRPD photo not available

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/m2)	Biomass Category	Entrained*	Substrate	Area (ha)
1	*Agarophyton* spp. (Agar weed)	20	Sparse (10 to <30%)	400	Moderate (201 - 500)	0	fMS10	0.02
2	Filamentous green algae	100	Complete (>=90%)	1000	High (501 - 1450)	0	fSM	0.08
3	Filamentous green algae	100	Complete (>=90%)	900	High (501 - 1450)	0	fSM	0.06
4	Filamentous green algae	100	Complete (>=90%)	1000	High (501 - 1450)	0	fSM	0.25
5	Filamentous green algae	100	Complete (>=90%)	900	High (501 - 1450)	0	fSM	0.196
6	Filamentous green algae	100	Complete (>=90%)	800	High (501 - 1450)	0	fSM	0.03
7	Filamentous green algae	100	Complete (>=90%)	1000	High (501 - 1450)	0	fSM	0.14
8	Filamentous green algae	100	Complete (>=90%)	900	High (501 - 1450)	0	fSM	0.16
9	Filamentous green algae	80	Dense (70 to <90%)	40	Very low (1 - 100)	0	fS	0.02
10	*Agarophyton* spp. (Agar weed)	3	Very sparse (1 to <10%)	60	Very low (1 - 100)	0	fS	0.14
11	*Agarophyton* spp. (Agar weed)	20	Sparse (10 to <30%)	400	Moderate (201 - 500)	0	fMS10	0.07
12	*Agarophyton* spp. (Agar weed)	20	Sparse (10 to <30%)	400	Moderate (201 - 500)	0	fS CKLE	0.02
13	*Agarophyton* spp. (Agar weed)	75	Dense (70 to <90%)	1280	High (501 - 1450)	1	sSM	0.04
14	*Agarophyton* spp. (Agar weed)	70	Dense (70 to <90%)	1500	Very high (>1450)	0	sSM	0.00
15	*Agarophyton* spp. (Agar weed)	100	Complete (>=90%)	4000	Very high (>1450)	1	vsSM	0.01
16	*Ulva spp* (Sea lettuce)	70	Dense (70 to <90%)	700	High (501 - 1450)	0	RF	0.03
17	*Ulva spp* (Sea lettuce)	80	Dense (70 to <90%)	800	High (501 - 1450)	0	fMS10	0.94
18	*Agarophyton* spp. (Agar weed)	75	Dense (70 to <90%)	3040	Very high (>1450)	1	vsSM	0.13
19	*Vaucheria* sp.	100	Complete (>=90%)	50	Very low (1 - 100)	0	fMS10	0.07
20	*Vaucheria* sp.	80	Dense (70 to <90%)	40	Very low (1 - 100)	0	fSM	0.57
21	*Vaucheria* sp.	70	Dense (70 to <90%)	40	Very low (1 - 100)	0	fSM	0.02
22	*Vaucheria* sp.	90	Complete (>=90%)	40	Very low (1 - 100)	0	fSM	0.06
23	*Vaucheria* sp.	50	High-Moderate (50 to <70%)	40	Very low (1 - 100)	0	fMS10 GF	0.08
24	*Vaucheria* sp.	80	Dense (70 to <90%)	40	Very low (1 - 100)	0	fMS10	0.11
25	*Vaucheria* sp.	70	Dense (70 to <90%)	40	Very low (1 - 100)	0	sSM	0.00
26	*Vaucheria* sp.	40	Low-Moderate (30 to <50%)	20	Very low (1 - 100)	0	fSM	0.10
27	*Vaucheria* sp.	90	Complete (>=90%)	40	Very low (1 - 100)	0	sSM	0.01

* Entrainment is scored as 1 (entrained) or 0 (not entrained)

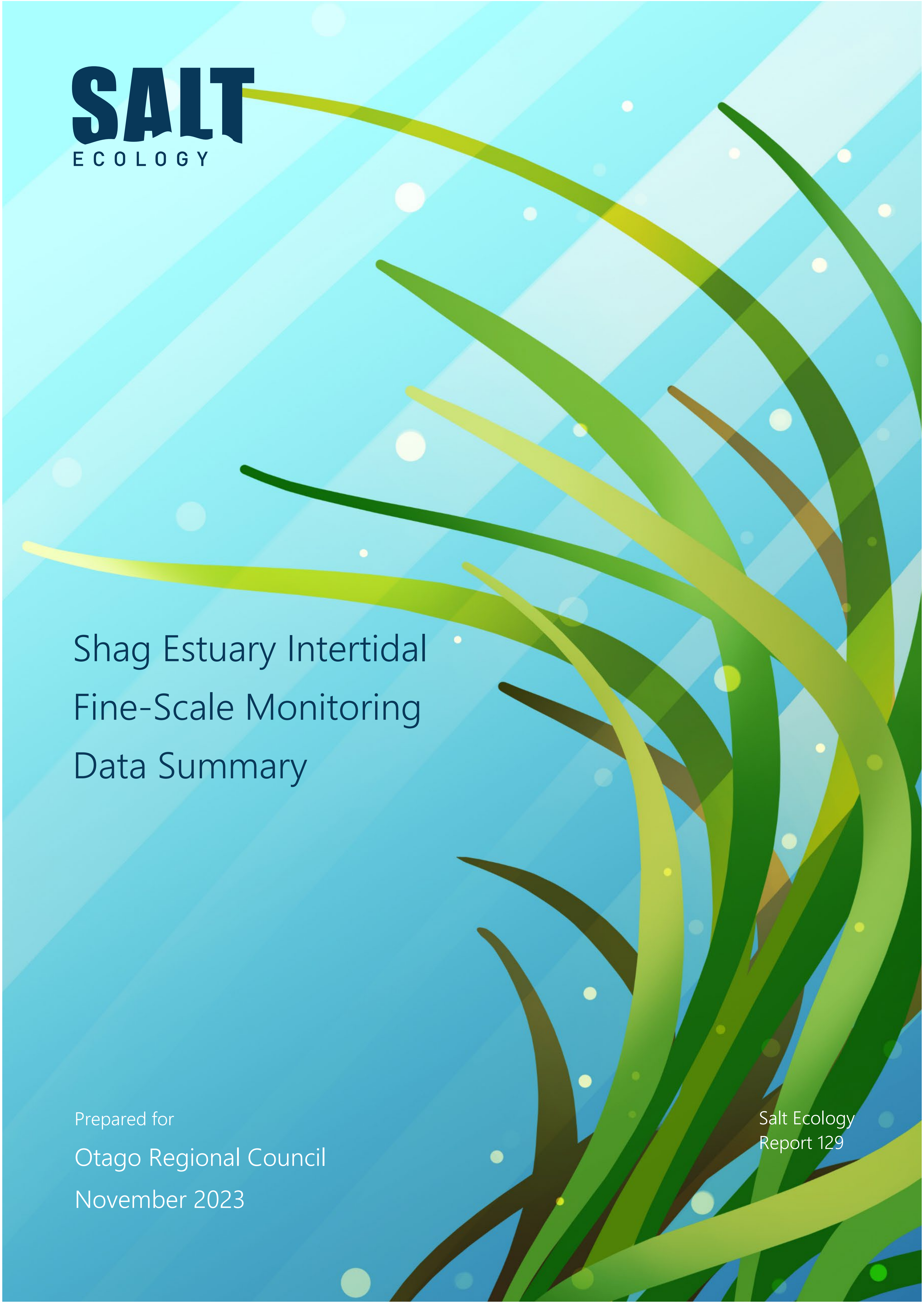
November 2023 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	7.0	0.760	Good
Average biomass (g/m^2) in AIH	58.7	0.883	Good
Average biomass (g/m^2) in AA	661.2	0.366	Poor
%entrained in AA	5.4	0.595	Good
Worst of AA (ha) and AA (% of AIH)		0.723	Good
AA (ha)	3.4	0.933	High
AA (% of AIH)	8.9	0.723	Good
Survey EQR		0.665	'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	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b
Amphipoda	*Paracalliope novizealandiae*	I	2				16	5	5	1	8	4			1	7	6	3
Amphipoda	*Paracorophium excavatum*	IV	299	423	5		275	229	233	249	339	341	291	193	152	197	356	304
Anthozoa	*Edwardsia sp.*	II													2	1		
Bivalvia	*Arthritica sp. 5*	III	1	2			1	4	2		9	2	1				3	3
Bivalvia	*Austrovenus stutchburyi*	II								1		1	15	7	18	9		
Bivalvia	*Macomona liliana*	II														1		
Copepoda	*Copepoda*	II			1													
Cumacea	*Colurostylis lemurum*	II													2	1		
Decapoda	*Hemiplax hirtipes*	III	1											1				
Gastropoda	*Amphibola crenata*	III	1															1
Gastropoda	*Cominella glandiformis*	III								1	3							
Gastropoda	*Notoacmea scapha*	II																1
Isopoda	*Exosphaeroma planulum*	V					1											
Nematoda	*Nematoda*	III			1	2	1		1			1	4	8				
Nemertea	*Nemertea*	III													1			
Oligochaeta	*Oligochaeta*	V	1	1				1	3	3	3	3	9	6			3	21
Polychaeta	*Abarenicola sp.*	I					1											
Polychaeta	*Aonides trifida*	I														1		
Polychaeta	*Boccardia proboscidea*	IV													3	1		
Polychaeta	*Boccardia syrtis*	II					2	3	2	4	5	5	2	2	26	28	3	12
Polychaeta	*Capitella cf. capitata*	V	2				12	6	2	1	10	3	41	27	1	1	6	1
Polychaeta	*Cossura consimilis*	I															1	
Polychaeta	*Euchone sp.*	II															2	
Polychaeta	*Glycera sp.*	II						1										
Polychaeta	*Heteromastus filiformis*	IV							2		4	4	1			2	2	
Polychaeta	*Microphthalmus riseri*	II									1							
Polychaeta	*Nereididae (juv)*	III														1		
Polychaeta	*Paradoneis lyra*	III					6	3	38	45	58	78	2	1	114	101	9	15
Polychaeta	*Perinereis vallata*	III			2	1			1	2			9	12				
Polychaeta	*Prionospio aucklandica*	III								1	1	1	1		3	5		
Polychaeta	*Scolecolepides benhami*	IV	17	7			24	38	23	21	15	21	9	9	9	7		17
Polychaeta	*Scoloplos cylindrifer*	I										1			3	2		
Abundance			324	433	9	3	339	290	312	329	456	465	385	266	335	365	391	378
Richness			8	4	4	2	10	9	11	11	12	13	12	10	13	16	10	10

Environmental Science and Policy Committee - 4 December 2024



SALT ECOLOGY

Shag Estuary Intertidal Fine-Scale Monitoring Data Summary

Prepared for

Otago Regional Council

November 2023

Salt Ecology Report 129

RECOMMENDED CITATION

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SALT
ECOLOGY

For the People
Mō ngā tāngata

Shag Estuary Intertidal Fine-Scale Monitoring Data Summary

Prepared by

Barrie Forrest

for

Otago Regional Council

November 2023

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For the environment
Mō te taiao

GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of Environment (Monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total phosphorus
Zn	Zinc

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Many thanks to Sam Thomas (ORC) for his support in undertaking this work and peer review of the report. Thanks also to Salt Ecology colleagues (Keryn Roberts, Leigh Stevens) for comments on the report draft.

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FIGURES

TABLES

1. INTRODUCTION

Between December 2016 and February 2019, Otago Regional Council (ORC) undertook three ecological and sediment quality surveys in Shag Estuary. A report was produced on the first survey (Robertson et al. 2017) but data from the two subsequent surveys were archived. This report provides a high-level summary of the data for all three surveys, to support a planned review of ORC's estuary State of the Environment (SOE) monitoring programme.

2. METHODS

The survey methods are described in Robertson et al. (2017) and were based on the 'fine-scale' approach in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). Monitoring was conducted at two sites (Fig. 1). Different providers have undertaken the surveys, namely Wriggle Coastal Management (December 2016), Ryder Associates (December 2017) and Salt Ecology (February 2019). Monitoring indicators and methods are described in Appendix 1, and were as follows:

- Sediment quality indicators: Included sediment mud content, oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients and organic content, and selected trace contaminants. Sediment aRPD was measured in the field. For the other variables, three samples (each composited from 3-4 sub-samples of the surface 20mm of sediment) were collected, and sent to Hill Laboratories for analysis.
- Biotic indicators: Included surface-dwelling snails and macroalgae, and benthic macrofauna. Macrofauna sampling was undertaken using cores (130mm diameter, 150mm deep, ~2L volume, sieved to 0.5mm). Macrofauna species taxonomy and counts were made by Ryder Associates in December 2017, and by Coastal Marine Ecology Consultants for the other two surveys. For reporting purposes, macrofauna naming differences among surveys have been standardised to the extent feasible.

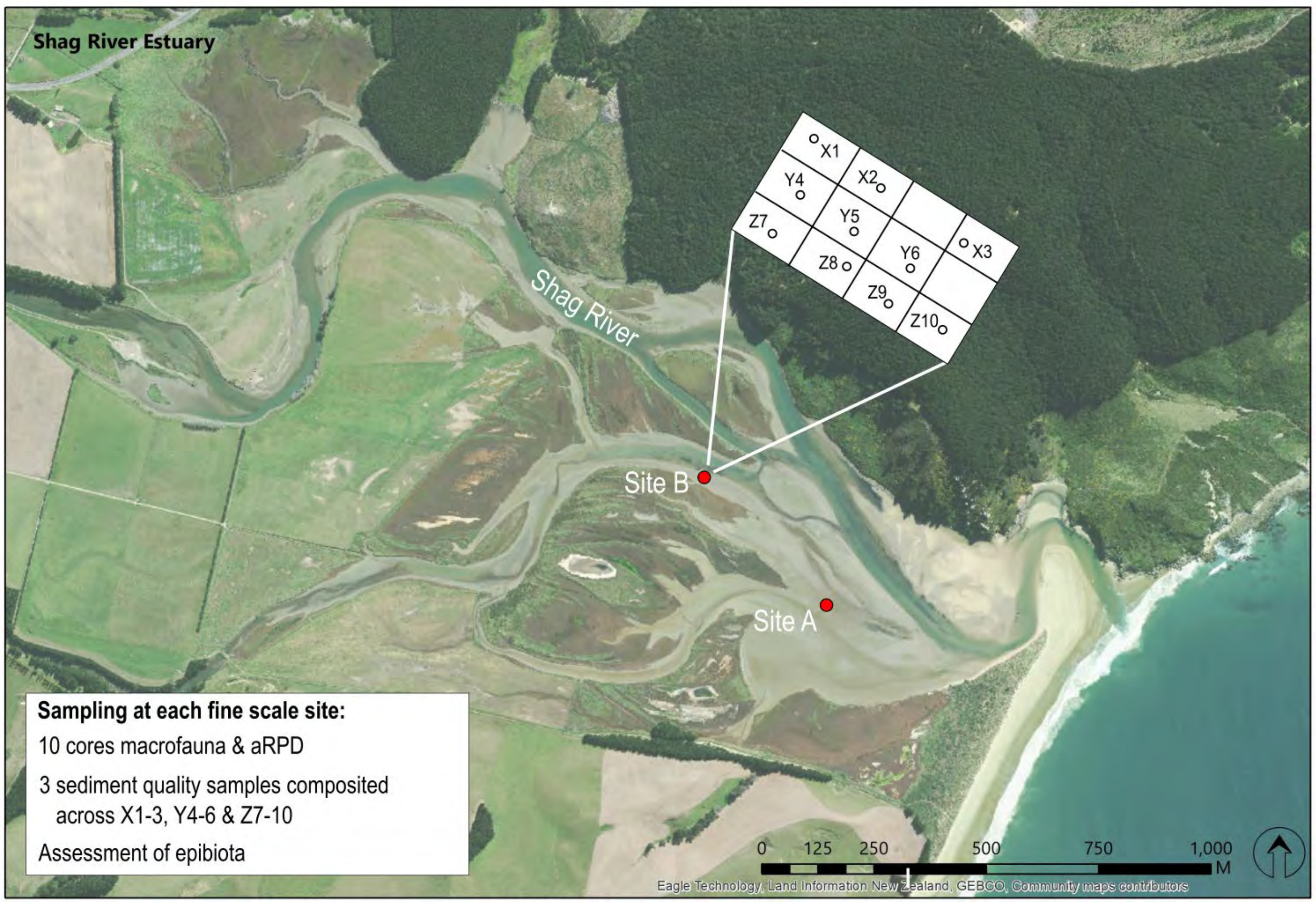


Fig. 1. Location of the two fine-scale monitoring sites in Shag Estuary. The schematic depicts the sediment sample and macrofauna core collection. Information on site GPS positions and other location information is provided in Robertson et al. (2017).

The data analysis methods are described in recent ORC reports (e.g., Forrest et al. 2022). Macrofauna assessment included calculation of scores for the international biotic health index 'AMBI'. To assess estuary health, results for most indicators are evaluated against 'condition ratings' described in Appendix 2.

3. KEY FINDINGS

An overall summary of results, with condition ratings applied where available, is provided in Table 1.

3.1 SEDIMENT QUALITY

Sediment quality data are collated in Appendix 3. Sediments consisted of muddy sands at both sites (Fig. 2, see photos adjacent), with a mean range in mud values of ~16-24% corresponding to a condition rating of 'fair' (Table 1). Site B had a relatively high gravel component compared with Site A, likely reflecting hydrological scouring due to the placement of Site B on the edge of a river channel.

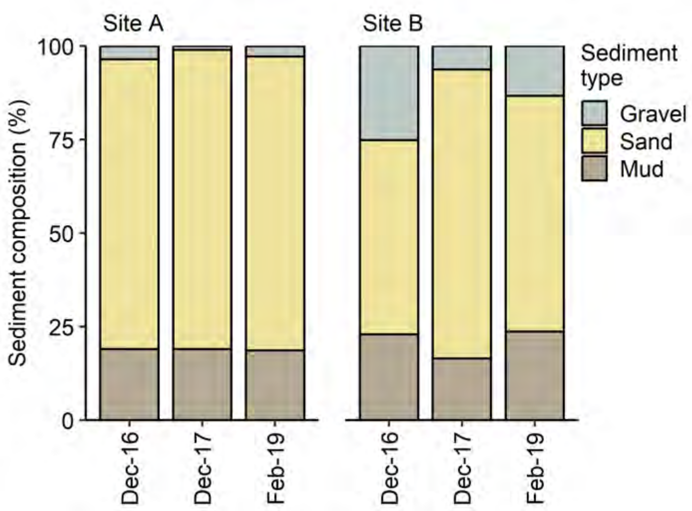


Fig. 2. Sediment particle grain size analysis showing percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm) from composite samples (n=3) at fine-scale sites.

Sediment oxygenation assessed by the aRPD method, was rated 'good' in all three surveys (Table 1, Fig. 3). Core photos (next page) illustrate the change in aRPD transition between brown surface sediment and deeper oxygen depleted sediment. There were no signs of excessive sediment enrichment; e.g., intense black colour throughout the depth profile, and a strong sulfide ('rotten egg') odour when disturbed.

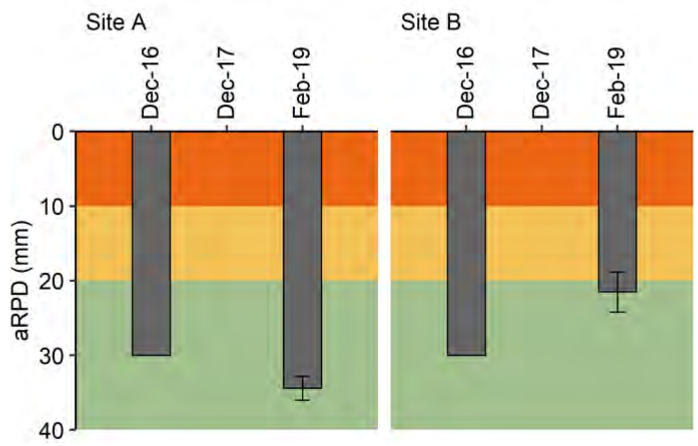


Fig. 3. Mean (±SE, n=3-10) aRPD depth relative to condition ratings. The aRPD depth was not recorded in December 2017.

Very Good	Good	Fair	Poor

Intertidal flats at Site A looking towards lower estuary.

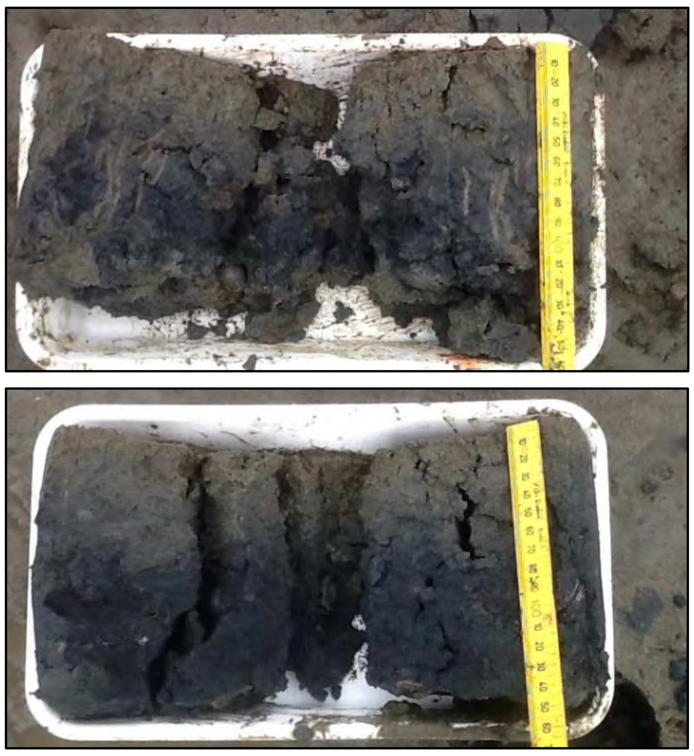
Site B on channel margin.

Table 1. Summary of mean values of key indicators at fine-scale monitoring sites in Shag Estuary. Values are rated against condition scores of ecological health, where available (Appendix 2). No rating criteria exist for Total Phosphorus (TP), macrofauna richness (Rich) or macrofauna abundance (Abun). See Glossary for definition of indicators.

Site	Survey	Sediment quality													Macrofauna		
		Mud %	aRPD mm	TN mg/kg	TP mg/kg	TOC %	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Hg mg/kg	Ni mg/kg	Zn mg/kg	Rich	Abun	AMBI
A	Dec-16	19.1	30	< 500	470	0.170	11.0	0.015	8.7	3.3	4.6	0.01	5.8	27.0	6.2	168.1	4.1
	Dec-17	19.0	-	< 500	557	0.170	11.5	0.018	8.4	3.0	4.7	< 0.02	5.2	30.0	12.3	435.6	3.9
	Feb-19	18.6	34	< 500	520	0.190	11.8	0.015	9.0	3.1	4.8	< 0.02	5.3	29.3	6.6	285.5	4.2
B	Dec-16	23.0	30	567	620	0.350	16.4	0.024	9.6	5.3	5.8	0.03	8.2	36.0	4.3	30.9	4.3
	Dec-17	16.5	-	< 500	603	0.220	15.1	0.025	10.2	4.6	5.7	0.03	7.3	37.0	7.5	125.1	4.4
	Feb-19	23.7	22	367*	617	0.300	15.3	0.027	10.0	4.7	5.9	0.02*	7.0	35.7	4.9	162.7	4.5

* Sample mean includes values below lab detection limits
< All values below lab detection limit

Very Good | Good | Fair | Poor



Sediment core profiles from Site A (top) and B (bottom) in 2019. Oxygen-depleted sediment is the deeper black colouring.

Laboratory sediment analyses revealed low levels of organic matter and nutrients, corresponding to ratings of 'good' or 'very good' (Table 1, Fig. 4). TN values were often less than routine laboratory method detection limits.

Sediment trace metals contaminants were very low in all three surveys, and mostly less than half of the national sediment quality Default Guideline Value (DGV; Table 1, Fig. 5). DGVs indicate *"...the concentrations below which there is a low risk of unacceptable effects occurring."* (ANZG 2018). The metalloid arsenic (As) was the only analyte whose concentration almost reached the DGV.

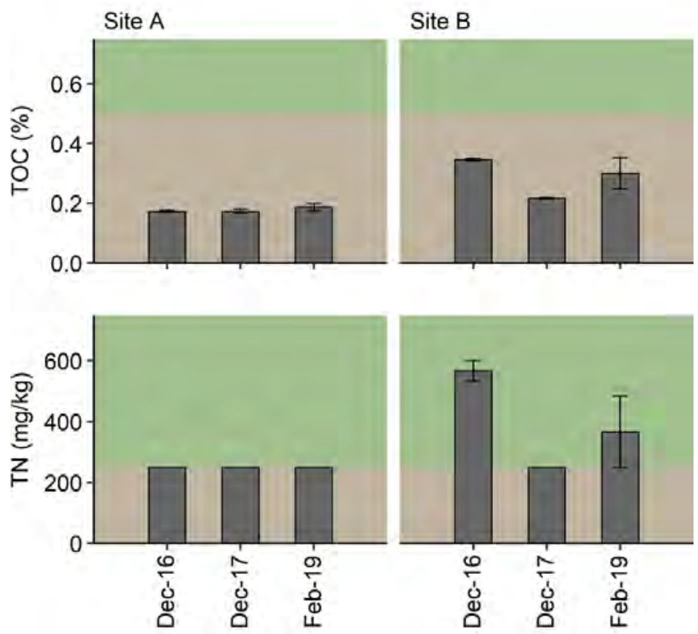


Fig. 4. Mean (±SE, n=3) sediment total organic carbon (TOC) and total nitrogen (TN) in composite samples, relative to condition ratings. TN values at Site A, and Site B in December 2017, were less than routine laboratory method detection limits. Values plotted are 50% of the detection limit.

Very Good | Good | Fair | Poor

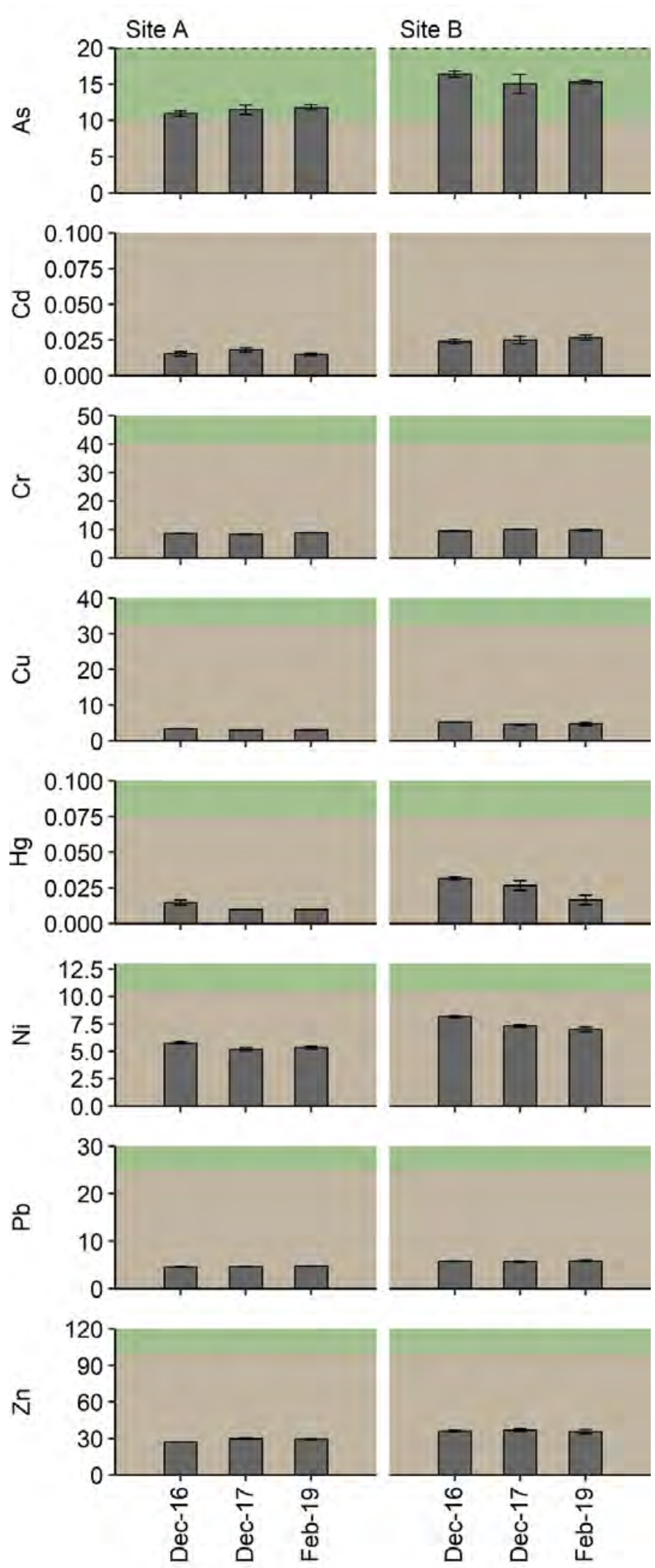


Fig. 5. Mean (±SE, n=3) trace element concentrations in composite samples, relative to condition ratings. The boundary between 'very good' and 'good' represents 50% of the ANZG (2018) sediment quality Default Guideline Value (DGV). Below the DGV there is a 'low risk' of unacceptable effects.

Very Good	Good	Fair	Poor

Elevated arsenic concentrations most likely reflect atypically high catchment sources in Otago Schist rock, including rock exposed by mining activities and subsequently mobilised (Blake et al. 2019). Despite the arsenic anomaly, results overall suggest that there are no significant chemical contaminant inputs from the catchment that are accumulating in the estuary.

3.2 BIOTA

Surface dwelling epibiota

Epibiota were sparse at both sites. Mudflat topshells (*Diloma subrostratum*) and mud snails (*Amphibola crenata*) have been recorded but are uncommon. The occasional mud whelk (*Cominella glandiformis*) was noted at Site A in February 2019. The seaweeds *Agarophyton* spp. (formerly *Gracilaria* spp.) and *Ulva* spp. ('sea lettuce') were described by Roberston et al. (2017) as 'rare' at Site A, but in 2019 were not recorded from either site.

Sediment-dwelling macrofauna

Macrofauna species and abundances are summarised in Appendix 4. Core sampling revealed the macrofauna to be moderately impoverished in terms of the range of species present, and dominated by hardy species. Key points are as follows:

- A total of 34 species or higher macrofauna taxa have been recorded from the two sites. Twelve main taxonomic groups have been described, but shrimp-like amphipods and polychaete worms are by far the most abundant (Appendix 4).
- Mean species richness was low (range ~4-12 taxa per core), with more species described in 2017 than in other years (Fig. 6, top). Similarly, the greatest abundances occurred in 2017 at Site A, with a mean of 436 organisms per core (Fig. 6, bottom). However, organism abundances exhibited marked temporal fluctuations, which will reflect natural variability as well as the use of different providers in each of the three survey years.
- Mean values of the biotic index AMBI corresponded to a condition rating of 'fair' at Site A and 'poor' at Site B (Table 1, Fig. 7). These ratings reflect that the macrofauna was dominated by hardy species in eco-group IV (Fig. 8).
- By far the most abundant of the hardy species was the tube-building amphipod *Paracorophium excavatum* (Appendix 4, photo next page). This species is common in disturbed environments, especially in river-dominated estuaries subject to highly variable flows and salinities.

- Also abundant were polychaete worm species that are commonly found in estuaries nationally, in particular *Paradoneis lyra* and *Scolecolepides benhami*.
- Cockles were present in both sites in all surveys, but were not particularly abundant and generally small in size (e.g., seldom >20mm shell length).

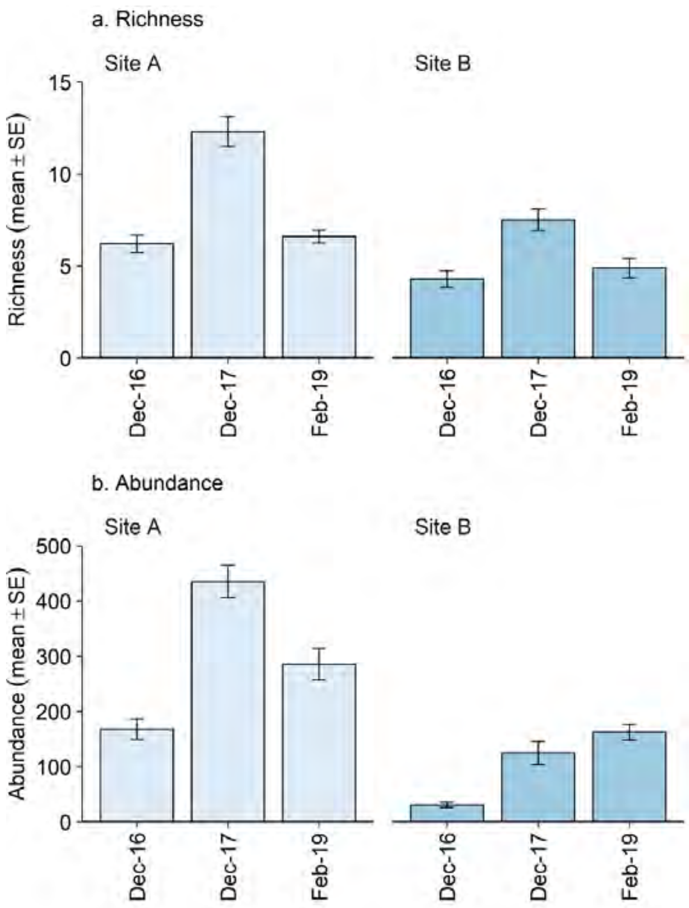


Fig. 6. Mean (±SE, n=10) macrofauna taxon richness and abundance per core.

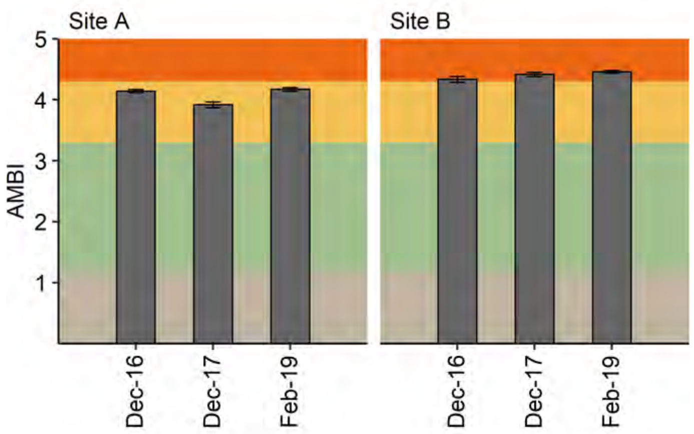


Fig. 7. Mean (±SE, n=10) AMBI scores relative to condition ratings. The differences between the two sites are small, and reasonably consistent over time.

Very Good	Good	Fair	Poor

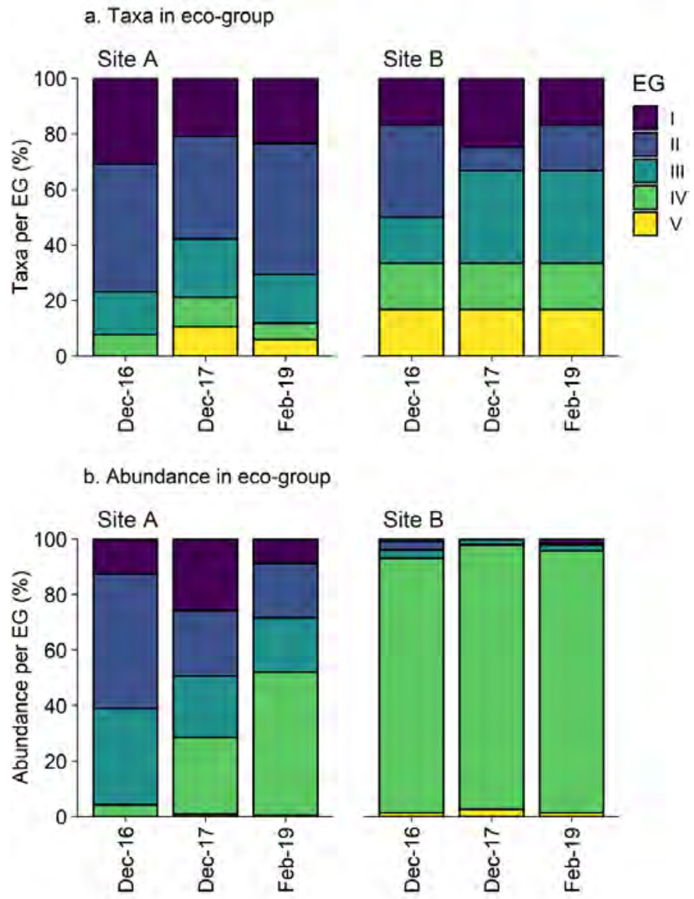


Fig. 8. Contribution to site richness and abundances of macrofauna species in eco-groups ranging from sensitive (EG-I) to resilient (EG-V). The graphs illustrate that the macrofauna was dominated by hardy (EG-IV) organisms.

The tube-building amphipod *Paracorophium excavatum* was by far the most dominant of the macrofauna. This species is common in physically disturbed environments, especially in river-dominated estuaries where water flows and salinities are highly variable (image from NIWA Otago estuaries collection).

A cursory analysis of macrofauna community composition differences among sites and surveys was undertaken. A multivariate method was used to 'group' sites according to their similarity in macrofauna composition (Fig. 9). The analysis revealed that differences in macrofauna composition among sites and survey were relatively subtle. For example:

- At Site B in 2017 and 2019 the composition of the macrofauna was identified as being distinct from the other sites. However, drilling into the detail reveals relatively minor composition shifts. For example, at Site B in those years the polychaetes *Boccardia syrtis* and *Paradoneis lyra* were the least abundant (Appendix 4).
- In all other site-survey combinations the macrofauna composition was quite similar. Differences reflected shifts in species abundances and minor changes in the range of uncommon species present, whose presence/absence is likely a random effect of chance sampling.

A limited analysis was undertaken to determine whether macrofauna differences among sites/surveys could be 'explained' by any of the sediment quality variables. Total organic carbon emerged as one of the potential explanatory variables, as the macrofauna composition differences in 2017 and 2019 at Site B were correlated with higher TOC values (Spearman rank correlation coefficient ρ = 0.601; see also Fig. 9). However, the absolute TOC values were low (see Table 1) and were not associated with any obvious sediment enrichment response (e.g., the aRPD did not become shallower; Table 1). As such, TOC may not itself be causal, but may in part reflect some unmeasured variable(s) that influences macrofauna composition.

4. MONITORING AND MANAGEMENT IMPLICATIONS

ORC have a 5-yearly schedule for estuary fine-scale monitoring, with the next survey for Shag Estuary due in the summer of 2023/24. One of the reasons for compiling the present summary report was to better understand the utility of the current monitoring approach. Once data for all Otago estuaries have been collated in a similar way, ORC will be in a better position to review the programme and determine monitoring priorities. In this broader context, Shag Estuary presents some features that will need to be accounted for in the review. These include the following:

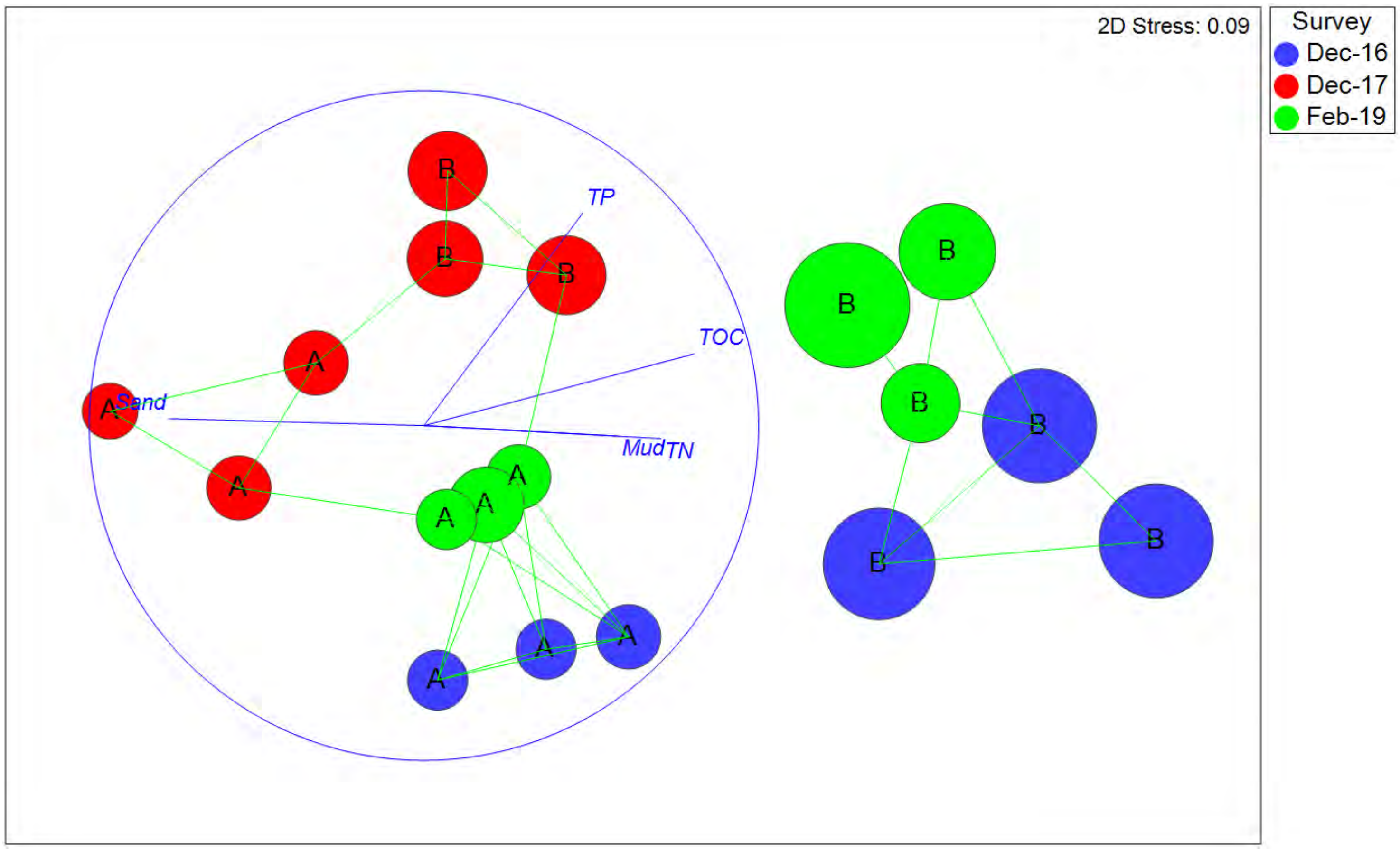


Fig. 9. Non-metric MDS ordination of macrofaunal core samples for data aggregated within each site-zone and survey.

Sample groups closer to each other are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of 0.09 indicates that a 2-dimensional plot provides a reliable representation of differences. The vectors show the direction and strength of association (length of line relative to circle) of the environmental variables that were most strongly correlated with the pattern of differences. Bubble sizes are scaled to sediment Total Organic Carbon. The green lines connect sample groups with a high similarity (70%) based on the Bray-Curtis measure.

- The estuary is clearly susceptible to catchment influences, especially muddy sediment inputs. A high proportion of the catchment is in land uses known to generate high sediment loads such as farming (71% of catchment area is pasture) and exotic forestry (11% of catchment area) (Stevens & Robertson 2017). ORC will need to consider priorities for managing these sources in the context of other regional catchment management priorities.
- Subsequent to the fine-scale monitoring, annual sedimentation monitoring revealed a spike in sediment mud content at Site A in 2021 (Forrest 2023). Since then, sediment mud content has remained about 50% higher than in the three 'baseline' surveys described in this report.
- The combination of catchment pressure and change in state (i.e., increase in 'muddiness') make it desirable to understand effects on the receiving environment. For this purpose, however, the current fine-scale approach and associated indicators are likely to be relatively insensitive to increased pressures.
- The sedimentation monitoring, combined with the analysis in this report, suggest that Shag Estuary is physically quite dynamic. Variable patterns of sediment deposition and erosion described by Forrest (2023), and a hardy macrofaunal community as described above, are symptomatic of a river-dominated hydrological setting with a fluctuating salinity. These features make it likely that the estuary macrofauna will be reasonably resilient to physical changes such as increased muddy sediment deposition.

The above situation means that ORC's review of the regional estuary SOE programme should consider the specific type of monitoring that is needed in the context of management goals in Shag Estuary, and the priorities for monitoring relative to other estuary systems in Otago.

5. RECOMMENDATIONS

It is recommended that the scheduled summer 2023/24 fine-scale survey be deferred, with a decision on future fine-scale and other monitoring needs for Shag Estuary determined as part of ORC's planned review of their regional estuary SOE programme. Ongoing annual sedimentation monitoring, and a NEMP broad-scale habitat mapping survey planned for this summer, will contribute to a broader understanding of estuary state and monitoring needs.

6. 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.

Blake F, Grant K, MacKenzie D, Scott J, Craw D 2019. Surficial arsenic redistribution above gold-mineralised zones in East Otago, New Zealand. New Zealand Journal of Geology and Geophysics 62(4): 573-587.

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.

Forrest BM 2023. Shag Estuary: 2022/2023 intertidal sediment monitoring summary. Salt Ecology Short Report 022, prepared for Otago Regional Council, March 2023. 2p.

Forrest BM, Roberts KL, Stevens LM 2022. Fine scale intertidal monitoring of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 093, prepared for Otago Regional Council, June 2022. 29p.

Robertson B, 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, Robertson BP, Stevens LM 2017. Shag Estuary: Fine Scale Monitoring 2016/17. Prepared for Otago Regional Council. 31p.

Robertson BM, Stevens L, Robertson B, et al. 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.

Stevens LM, Robertson BM 2017. Shag Estuary broad scale habitat mapping 2016/17. Prepared for Otago Regiona Council, May 2017. 26p.

APPENDIX 1. SUMMARY OF NEMP FINE-SCALE INDICATORS

The rationale for each indicator and sampling method is provided. The main 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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Samples sent to Hill Laboratories for analysis.
Nutrients (nitrogen and phosphorus), and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Organic matter measured as Total Organic Carbon (TOC) (note 1). Samples sent to Hill Laboratories for analysis.
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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site (note 2). Samples sent to Hill Laboratories for analysis.
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.	Ten sediment cores per site, split vertically, with average depth of aRPD (for each core) 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.	Ten sediment cores per site (130mm diameter, 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 (note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR (note 3).
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR (notes 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 used quadrat sampling in the first two surveys, but for the last survey used the 'SACFOR' approach: S = super abundant, A = abundant, C = common, F = frequent, O = occasional, R = rare . SACFOR was used instead of the quadrat sampling, which is subject to considerable within-site variation for epibiota that have clumped or patchy distributions (see Forrest et al. 2022 for further detail).

[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.

APPENDIX 2. CONDITION RATINGS FOR ASSESSING ESTUARY HEALTH

No rating criteria exist for Total Phosphorus (TP), or macrofauna variables other than AMBI. See Glossary for definition of indicators.

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		Requires development			
TOC[1]	%	<0.5	0.5 to <1	1 to <2	≥2
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.

APPENDIX 3. SEDIMENT QUALITY DATA

Values based on a composite sample within each of Zone X (reps X1-3), Y (reps Y4-6) and Z (reps Z7-10), except for aRPD in February 2019 for which the mean and range is shown for 10 replicates. The aRPD depth was not reported in December 2017.

Site	Year	Zone	Gravel %	Sand %	Mud %	TOC %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
A	Dec-16	X	2.9	72.7	24.3	0.17	<500	450	30	10.3	0.013	8.5	3.3	0.01	5.6	4.5	27
		Y	3.6	80.7	15.7	0.17	<500	470	30	11.5	0.015	8.7	3.4	0.02	5.9	4.7	27
		Z	3.9	78.8	17.2	0.18	<500	490	30	11.1	0.018	8.9	3.3	0.02	5.8	4.7	27
	Dec-17	X	0.7	78.4	20.9	0.18	<500	540	-	10.4	0.019	8.1	3	<0.02	4.9	4.6	29
		Y	1.2	81	17.8	0.18	<500	580	-	11.4	0.02	8.3	3.1	<0.02	5.3	4.6	30
		Z	1	80.7	18.3	0.16	<500	550	-	12.6	0.015	8.8	3	<0.02	5.4	4.8	31
	Feb-19	X	2.2	79.7	18.1	0.18	<500	500	33.3 (30 to 40)	12.4	0.017	9.2	3	<0.02	5.3	4.8	29
		Y	3.2	77.7	19	0.21	<500	530	36.0 (30 to 45)	11.1	0.014	8.9	3.2	<0.02	5.6	4.9	30
		Z	2.9	78.3	18.8	0.17	<500	530	34.0 (30 to 36)	11.9	0.014	9	3	<0.02	5.1	4.7	29
B	Dec-16	X	13.2	61.2	25.6	0.35	600	610	30	15.6	0.025	9.8	5.3	0.03	8.2	5.9	37
		Y	31.2	46.7	22.1	0.35	600	600	30	16.7	0.026	9.4	5.4	0.03	8.3	5.9	36
		Z	31	47.8	21.2	0.34	500	650	30	16.9	0.021	9.5	5.2	0.03	8	5.7	35
	Dec-17	X	8.8	75.7	15.5	0.21	<500	640	-	16.9	0.029	10.4	4.5	0.02	7.4	5.9	39
		Y	4.5	77.3	18.3	0.22	<500	550	-	12.5	0.02	9.9	4.4	0.03	7.1	5.4	35
		Z	5.6	78.6	15.8	0.22	<500	620	-	15.8	0.026	10.2	4.8	0.03	7.5	5.9	37
	Feb-19	X	28.3	47.1	24.6	0.4	600	650	15.0 (5 to 15)	15.5	0.028	10.5	5.7	0.02	7.4	6.2	39
		Y	7.5	67.5	24.9	0.28	<500	620	21.7 (15 to 25)	15.6	0.029	9.7	4.3	<0.02	6.9	5.8	34
		Z	4	74.5	21.6	0.22	<500	580	26.3 (20 to 35)	14.8	0.023	9.7	4.2	0.02	6.7	5.6	34
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

APPENDIX 4. MACROFAUNA CORE DATA SUMMED ACROSS TEN REPLICATES FOR EACH SURVEY AND SITE

Minor macrofauna renaming or aggregation to genus has been undertaken to standardise (to the extent feasible) across the different providers in December 2017 vs the other two surveys.

Main group	Taxa	EG	Dec-16 A	Dec-17 A	Feb-19 A	Dec-16 B	Dec-17 B	Feb-19 B
Amphipoda	Josephosella awa	II						4
Amphipoda	Paracalliope novizealandiae	I		166	29		19	
Amphipoda	Paracorophium excavatum	IV	1254	2946	2208	234	1017	1411
Amphipoda	Paramoera chevreuxi	II		6				
Anthozoa	Edwardsia sp. 1	II		2				
Bivalvia	Arthritica sp. 5	III	1	9			5	
Bivalvia	Austrovenus stutchburyi	II	15	21	20	3	2	1
Bivalvia	Legrandina turneri	na		4				
Bivalvia	Macomona liliana	II	1		1			
Copepoda	Copepoda	II	1					
Cumacea	Colurostylis lemurum	II		1				
Decapoda	Halicarcinus whitei	III		3	1			1
Decapoda	Hemiplax hirtipes	III	1	5	4	2	10	15
Gastropoda	Cominella glandiformis	III	1	2	2	4	2	1
Gastropoda	Diloma subrostratum	II		2			1	
Gastropoda	Micrelenchus huttonii	na		1				
Gastropoda	Notoacmea spp.	II		1				
Isopoda	Exosphaeroma planulum	V		1				
Mysida	Mysida	II		5			3	
Nemertea	Nemertea	III		1				
Oligochaeta	Oligochaeta	V		5			26	1
Polychaeta	Aglaophamus macroura	II		4				
Polychaeta	Aonides trifida	I		5			1	
Polychaeta	Boccardia syrtis	II	21	49	20	1	4	2
Polychaeta	Capitella spp.	V		8			21	
Polychaeta	Capitellidae (juv)	V			1			5
Polychaeta	Glycera spp.	II	1	1			2	
Polychaeta	Heteromastus filiformis	IV	7	5	2		2	
Polychaeta	Nereididae (juv)	III	3			4		3
Polychaeta	Paradoneis lyra	III	322	939	451	8	27	6
Polychaeta	Perinereis vallata	III		2		7	3	4
Polychaeta	Prionospio aucklandica	III	3	22		1		
Polychaeta	Scolecolepides benhami	IV	49	139	114	45	106	173
Polychaeta	Scoloplos cylindrifer	I	1	1	2			
	Richness		15	29	13	10	17	13
	Abundance		1681	4356	2855	309	1251	1627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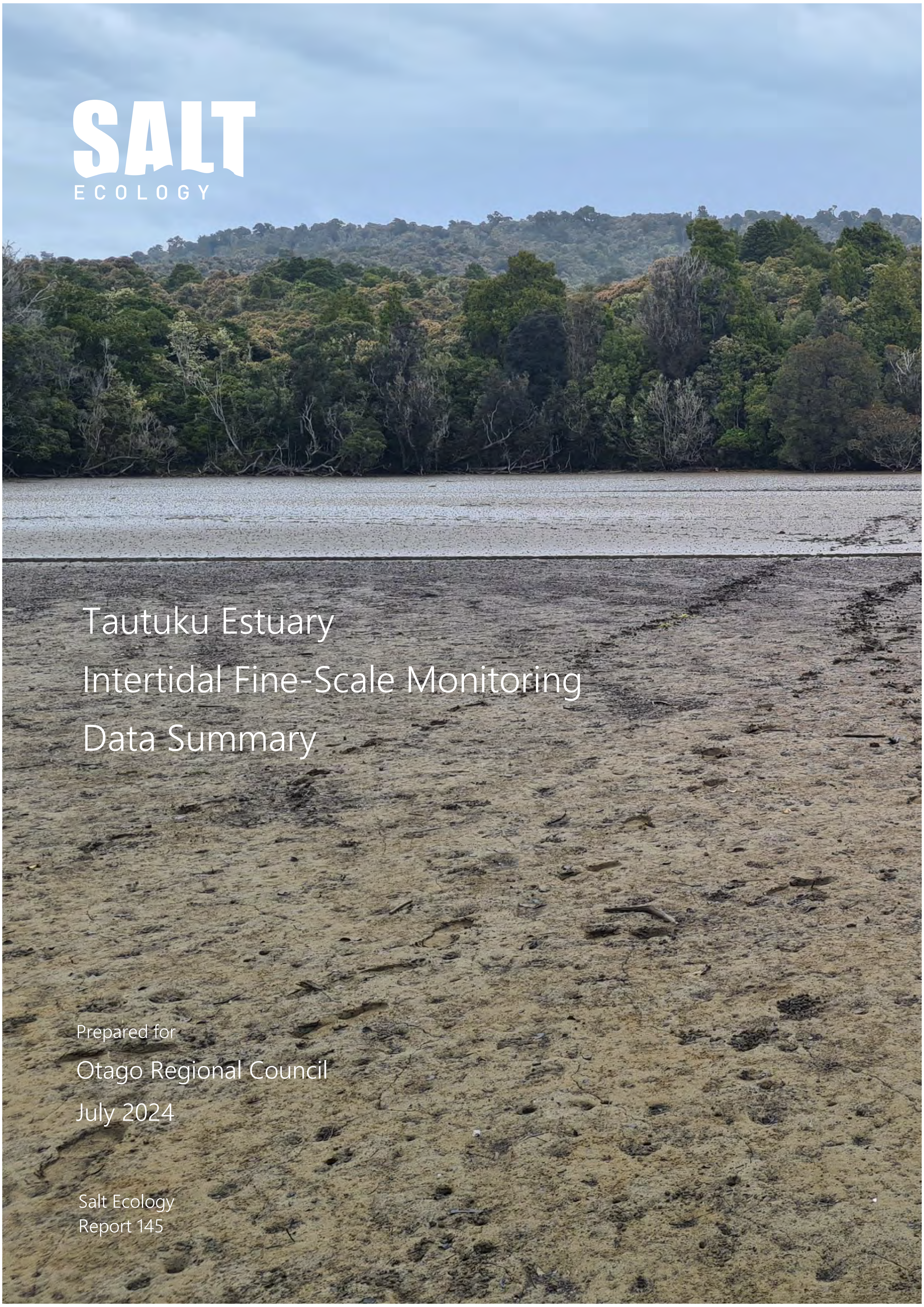

SALT ECOLOGY

Tautuku Estuary
Intertidal Fine-Scale Monitoring
Data Summary

Prepared for

Otago Regional Council

July 2024

Salt Ecology
Report 145

Cover photo: Tautuku Estuary, December 2023, intertidal flats and native bush catchment in the background which extends to the estuary margin.

RECOMMENDED CITATION

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For the People
Mō ngā tāngata

Tautuku Estuary Intertidal
Fine-Scale Monitoring Data Summary

Prepared by

Sorrel O'Connell-Milne,
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and Barrie Forrest

for

Otago Regional Council
July 2024

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For the environment
Mō te taiao

GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of Environment (Monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
Zn	Zinc

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TABLES

1. INTRODUCTION

Since December 2021, Otago Regional Council (ORC) has undertaken annual ecological and sediment quality surveys at two sites in Tautuku Estuary (hereafter Tautuku; Fig. 1). An initial report was compiled on the results of the first survey (Forrest et al. 2022) but data from the two subsequent surveys were archived. This report provides a high-level summary of the data for the three surveys to date, to support a planned review of ORC's estuary State of the Environment (SOE) monitoring programme. Tautuku is of particular interest as it is a relatively unmodified 'reference' estuary.

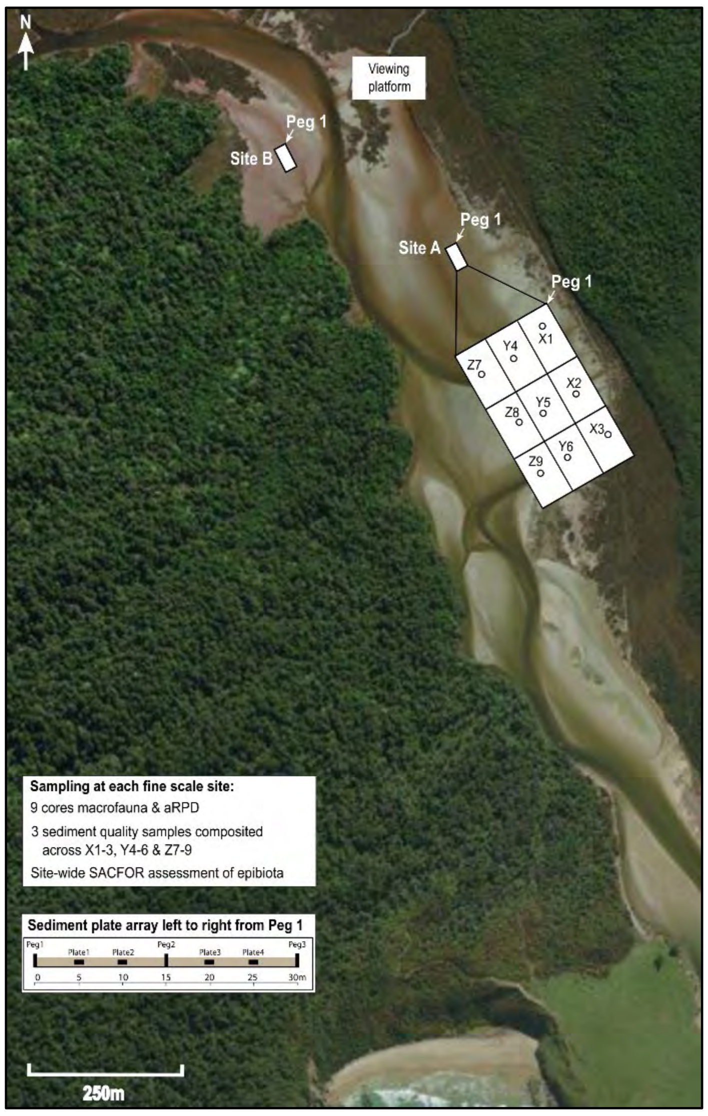

Fig. 1. Location of the two fine-scale monitoring sites in Tautuku. The schematic depicts the sediment sample and macrofauna core collection. Site information and GPS positions are provided in Forrest et al. (2022).

2. METHODS

The survey methods are described in Forrest et al. (2022) and were based on the 'fine-scale' approach in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). Monitoring indicators and methods are described in Appendix 1, and included:

<u>Sediment quality indicators:</u> Sediment mud content, oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients and organic content, and selected trace contaminants.

Sediment aRPD was measured in the field. For the other variables, three samples (each composited from 3-4 sub-samples of the surface 20mm of sediment) were collected and sent to Hill Labs for analysis. Annual sedimentation rates have also been measured, with results described in a separate report (Rabel 2024).

<u>Biotic indicators:</u> Surface-dwelling snails and macroalgae, and benthic macrofauna. Macrofauna sampling was undertaken using nine cores (130mm diameter, 150mm deep, ~2L volume, sieved to 0.5mm).

Macrofauna species taxonomy and counts were made by NIWA for all surveys. The data analysis methods are described in Forrest et al. (2022). Macrofauna assessment included calculation of scores for the international biotic health index 'AMBI'.

To assess estuary health, results for most indicators are evaluated against 'condition ratings' described in Appendix 2.

3. KEY FINDINGS

An overall summary of results, with condition ratings applied where available, is provided in Table 1.

3.1 SEDIMENT QUALITY

Sediment quality data are collated in Appendix 3. Sediments primarily comprised sand at Site A and sandy mud at Site B (Fig. 1). The amount of mud at each site has remained relatively stable in consecutive years. Site A is located on firm sand-dominated flats and mud content (~15-17%) was rated 'Fair' across all surveys. Site B is in a more depositional area further up the estuary and is less well-flushed than Site A. Mud content at Site B ranged from ~49-52%, which corresponds to a rating of 'Poor' as these values exceed a biologically relevant threshold of 25% mud where major changes in macrofauna composition are known to occur (Table 1). This overall pattern is consistent with concurrent sediment plate monitoring (Rabel 2024).

Table 1. Summary of mean values of key indicators at fine-scale monitoring sites in Tautuku. Values are rated against condition scores of ecological health, where available (Appendix 2). See Glossary for definitions.

Site	Survey Year	Mud %	aRPD mm	TN mg/kg	TP mg/kg	TOC %	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	Rich. na	Abun. na	AMBI na
A	Dec-21	14.8	45	< 500	367	0.39	7.6	0.012	7.7	3.1	< 0.02	5.0	2.0	20.6	6	453	4.5
	Dec-22	16.8	45	< 500	353	0.46	7.8	0.009*	7.7	3.1	< 0.02	4.9	2.0	20.5	4	392	4.5
	Dec-23	16.2	42	367	363	0.43	7.8	0.013	7.9	3.2	< 0.02	5.2	2.0	21.3	6	277	4.5
B	Dec-21	49.2	27	833	427	1.17	6.0	0.020	9.4	4.8	< 0.02	6.4	3.0	29.3	7	132	4.4
	Dec-22	49.0	22	900	413	1.32	5.5	0.022	9.2	5.0	< 0.02	6.2	3.2	29.3	5	153	4.4
	Dec-23	52.7	34	1167	457	2.03	5.8	0.035	10.5	5.9	0.02*	6.9	3.7	34.0	6	221	4.5

** Sample mean includes values below lab detection limits*
< All values below lab detection limit

Very Good | Good | Fair | Poor

Sediment oxygenation, assessed as aRPD, was rated 'Good' in all surveys and was deeper at Site A where sandier sediments enable more oxygen penetration, than at Site B (Table 1, Fig. 3). The core photos (right) illustrate the change in aRPD transition between brown surface sediment and deeper oxygen-depleted sediment at both sites. There were no signs of excessive sediment enrichment, such as an intense black colour throughout the depth profile or a strong sulphide ('rotten egg') odour when the sediment was disturbed.

Laboratory sediment analyses revealed low levels of organic matter (total organic carbon; TOC) and total nitrogen (TN) at Site A, corresponding to ratings of 'Very good' and 'Good', respectively (Table 1, Fig. 4). Elevated levels of TOC and TN were evident at Site B. TOC increased from 1.2 to 2.0% over the three surveys (declining in condition rating from 'Fair' to 'Poor'), and TN increased from 833 to 1167mg/kg (declining in rating from 'Good' to 'Fair'). Levels of the nutrient total phosphorus were also higher at Site B relative to Site A, yet remained low overall (Appendix 3).

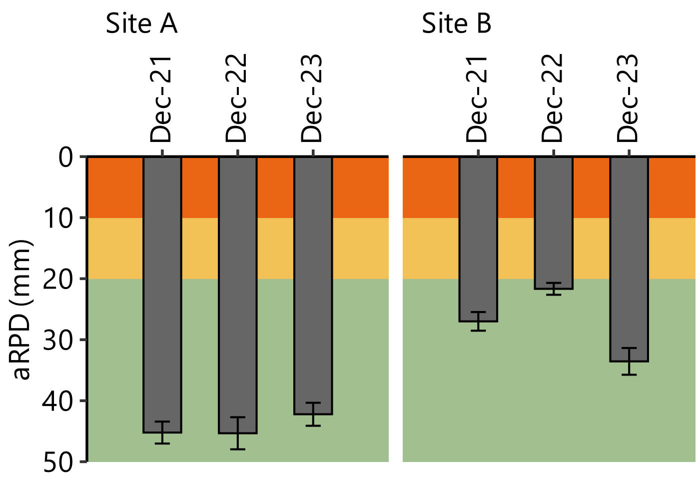

Fig. 3. Mean (±SE, n=9) aRPD depth, relative to condition ratings.

Very Good | Good | Fair | Poor

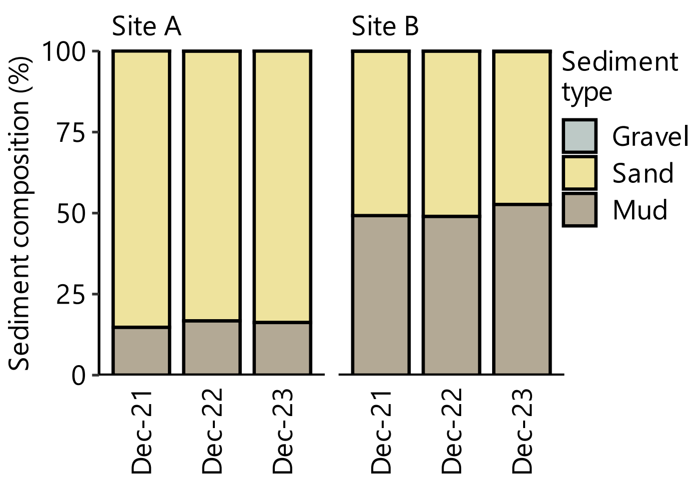

Fig. 2. Sediment particle grain size analysis showing percentage composition of mud (<63μm), sand (<2mm to ≥63μm) and gravel (≥2mm) from composite samples (n=3) at fine-scale sites.

Sediment core profiles from Site A (top, sand) and B (bottom, sandy mud) in December 2022. Oxygen-depleted sediment is illustrated by the deeper grey/black colour.

Generally, TOC levels above a threshold of 2% are expected to cause severe ecological effects (Sutula et al. 2014; Stevens et al. 2024). Therefore, it is surprising that the high TOC and TN levels at Site B were not accompanied by strong sediment enrichment. A plausible explanation is that TOC and TN concentrations are elevated due to inputs of terrestrial organic matter, which is refractory in nature. This means the material is not easily broken down by microbes, so even though the organic content is high, it does not lead to sediment enrichment.

Additionally, TOC/TN ratio values ≥12 are considered to represent a terrestrial organic matter source (e.g., Forrest et al. 2007 and references therein). Based on Table 1, the ratio of TOC/TN (when expressed on the same scale) is >14 at Site B. This result is therefore consistent with terrestrially derived organic material, and also consistent with field observations of terrestrial detritus within the sediment at Site B, especially in 2023 (see photos adjacent).

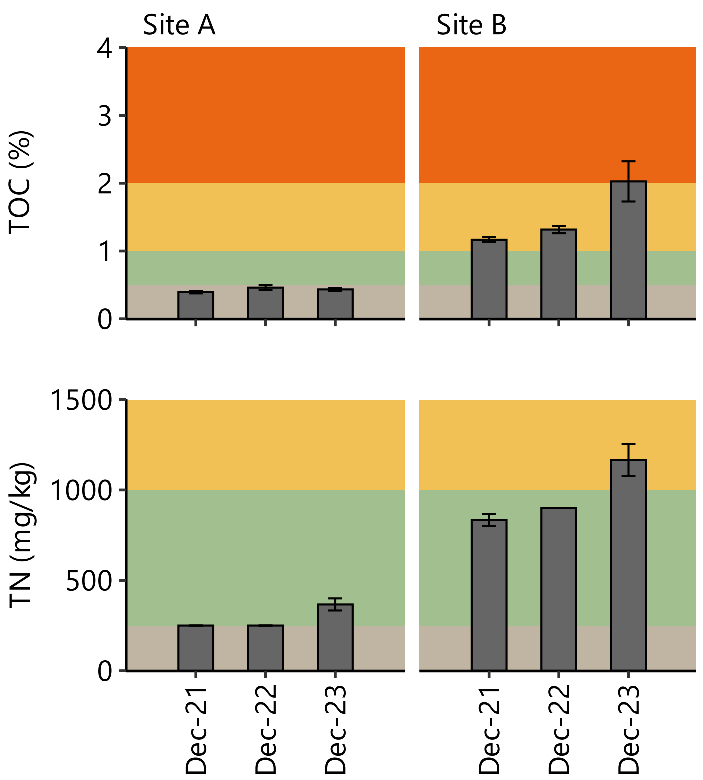

Fig. 4. Mean (±SE, n=3) total organic carbon (TOC) and total nitrogen (TN), relative to condition ratings. TN values at Site A in 2021 and 2022 were less than routine laboratory method detection limits and the values plotted are 50% of the detection limit.

Very Good | Good | Fair | Poor

Site A had firm sand dominated substrate low in organic material and nutrients, as pictured here in December 2022.

At Site B, during the most recent survey on 6 December 2023, there was evidence of considerable deposition of river-derived organic material such as leaf litter and smaller detritus.

Sediment trace metal contaminants were at very low concentrations in all three surveys. All values were less than half of the ANZG (2018) Default Guideline Value (DGV) which indicates "*...the concentrations below which there is a low risk of unacceptable effects occurring*" (Table 1, Fig. 5). Overall, these results suggest that there are no significant chemical contaminant inputs from the catchment that are accumulating in the estuary, and there were no trends of interest in concentration changes over time.

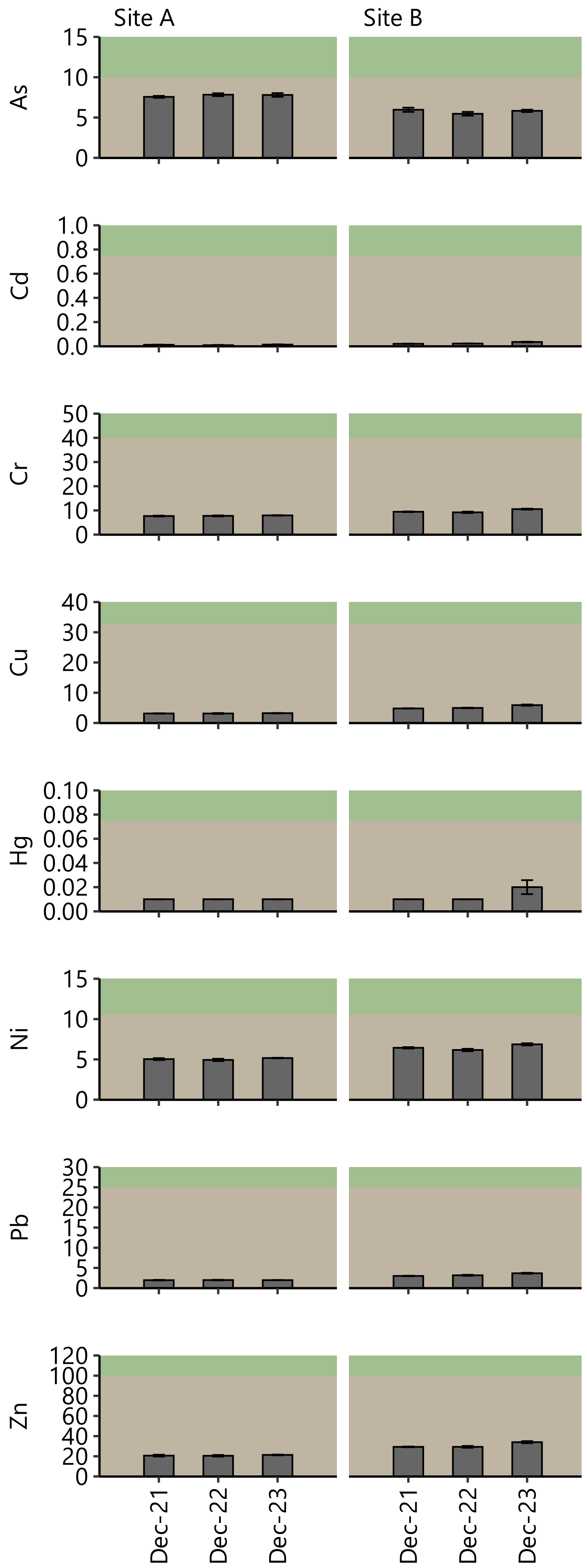

Fig. 5. Mean (±SE, n=3) trace metal concentrations, relative to condition ratings. The 'Very good' / 'Good' boundary represents 50% of the ANZG (2018) sediment quality Default Guideline Value (DGV).

3.2 BIOTA

Surface dwelling epibiota

Epibiota were sparse across both sites and reflective of the site characteristics discussed above. This observation mirrored the wider estuary, as few epibiota were observed during the broad scale survey (Forrest et al. 2022).

At Site A, the mud snail *Amphibola crenata* was frequent (2-8/m^2) across all years, and the estuary mud whelk *Cominella glandiformis* was rare (0.01m^2) in 2021, absent in 2022, and occasional (0.1m^2) in 2023. The substrates with elevated mud contents at Site B within the upper estuary supported more mud snails, which were common (11-20/m^2) in all years.

Both sites were bare of macroalgae in all surveys, however, in December 2021, microalgae were visible within areas of pooled water at Site A.

Mud snails *Amphibola crenata* were frequent at Site A (top) and common at Site B (bottom).

Sediment-dwelling macrofauna

Macrofauna core species and their abundances are summarised in Appendix 4. Macrofauna had low diversity in terms of the species present, with hardy species being most prevalent. Key points are as follows:

- A total of 30 species or higher macrofauna taxa have been recorded from the two sites over the three surveys. Thirteen main taxonomic groups were present, with polychaete worms by far the most abundant (Appendix 4).
- Mean species richness was similar across both sites, with an average of ~4-6 taxa per core across all three monitoring years. Slightly fewer taxa were identified at both sites in 2022 (Fig. 6a). This temporal fluctuation may reflect natural variability.
- The greatest abundances occurred at Site A, but decreased from a mean of 453 to 277 organisms per core between 2021 and 2023. Site B had lower abundances, but increased from a mean of 132 to 221 organisms per core between 2021 and 2023 (Fig. 6b; Table 1).

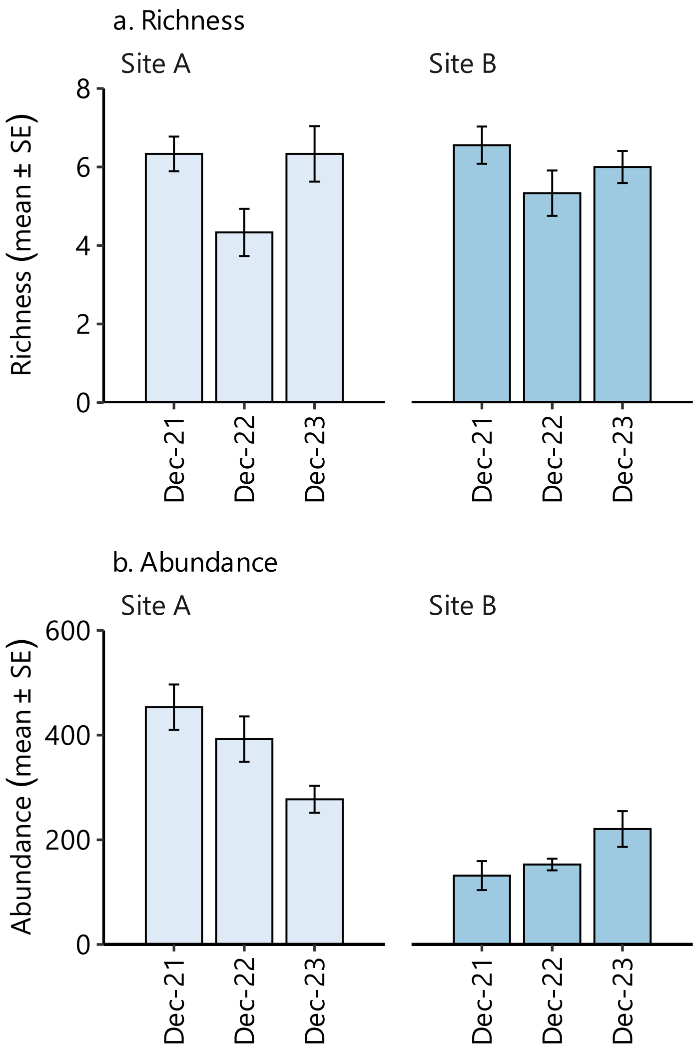

Fig. 6. Mean (±SE, n=9) macrofauna taxon richness and abundance per core.

- Mean values of the biotic index AMBI corresponded to a condition rating of 'Poor' at both sites across all survey years (Table 1, Fig. 7).
- Despite the taxa present representing all AMBI eco-groups (Fig. 8a, Table 2), macrofauna abundances were dominated by the tube-building amphipod *Paracorophium excavatum*, a hardy species in eco-group IV (Fig. 8b, Table 2). *P. excavatum* was more abundant at Site A than Site B. This species is common in disturbed environments, especially in river-dominated estuaries subject to highly variable flows and salinities.
- Although *P. excavatum* was numerically dominant, polychaete worms were the most well-represented group, and some species were present in moderate abundances. Many of the polychaetes are commonly found in estuaries nationally. In particular, the deposit-feeding *Scolecolepides benhami* (EG-IV) and *Capitella cf. capitata* (EG-V), and freshwater tolerant *Nicon aestuariensis* (EG-III), were ubiquitous across all sites and generally more abundant at Site B than Site A.
- Abundances of other organisms were relatively low. However, the small bivalve *Arthritica* sp.5, which is tolerant of fine sediments, was reasonably numerous with higher densities at Site B than Site A (Table 2). In 2023, *Arthritica* sp.5 decreased in abundance at both sites.

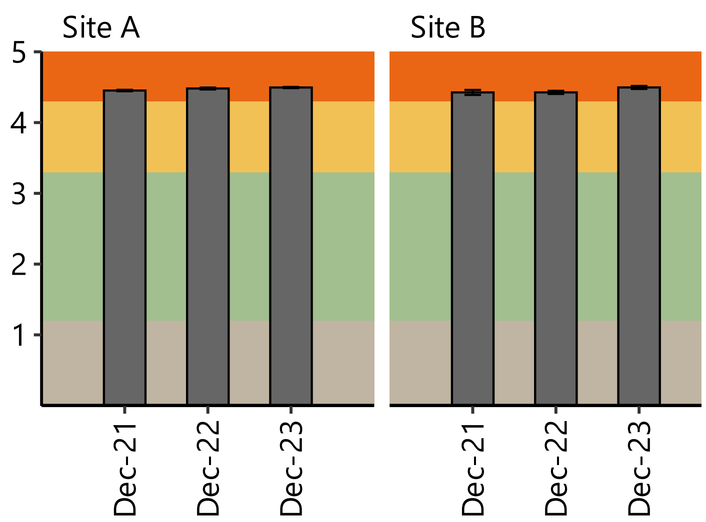

Fig. 7. Mean (±SE, n=9) AMBI scores, relative to condition ratings.

Table 2. Dominant sediment-dwelling macrofauna at Sites A and B. Numbers are site-aggregated total abundances.

Main group	Taxa	EG	Site A			Site B			Description
			Dec-21	Dec-22	Dec-23	Dec-21	Dec-22	Dec-23	
Amphipoda	*Paracorophium excavatum*	IV	3912	3401	2367	978	1149	1729	Corophioid amphipod that is an opportunistic tube-dweller, tolerant of muddy and low salinity conditions.
Bivalvia	*Arthritica sp. 5*	III	84	56	7	78	78	52	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.
Polychaeta	*Scolecolepides benhami*	IV	42	37	56	56	101	104	A spionid, surface deposit feeder. It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark.
Oligochaeta	*Naididae*	V	10	17	16	7	21	3	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered pollution or disturbance tolerant.
Polychaeta	*Capitella cf. capitata*	V	4	12	25	30	8	76	Subsurface deposit feeder, which is a common indicator of disturbance and dominant inhabitant of sediments polluted heavily with organic matter.
Decapoda	*Hemiplax hirtipes*	III	10	1	2	2	1	2	Deposit feeding stalk-eyed mud crab, endemic to New Zealand. Can be common in wet areas at the mid to low water level. Makes extensive burrows in the mud.
Polychaeta	*Nicon aestuariensis*	III	3	1	4	14	4	5	Omnivorous worm that is tolerant of freshwater.
Bivalvia	*Austrovenus stutchburyi*	II	3	0	2	2	2	3	Cockles are suspension feeding bivalves, living near the sediment surface. They can improve sediment oxygenation, increasing nutrient fluxes and influencing the type of macrofauna present. Important in diet of certain birds, rays and fish.
Decapoda	*Austrohelice crassa*	V				8	1	0	Endemic, burrowing mud crab, often found above mid-tide level. Highly tolerant of high silt/mud content.

The tube-building amphipod *Paracorophium excavatum* was by far the most dominant of the macrofauna at both sites (image from NIWA Otago estuaries collection).

The polychaete worm *Scolecolepides benhami* is a nationally ubiquitous species that was moderately abundant in Tautuku Estuary (image from NIWA Otago estuaries collection).

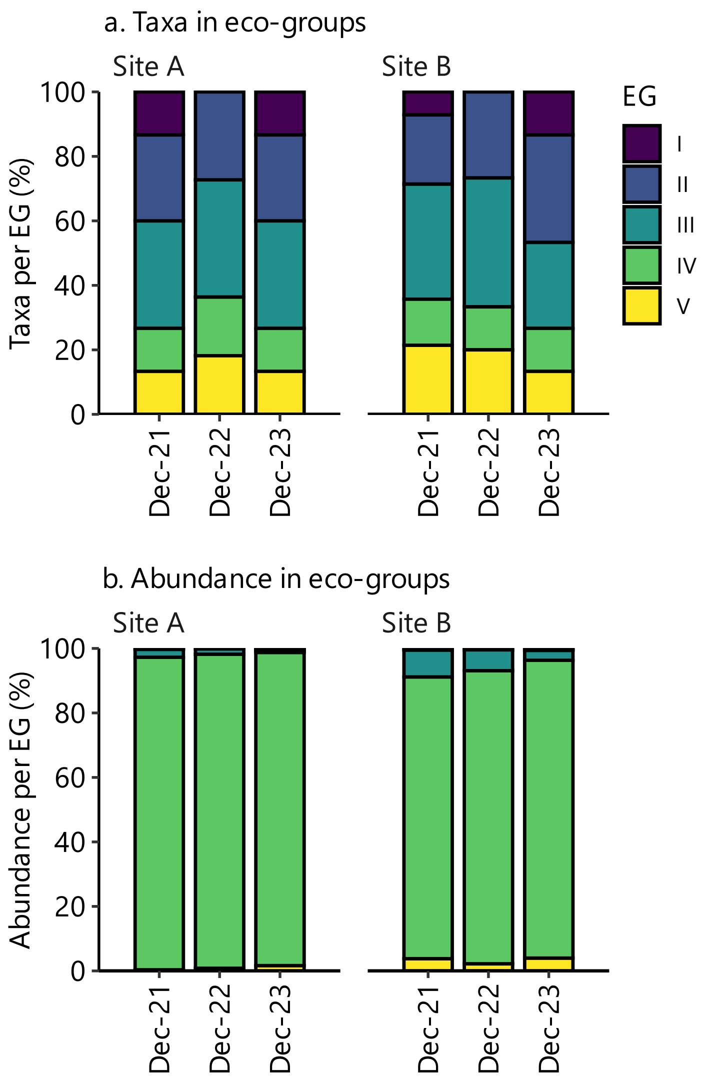

Fig. 8. Contribution to site richness and abundances of macrofauna species in eco-groups ranging from sensitive (EG-I) to resilient (EG-V).

A cursory analysis of overall macrofauna community composition differences among sites and surveys was undertaken. A multivariate method was used to 'group' sites according to their similarity in macrofauna composition (Fig. 9a), and reinforced the main patterns described above. Some key points are as follows:

- Macrofauna differences between the two sites were most evident in 2021 and 2022, but relative site differences were negligible in the latest December 2023 survey, with Site A and B clustering together on the MDS plot in Fig. 9.
- Despite the groupings in Fig. 9, the magnitude of community composition differences among sites and surveys is fairly minor. A 'Similarity Procedures' (SIMPER) analysis in Primer revealed that macrofaunal composition similarity among the three clusters in Fig. 9 was quite high (~70% as measured by the Bray-Curtis similarity index). Moreover, the within-group similarity was not much higher, and ranged from ~75-77%.

The above results mainly reflect abundance shifts in *P. excavatum* and some of the subdominant species, such as evident in Table 2. However, there were also composition differences among the minor species. For example, there were 4 species or higher taxa present at Site A in 2021 and 2022 that were not recorded at Site B, and 4 at Site B that were not recorded at Site A. In 2023 there were 5 species recorded across both sites which had not previously been observed in the estuary (Appendix 4). In all cases, these were subtle differences evident in organisms that occurred in low abundance, and hence have a relatively low chance of being detected by core sampling, i.e., they may have been present at each site/survey but missed during sampling due to their low numbers.

An examination of the influence of sediment quality parameters on community composition did not reveal any patterns that were strongly related. TOC, TN and mud were all highly correlated with each other ($r \geq 0.92$). Although Fig. 9 revealed an association between these parameters and the MDS ordination pattern, in a biota-environmental (BIO-ENV) analysis none had a strong influence on overall macrofauna composition changes (Spearman rank correlation coefficients, $\rho=0.06$ for mud, 0.04 for TN, -0.13 for TOC). Although the BIO-ENV correlation with aRPD was slightly stronger ($\rho=0.24$) it still points to only a weak association. Furthermore, given a condition rating of 'Good' across all years for aRPD, this indicator is unlikely to be ecologically significant in terms of cause-effect. Overall, the subtle shifts in macrofauna among sites and over time probably have little to do with the changes in sediment quality indicators.

The preceding conclusion contrasts the first survey report (Forrest et al. 2022), in which mud (and correlated variables) emerged as a potential explanation for differences between Sites A and B. However, that analysis was based on a single sampling event, with our subsequent analysis highlighting the importance of establishing a multi-year baseline to better understand natural variability, and provide further insight into potential explanations for ecological changes. In the absence of strong evidence for the importance of any of the measured sediment quality variables, other plausible explanations need to be recognised. These include the random sampling variation noted above, macrofauna recruitment variability, and strong physical influences from Tautuku River that may over-ride the effects of the sediment indicators (e.g., fluctuations in salinity and organic matter delivery, and flow-related changes in sediment scouring or deposition).

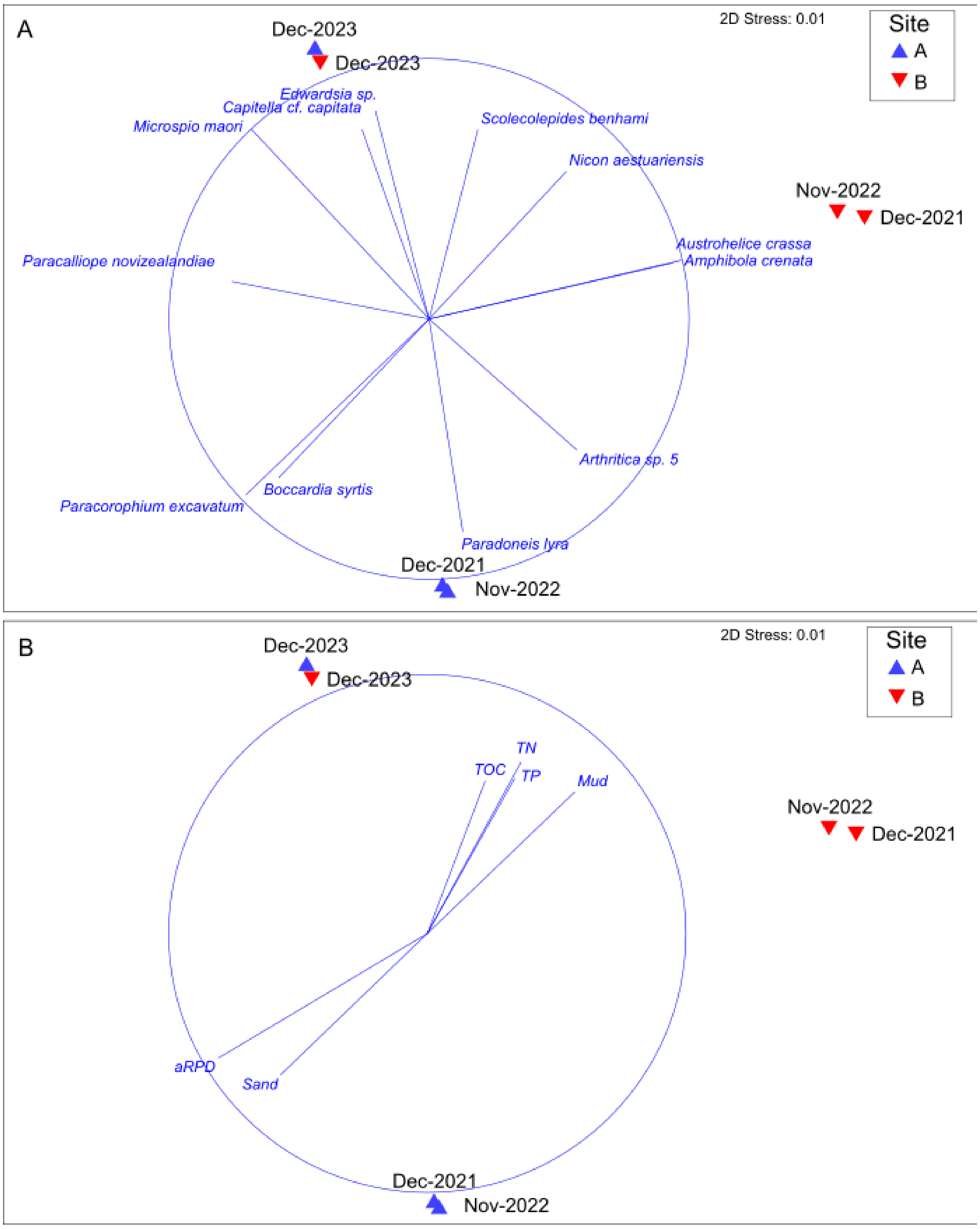

Fig. 9. Non-metric MDS ordination of macrofaunal core samples for data aggregated within each site and survey.

Sample groups closer to each other are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of 0.01 indicates that a 2-dimensional plot provides a reliable representation of differences. The vectors show the direction and strength of association (length of line relative to circle) of the species (A) and measured sediment quality variables (B) most strongly correlated with the pattern of differences. Although some of the sediment quality variables appeared associated with the ordination pattern above, they were only weakly correlated with overall changes in macrofaunal composition (see text).

4. MONITORING AND MANAGEMENT IMPLICATIONS

ORC undertook broad-scale habitat mapping of Tautuku in 2021 (Roberts et al. 2022), complemented by the comprehensive baseline fine-scale monitoring described in this report. The combined results of these reports suggest that the estuary is in good health overall, despite some areas of muddy sediment accumulation. This, alongside a high degree of naturalness in the catchment following recovery from past disturbances, makes Tautuku a reference system for other estuaries in Otago.

That said, the fine scale sites themselves appear less useful in a reference estuary sense than alternative approaches such as broad-scale habitat mapping. The sites are in the mid-upper estuary and appear to be strongly influenced by Tautuku River. Although Tautuku was classified by Plew et al. (2018) as a shallow intertidally dominated estuary (SIDE), the area in which the fine scale sites are located has characteristics that align more closely with tidal river-dominated estuaries. A recent overview of these systems in a report to the Ministry for the Environment highlighted the over-riding influence of physical drivers (especially river flow, salinity regime & water column stratification) in determining ecological state (Forrest et al. 2024). The Tautuku fine-scale sites have many of the characteristics described for tidal river estuaries generally. In particular, the biota appears to be naturally impoverished, with poor AMBI scores in the Tautuku situation driven by very high abundances of a single hardy amphipod species (*P. excavatum*).

These same features can be seen in other river-dominated estuaries in Otago and nationally, despite most of the comparable systems being at the bottom of highly modified catchments (e.g., Tokomairiro Estuary). In other words, the physical drivers of state in river-dominated estuary areas can be so influential that they over-ride the potential effects due to catchment land use differences. A specific implication is that these types of systems are relatively insensitive to changes in anthropogenic stressors such as increased muddy sediment loads. Despite this situation, it has been valuable to establish a monitoring baseline at the Tautuku fine-scale sites, as it highlights the importance of natural drivers of estuary state in river-dominated systems, irrespective of anthropogenic influences (bearing in mind that elevated muddiness in the upper estuary is most likely a legacy of historic catchment land use such as logging and drainage). However, like other similar estuaries in Otago, the utility of the Tautuku sites for long-term monitoring is less clear and needs further discussion.

In the very long term (i.e., decades) there is an intuitive appeal in undertaking fine-scale monitoring in an estuary in a relatively unmodified catchment. Better sites would be ideal, but there appears to be little scope to fine alternative locations in Tautuku that would be more useful for long-term monitoring of reference state. A cursory check during initial fine-scale site reconnaissance in 2021 suggested that the tidal flats in the mid-lower estuary, which consisted mainly of mobile sands, also appeared quite impoverished in terms of their biota (Forrest et al. 2022). One potential concept to enhance the benefit of having a reference estuary would be to increase macrofauna sampling effort (given sufficient funds and resources) to better characterise the depauperate macrofauna community present (i.e., better sample the uncommon species) and enhance the ability to detect community shifts due to climate driven changes such as sea level rise and marine heat waves, as well as recruitment events and natural variability.

One of the reasons for compiling the present summary report was to better understand the utility of the current monitoring approach. Once data for all Otago estuaries have been collated in a similar way, ORC will be in a better position to review the regional estuary programme and determine monitoring priorities. In this broader context, Tautuku presents some features described above that will need to be accounted for. The review should consider the specific type of monitoring that is needed in the context of management goals in Tautuku, the utility of Tautuku as a reference estuary, and the priorities for monitoring relative to other estuary systems in Otago.

5. RECOMMENDATIONS

There is merit in continued monitoring in Tautuku given its recognised value as a reference estuary, but the limitations of the current fine-scale sites need to be recognised. It is recommended that a decision on the approach taken to future fine-scale and other monitoring needs for Tautuku is determined as part of ORC's planned review of the regional estuary SOE programme.

6. 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.

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.

Forrest BM, Gillespie PA, Cornelisen C, Rogers K 2007. Multiple indicators reveal river plume influence on sediments and benthos in a New Zealand coastal embayment. New Zealand Journal of Marine and Freshwater Research 41: 13-24.

Forrest BM, Roberts KL, Stevens L 2022. Fine Scale Intertidal Monitoring of Tautuku Estuary. Salt Ecology Report 092, prepared for Otago Regional Council, June 2022. 27p.

Forrest BM, Roberts KL, Plew DR, Dudley BD, Stevens LM 2024. Guidance for Assessment and Monitoring of Tidal River Estuaries. Salt Ecology Report 133, prepared for Ministry for the Environment, June 2024. 53p.

Plew D, Dudley B, Shankar U, Zeldis J 2018. Assessment of the eutrophication susceptibility of New Zealand estuaries. Prepared by NIWA for the Ministry for the Environment. 64p.

Rabel H 2024. Tautuku Estuary: 2023/2024 Intertidal Sediment Monitoring Summary. Salt Ecology Short Report 045 for Otago Regional Council, May 2024.

Roberts KL, T. S-S, Stevens L, Forrest BM 2022. Broadscale intertidal habitat mapping of Tautuku Estuary. Salt Ecology Report 087, prepared for Otago Regional Council, June 2022. 48p.

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 L, 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.

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 Indicators 34: 560-570.

Stevens LM, Roberts KL, Forrest BM, Morrisey D, Zeldis JR, Dudley BD, Mangan S, Lam-Gordillo O, Lundquist C, Lohrer AM, Plew DR 2024. Advice on Indicators, Thresholds and Bands for Estuaries in Aotearoa New Zealand. Salt Ecology Report 141, prepared for Ministry for the Environment, June 2024. 182p.

Sutula M, Green L, Cicchetti G, Detenbeck N, Fong P 2014. Thresholds of Adverse Effects of Macroalgal Abundance and Sediment Organic Matter on Benthic Habitat Quality in Estuarine Intertidal Flats. Estuaries and Coasts 37(6): 1532-1548.

APPENDIX 1. SUMMARY OF NEMP FINE-SCALE INDICATORS

The rationale for each indicator and sampling method is provided. The main 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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Samples sent to Hill Labs for analysis.
Nutrients (nitrogen and phosphorus), and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Organic matter measured as Total Organic Carbon (TOC)[1]. Samples sent to Hill Labs for analysis.
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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site[2]. Samples sent to Hill Labs for analysis.
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.	Nine sediment cores per site, split vertically, with average depth of aRPD (for each core) 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.	Ten sediment cores per site (130mm diameter, 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[3].
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR[3].
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR[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 (abundance), macroalgae (%) and microalgae (%) used the 'SACFOR' approach: S=Super abundant (>1000 organisms/m^2, >50% cover), A=Abundant (100-999 organisms/m^2, 20-50% cover), C=Common (10-99 organisms/m^2, 10-19% cover), F=Frequent (2-9 organisms/m^2, 5-9% cover), O=Occasional (0.1-1 organisms/m^2, 1-4% cover), and R=Rare (<0.1 organisms/m^2, <1% cover). See Forrest et al. 2022 for further detail.

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.

APPENDIX 2. CONDITION RATINGS FOR ASSESSING ESTUARY HEALTH

No rating criteria exist for Total Phosphorus (TP), or macrofauna variables other than AMBI. See Glossary for definition of indicators.

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
TOC[1]	%	<0.5	0.5 to <1	1 to <2	≥2
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.

APPENDIX 3. SEDIMENT QUALITY DATA

Values based on a composite sample within each of Zone X (reps X1-3), Y (reps Y4-6) and Z (reps Z7-9), except for aRPD for which the mean and range is shown for 9 replicates.

DGV = Default guideline value for sediment quality (ANZG 2018); GV-High = Guideline Value High.

Site	Survey	Zone	Gravel %	Sand %	Mud %	TOC %	TN mg/kg	TP mg/kg	aRPD mm (range)	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
A	Dec-21	X	<0.1	87.1	13.0	0.37	<500	360	48.3 (40 to 55)	7.40	0.014	7.3	3.0	<0.02	4.8	1.83	19
		Y	<0.1	85.3	14.7	0.43	<500	380	40.7 (40 to 42)	7.80	0.011	7.9	3.2	<0.02	5.1	2.10	22
		Z	<0.1	83.4	16.6	0.38	<500	360	46.7 (45 to 50)	7.50	0.011	7.8	3.2	<0.02	5.2	1.93	21
	Nov-22	X	<0.1	83.7	16.3	0.40	<500	320	46.7 (40 to 55)	7.50	0.01	7.4	2.9	<0.02	4.7	1.85	19
		Y	<0.1	82.9	17.1	0.46	<500	360	46.0 (38 to 60)	8.10	0.011	7.7	3.1	<0.02	4.9	2.00	20
		Z	<0.1	83.0	16.9	0.52	<500	380	43.3 (40 to 50)	7.90	<0.010	8.1	3.4	<0.02	5.2	2.10	22
	Dec-23	X	<0.1	83.6	16.4	0.40	300	350	43.3 (40 to 45)	7.40	0.011	7.8	3.1	<0.02	5.1	1.90	21
		Y	<0.1	84.7	15.3	0.43	400	350	38.3 (30 to 45)	8.20	0.011	7.9	3.3	<0.02	5.2	1.98	21
		Z	<0.1	83.0	17.0	0.47	400	390	45.0 (40 to 50)	7.80	0.018	8.1	3.3	<0.02	5.2	2.00	22
B	Dec-21	X	<0.1	51.7	48.2	1.13	900	440	26.7 (20 to 30)	6.40	0.018	9.7	4.9	<0.02	6.6	3.10	30
		Y	0.1	48.7	51.2	1.13	800	430	24.3 (23 to 25)	6.00	0.020	9.3	4.7	<0.02	6.3	3.00	29
		Z	<0.1	51.7	48.3	1.24	800	410	30.0 (25 to 35)	5.50	0.022	9.3	4.8	<0.02	6.4	2.90	29
	Nov-22	X	<0.1	53.2	46.8	1.22	900	470	20.0 (17 to 23)	5.90	0.024	9.7	5.1	<0.02	6.4	3.40	31
		Y	<0.1	55.0	44.9	1.41	900	380	21.7 (20 to 25)	5.10	0.021	8.7	4.8	<0.02	5.9	3.00	28
		Z	<0.1	44.7	55.3	1.32	900	390	23.3 (20 to 25)	5.40	0.022	9.2	5.0	<0.02	6.2	3.10	29
	Dec-23	X	0.1	49.8	50.1	2.60	1300	480	39.3 (35 to 45)	5.80	0.040	10.9	6.3	0.03	7.0	3.90	36
		Y	0.3	46.8	52.9	1.87	1200	460	30.3 (27 to 32)	5.60	0.033	10.3	5.7	0.02	6.6	3.50	33
		Z	<0.1	44.9	55.0	1.61	1000	430	31.0 (25 to 40)	6.10	0.032	10.4	5.7	<0.02	7.0	3.60	33
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

APPENDIX 4. MACROFAUNA CORE DATA SUMMED ACROSS NINE REPLICATES FOR EACH SURVEY AND SITE

Main group	Taxa	EG	Dec-21		Dec-22		Dec-23	
			A	B	A	B	A	B
Amphipoda	*Josephosella awa*	II						2
	Paracalliope novizealandiae	I	4				2	2
	Paracorophium excavatum	IV	3912	978	3401	1149	2367	1729
	Parawaldeckia kidderi	II	1	1				
Anthozoa	*Edwardsia* sp.	II				1	1	1
Bivalvia	*Arthritica* sp. 5	III	84	78	56	78	7	52
	Austrovenus stutchburyi	II	3	2		2	2	3
Copepoda	Copepoda	II			2	1		2
Cumacea	*Colurostylis lemurum*	II					3	
Decapoda	*Austrohelice crassa*	V		8		1		
	Hemiplax hirtipes	III	10	2	1	1	2	2
Gastropoda	*Amphibola crenata*	III		2		1		
	Diloma subrostratum	II			1			
Mysida	Mysida	II				2	7	
Nematoda	Nematoda	III						2
Nemertea	Nemertea	III	1				1	
	Nemertea sp. 2	III					2	
Oligochaeta	Naididae	V	10	7	17	21	16	3
Polychaeta	*Aonides trifida*	I		2				
	Boccardia syrtis	II	1		2			1
	Capitella cf. capitata	V	4	30	12	8	25	76
	Exogoninae spp.	II		1				
	Microspio maori	I					1	1
	Nicon aestuariensis	III	3	14	1	4	4	5
	Paradoneis lyra	III	2		1	1		
	Perinereis vallata	III				4		
	Prionospio aucklandica	III		3				
	Sabellidae	I	1					
	Scolecolepides benhami	IV	42	56	37	101	56	104
Tanaidacea	Tanaidacea	II	2					
	Site richness		15	14	11	15	15	15
	Site abundance		4080	1184	3531	1375	2496	1985


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TAUTUKU ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 045. Prepared by Hayden Rabel for Otago Regional Council, May 2024

OVERVIEW

Since December 2021, Otago Regional Council has undertaken annual State of the Environment monitoring in Tautuku Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 6 December 2023. Tautuku is of particular interest as a relatively unmodified "reference" estuary (Forrest et al. 2022).

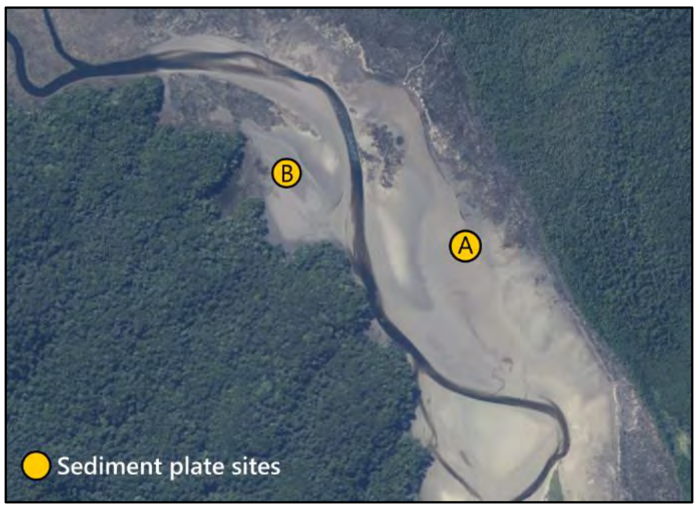
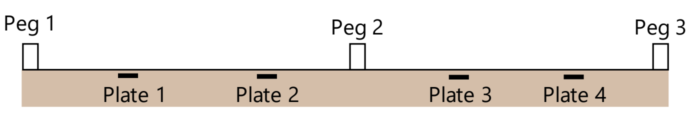


Fig. 1. Location of Tautuku Estuary monitoring sites.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., Forrest et al. 2022). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness.

Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Annual results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2.

Table 2. Indicator summary and condition ratings from the December 2023 survey.

Indicator	A	B
Sedimentation (mm/yr)*	+3.0	+3.9
Mud content (%)	17.3	55.3
aRPD (mm)	35	31

* Sedimentation is presented as the mean annual rate over the monitored period (n=2 yrs). Five years of data are recommended for a meaningful trend.

Sedimentation rate

Sedimentation has been variable in the first two years of monitoring, especially among plates at Site B (Table 3, Fig 2). Site B appears strongly affected by Tautuku River, with deposition of mud and detritus apparent in December 2023. At both sites average sedimentation has exceeded of the 2mm/yr guideline (Table 2). However, meaningful characterisation of trends may require at least five years of data.

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in Forrest et al. (2022).

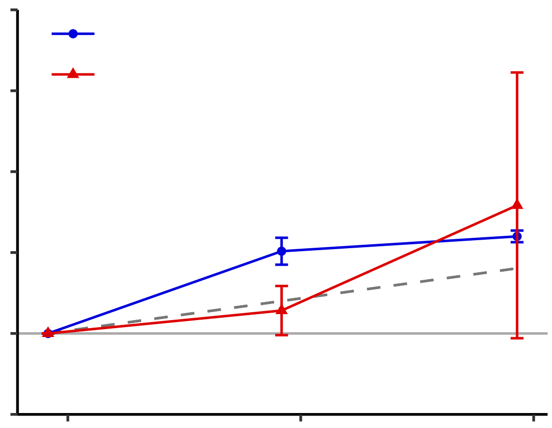


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment oxygenation (aRPD transition from brown to dark grey sediment) at Site A (left) and Site B (right) in December 2023.

Sediment mud content and oxygenation

Sites A and B continue to have 'fair' and 'poor' sediment mud-content ratings, respectively (Table 1, Table 3). For Site B, these sediment mud-contents are in exceedance of the biologically relevant threshold of 25%, which is likely due to this site being in a depositional area that is less well-flushed than Site A (which is located on more exposed flats).

Table 3. Annual sedimentation, grain size and aRPD results up to December 2023.

Site	Survey	Sed rate mm/yr	Gravel %	Sand %	Mud %	aRPD mm
A	Dec-2021	na	< 0.1	83.9	16.1	50
	Dec-2022	5.1	< 0.1	79.7	20.3	45
	Dec-2023	0.9	0.1	82.7	17.3	35
B	Dec-2021	na	0.1	46.4	53.5	20
	Dec-2022	1.4	0.2	51.5	48.3	12
	Dec-2023	6.4	0.2	44.6	55.3	31

< All values below lab detection limit

Sand-dominated sediment at Site A (left) and deposits of mud and detritus along Site B margins (right) in December 2023.

Sediment oxygenation appears to be linked to sediment grain-size patterns, where the coarser sediments of Site A allow more oxygen to penetrate through sediment layers, resulting in a deeper aRPD than in the finer sediment at Site B. However, both sites are generally well oxygenated, receiving condition ratings of 'good' in December 2023 (Table 1, Table 3).

CONCLUSION

Given that the Tautuku Estuary catchment is largely unmodified, the benefit of monitoring its sediment is largely to provide a 'reference' for other river-dominated estuaries in the region (Forrest et al. 2022). At least five years of data are recommended for meaningul trends to be established. However, early results are building a picture of the difference in sediments between depositional areas such as at Site B and the more exposed mid-upper estuary flats represented by Site A.

RECOMMENDED MONITORING

Continue annual monitoring and reporting of sedimentation rate, sediment grain size and aRPD depth.

REFERENCES

Forrest BM, Roberts, KL, Stevens LM. 2022. Fine Scale Intertidal Monitoring of Tautuku Estuary. Salt Ecology Report 092, prepared for Otago Regional Council, June2022. 27p

TOKOMAIRIRO ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 046. Prepared by Hayden Rabel for Otago Regional Council, May 2024

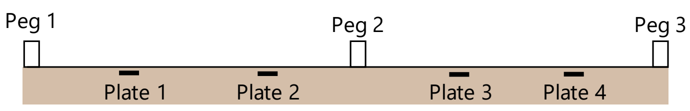
OVERVIEW

Since December 2017, Otago Regional Council has undertaken annual State of the Environment monitoring in Tokomairiro Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring was initially undertaken at three sites, with ongoing monitoring at Sites B and C only (Fig. 1). The latest survey was carried out on 12 January 2024.

Fig. 1. Location of Tokomairiro Estuary monitoring sites. Site A has been discontinued.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., Forrest et al. 2020). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness.

Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Annual results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2.

Table 2. Indicator summary and condition ratings from the January 2024 survey.

Indicator	B	C
Sedimentation (mm/yr)*	+0.9	-1.3
Mud content (%)	71.6	51.2
aRPD (mm)	10	5

* Sedimentation is presented as the long-term mean annual rate over the monitored period (n=6 yrs).

Sedimentation rate

Net sediment erosion was observed for a second consecutive year at both sites, with -0.7mm at Site B and -2.4mm at Site C (Table 3). These latest results improve the long-term sedimentation rating at Site B from 'fair' in Nov-2022 to 'good' in Jan-2024 (Table 1, Table 3). The long-term annual rates at both sites are less than the upper guideline value of 2mm/yr (Fig. 2).

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in Forrest et al. (2020).

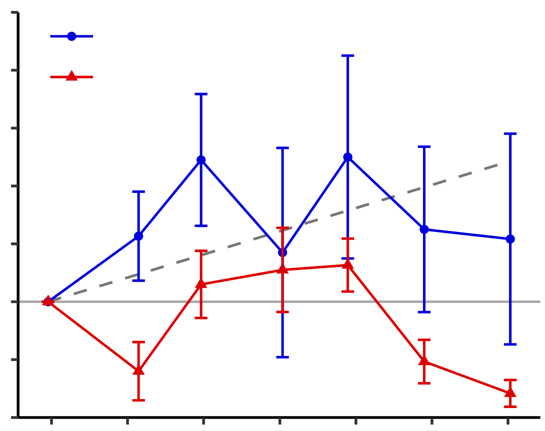


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

Sediment mud content continues to exceed the biologically relevant threshold of 25% (Table 3). Tokomairiro Estuary drains a large catchment whose land uses are predominantly agriculture (54%) and forestry (35%), which are known sources of muddy sediment (Forrest et al. 2020).

Measurements of aRPD depths in Jan-2024 were largely consistent with earlier surveys (rated 'fair' Site B, 'poor' Site C). Note that the aRPD at Site C reflects a minimum depth of 5mm, however sediment cores were oxygenated to a depth of >100mm in places.

Table 3. Annual sedimentation, grain size and aRPD results up to January 2024.

Site	Survey	Sed rate mm/yr	Gravel %	Sand %	Mud %	aRPD mm
B	Dec-2017	na	0.6	34.9	64.6	10
	Feb-2019	4.8	0.6	31.0	68.4	5
	Dec-2019	13.0	0.9	38.5	60.6	5
	Jan-2021	-7.5	0.4	31.7	67.9	7
	Nov-2021	9.6	0.1	36.7	63.2	17
	Nov-2022	-6.2	0.7	29.6	69.7	15
	Jan-2024	-0.7	0.3	28.2	71.6	10
C	Dec-2017	na	3.0	40.7	56.3	10
	Feb-2019	-5.0	2.2	40.2	57.6	3
	Dec-2019	9.7	6.0	35.8	58.2	4
	Jan-2021	1.2	4.1	47.9	47.9	5
	Nov-2021	0.5	3.2	39.8	57.0	8
	Nov-2022	-8.3	1.8	42.7	55.5	8
	Jan-2024	-2.4	1.9	46.8	51.2	5

Muddy sediment at Site C in January 2024, with shallow aRPD in parts but also areas that appear oxygenated to >100mm .

CONCLUSIONS

Sedimentation rates since December 2017 have been variable at both sites in Tokomairiro Estuary, with recent surveys suggesting the sites are experiencing minor erosion. Given these sites' proximity to the Tokomairiro River channel, sedimentation is likely to continue fluctuating over time. The consistent muddiness of sediment and usually low (although variable at Site C) sediment oxygenation at both sites, indicate degraded ecosystem health and reinforce previous recommendations (e.g., Forrest et al. 2020) to manage catchment inputs to the estuary. While the sediments are showing only mild symptoms of organic enrichment, both sites have a patchy cover of *Ulva* spp. and/or other algae, which suggests these sites may be susceptible to elevated nutrient inputs. Algal growth prior to the January 2024 survey may have been exacerbated by sand build-up that blocked the estuary and resulted in a lagoon forming in the estuary.

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Consider site suitability and ongoing monitoring as part of a wider estuary programme review to be undertaken by ORC.

REFERENCES

Forrest BM, Stevens LM, Rabel H. 2020. Fine scale intertidal monitoring of Tokomairiro Estuary. Salt Ecology Report 043, prepared for Otago Regional Council. 42p.

WAIKOUAITI ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 047. Prepared by Hayden Rabel for Otago Regional Council, May 2024

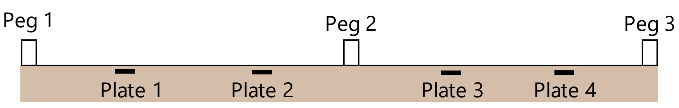
OVERVIEW

Since December 2016, Otago Regional Council has undertaken annual State of the Environment monitoring in Waikouaiti Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at three sites (Fig. 1), with the latest survey carried out on 2 December 2023.

Fig. 1. Location of Waikouaiti Estuary monitoring sites. In 2020, Site B1 replaced nearby Site B, which was washed away.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., O'Connell-Milne et al. 2023). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness. Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Annual results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2.

Table 2. Indicator summary and condition ratings from the December 2023 survey.

Indicator	A	B1	C
Sedimentation (mm/yr)*	-2.1	+0.7	-2.4
Mud content (%)	8.6	6.9	29.6
aRPD (mm)	30	8	20

* Sedimentation is presented as the long-term mean annual rate over the monitored period (n=4 yrs Sites A & B1, and n=7 yrs Site C). Five years of data are recommended for a meaningful trend.

Sedimentation rate

Sites A and C have had net erosion of sediment since monitoring began, with a rating of 'very good', while Site B1 has had minimal sediment accrual, rated 'good' (Table 2). Sites A and B1 have been highly variable and show almost opposing patterns of annual erosion and accrual (Fig. 2, Table 3). The variability at Sites A and B1 likely reflects the dynamic hydrological environment of these sites, as they are both close to the river channel. Site C is in a relatively sheltered estuary side-arm.

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in O'Connell-Milne et al. (2023).

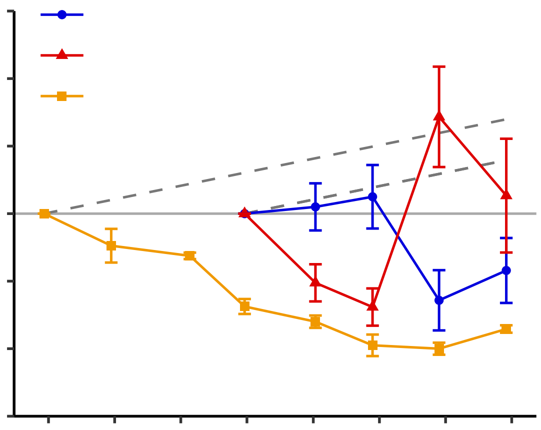


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey lines show sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

Sediment mud content has remained relatively stable at each site over the monitoring period (Table 3). Sites A and B1 have been predominantly rated 'good', with mostly gravel and sand sediment. Contrastingly, Site C consists of soft, muddy sand, with a sediment mud content consistently exceeding the biologically relevant threshold of 25% (Table 1; rated 'poor').

Table 3. Annual sedimentation, grain size and aRPD results up to December 2023.

Site	Survey	Sed rate mm/yr	Gravel %	Sand %	Mud %	aRPD mm
A	Dec-2019	na	11.8	80.4	7.8	75
	Jan-2021	0.9	24.9	69.4	5.7	30
	Nov-2021	1.7	15.4	78.0	6.6	50
	Nov-2022	-15.2	7.3	83.9	8.7	60
	Dec-2023	4.3	17.7	73.7	8.6	30
B1	Dec-2019	na	25.3	67.7	7.0	10
	Jan-2021	-9.6	27.8	66.8	5.4	8
	Nov-2021	-4.2	18.7	76.7	4.6	8
	Nov-2022	28.0	4.1	92.1	3.8	50
	Dec-2023	-11.5	10.5	82.6	6.9	8
C	Dec-2016	na	0.3	68.9	30.9	0
	Dec-2017	-4.7	0.2	69.5	30.3	-
	Feb-2019	-1.3	0.4	71.4	28.3	20
	Dec-2019	-9.1	0.2	70.8	29.1	18
	Jan-2021	-2.1	0.3	71.3	28.4	25
	Nov-2021	-4.1	0.2	73.3	26.5	12
	Nov-2022	-0.5	< 0.1	67.0	33.0	10
	Dec-2023	2.9	0.6	69.8	29.6	20

< All values below lab detection limit

The aRPD depth has been highly variable within and among sites (Table 3). Generally, the aRPD is shallower in muddy rather than sandy sediments, due to mud limiting oxygen diffusion into deeper sediment layers However, in Waikouaiti Estuary, the aRPD tends to be the shallowest in the sandy sediments at Site B1, and at intermediate values in the muddiest sediments at Site C. The shallower aRPD at Site B1 may reflect sediment enrichment with river-derived detritus. Note that the relatively deep aRPD at Site B1 in 2022 was an anomaly associated with deposition of clean sand across the site (see Fig. 2, Table 3, and photos below). Overall, aRPD variability can reflect a range of factors, including the subjective nature of the method, and bioturbation of sediments by organisms such as crabs and cockles (e.g., Site C).

Deep aRPD at Site B1 in November 2022 (left), compared with the shallower appearance in December 2023 (right).

CONCLUSIONS

There have been significant changes in sediment depth at the Waikouaiti Estuary sites. However, erosion and accrual, particularly at Sites B1 and C, are more likely due to hydrodyamic processes than deposition of sediment from the catchment. Nonetheless, the shallow aRPD depths at Site B1, and muddy nature of the sediments at Site C, reinforce previous recommendations (e.g., Forrest 2023) to manage catchment influences on the estuary.

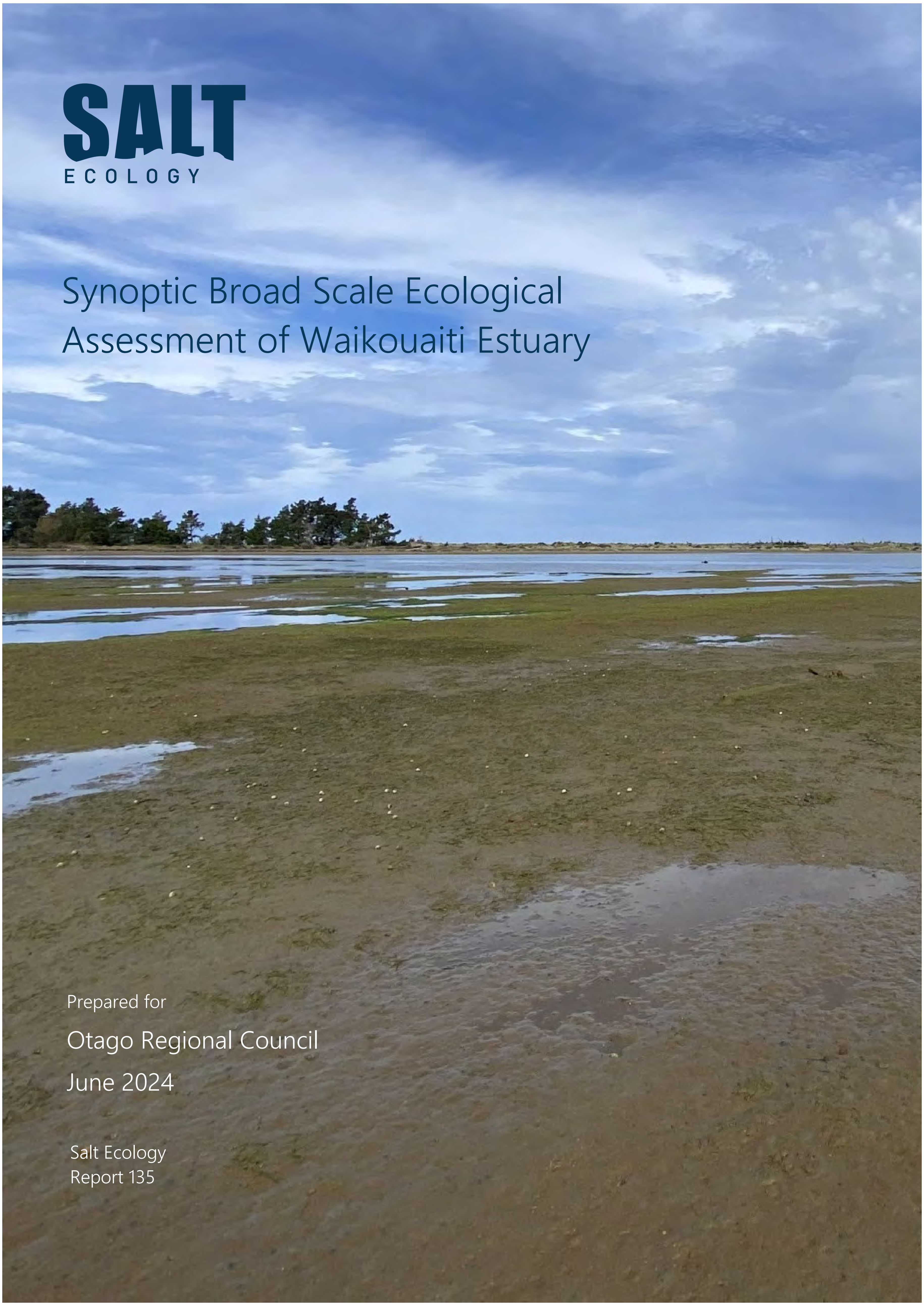
RECOMMENDED MONITORING

Continue monitoring of sedimentation rate, sediment grain size and aRPD depth, and produce an annual summary report of results. Consider site suitability and ongoing monitoring as part of a wider estuary programme review to be undertaken by ORC.

REFERENCES

Forrest BM 2023. Waikouaiti Estuary: 2022/2023 intertidal sediment monitoring summary. Salt Ecology Short Report 023, prepared by Barrie Forrest for Otago Regional Council, March 2023. 2p.

O'Connell-Milne S, Forrest BM, Rabel H. 2023. Fine Scale Intertidal Monitoring of Blueskin Bay, Waitati Inlet. Salt Ecology Report 110, prepared for Otago Regional Council, July 2023. 40p.



SALT ECOLOGY

Synoptic Broad Scale Ecological Assessment of Waikouaiti Estuary

Prepared for

Otago Regional Council

June 2024

Salt Ecology
Report 135

Cover and back photo: Seagrass beds in the central reach of Waikouaiti Estuary.

RECOMMENDED CITATION

O'Connell-Milne S, Roberts KL, Stevens LM, Forrest BM. 2024. Synoptic Broad Scale Ecological Assessment of Waikouaiti Estuary. Salt Ecology Report 135, prepared for Otago Regional Council, June 2024. 88p.

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SALT ECOLOGY

Synoptic Broad Scale Ecological Assessment of Waikouaiti Estuary

Prepared by

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June 2024

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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
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 Sulfur
Zn	Zinc

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for reviewing the draft report. We are also grateful to Thomas Scott-Simmonds 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 the GIS data and produce summaries and maps were developed by Megan Southwick of Salt Ecology.

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SUMMARY

In December 2023, a synoptic broad scale ecological assessment was conducted in Waikouaiti Estuary, 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 (including associated biota) at discrete sites, and compares findings with a 2016 survey. Historical data on seagrass and salt marsh extent were also derived from 1958, 1969, 1987 and 2006 imagery.

Monitoring results are summarised below, and assessed against preliminary condition rating criteria in the tables on the following page. Key findings are:

- Mud-elevated (≥25-100% mud) substrate covered ~34ha (~34%) of the available intertidal habitat (AIH), a condition rating of 'Poor', indicating elevated inputs to the estuary from catchment sources.
- Discrete sampling at mud-elevated sites showed a macrofaunal community dominated by hardy taxa that are resilient to elevated mud and most forms of disturbance. Macrofauna AMBI scores were generally rated 'Fair'.
- Substrates had very low trace metal contaminant concentrations (condition ratings of 'Very good'), and low to moderate nutrient concentrations (condition ratings of 'Good' to 'Fair') indicating low contaminant inputs.
- Seagrass with ≥50% cover comprised only 0.5ha representing a >95% loss since 1958, a rating of 'Poor'.
- Salt marsh covered 94ha (49% of the intertidal area), a condition rating of 'Very good'. However, only 45% of historical salt marsh remains, a condition rating of 'Fair'. Grazing and drainage continue to cause salt marsh loss.
- Nuisance macroalgae with >50% cover was highly localised and present across 6ha (6% of the AIH). The OMBT-EQR score was 0.658, a condition rating of 'Good' and was consistent with the 2016 result. High Enrichment Conditions (HEC) in the AIH were small (3ha, 3% of AIH), a condition rating of 'Good'.
- The 200m terrestrial margin was dominated by pasture (66%). Dense vegetation covered 13%, a condition rating of 'Poor'. Positively, extensive restoration plantings in Merton Arm are improving margin habitat.

RECOMMENDATIONS

Based on the 2023 survey, and changes between 2016 and 2023, it is recommended ORC consider the following:

Monitoring

- Undertake broad scale monitoring ~5-yearly to track changes in the dominant features of the estuary.
- Synoptically assess macroalgae and HEC areas annually. If expansion is observed, initiate targeted monitoring.
- Utilise existing estuary monitoring data to review the SOE monitoring programme and assess monitoring needs in Waikouaiti Estuary alongside priorities for other estuaries regionally.

Management

- Continue work to identify and prioritise salt marsh areas for ecological restoration, protection, and resilience to sea level rise.
- 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 potentially impact the estuary.
- Improve estimates of sediment and nutrient loads to the estuary, determine potential sources, and investigate options for reducing inputs where loads exceed guidance thresholds, or adverse impacts are identified.
- Include Waikouaiti Estuary in 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.

Overall, Waikouaiti Estuary is susceptible to, and affected by, fine sediment and (to a lesser extent) nutrient inputs both of which are exacerbated by continued salt marsh loss. However, there is a high potential for ecological restoration, particularly through exclusion of grazing animals on salt marsh, restricting drainage of salt marsh and the removal of barriers to facilitate salt marsh migration in response to sea level rise.

Summary of broad scale indicator condition ratings.

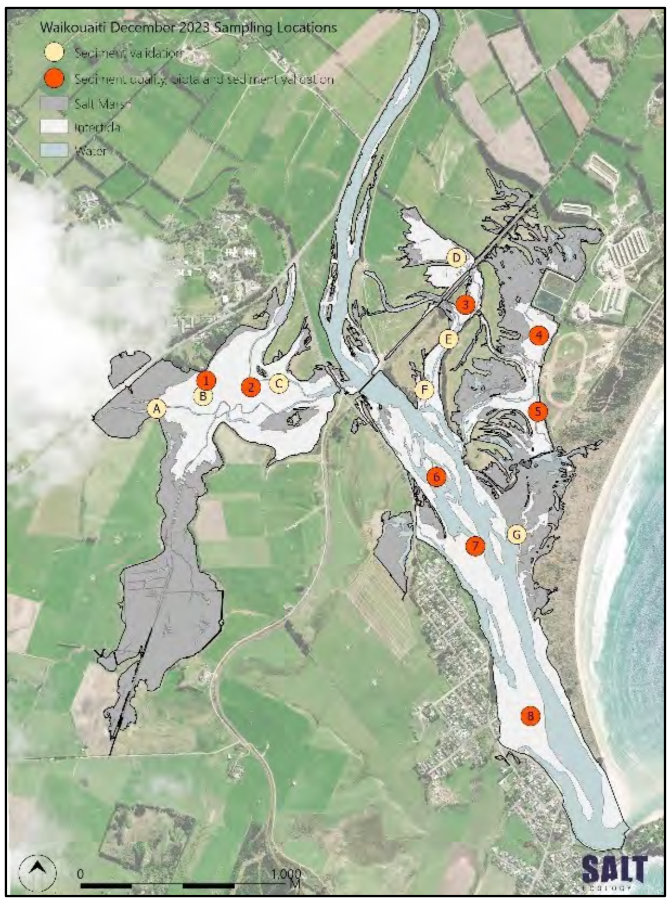
Condition rating key: Very Good | Good | Fair | Poor

Broadscale Indicators	Unit	December 2016	December 2023
200m terrestrial margin	% densely vegetated	7.4	12.7
Mud-elevated (≥25%-100%) substrate	% AIH[1] area	35.6	33.6
Macroalgae (OMBT[2])	Ecological Quality Rating (EQR)	0.692	0.658
Seagrass (>50% cover)[3]	% decrease from baseline	87.0	96.4
Salt marsh extent (current)	% of intertidal area	45.4	49.0
Historical salt marsh extent[4]	% of historical remaining	47.0	55.2
High Enrichment Conditions	ha	0	2.9
High Enrichment Conditions	% of AIH	0	3.0

[1]Available Intertidal Habitat (AIH; excluding salt marsh); [2]Opportunistic Macroalgal Blooming Tool (OMBT) scores have been updated following Stevens et al. (2022); [3]Seagrass baseline 1958; [4]Estimated from historic aerial imagery. Data from 2016 revised following QA/QC of GIS files.

Synoptic sampling sites (1-8) and indicator condition ratings for sediment quality and macrofauna AMBI.

Parameter	Unit	1	2	3	4	5	6	7	8
Mud	%	29.6	26.5	50.2	47.1	17.9	8.1	6.9	8.6
aRPD	mm	20	15	5	2	15	2	8	30
TN	mg/kg	400	300	700	1000	300	700	400	500
TP	mg/kg	480	580	690	680	380	550	400	530
TOC	%	0.26	0.26	0.63	0.78	0.20	0.43	0.22	0.31
TS	%	0.11	0.07	0.12	0.20	0.11	0.09	0.40	0.50
As	mg/kg	4.2	3.5	6.3	5.6	3.7	5.6	4.0	6.2
Cd	mg/kg	0.027	0.018	0.025	0.027	0.014	0.017	0.005	0.019
Cr	mg/kg	5.5	3.9	7.4	6.3	3.8	5.2	4.3	6.6
Cu	mg/kg	2.2	2.3	7.6	5.1	2.4	5.0	4.2	4.2
Hg	mg/kg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ni	mg/kg	3.4	3.3	8.1	5.6	3.3	6.0	5.0	6.2
Pb	mg/kg	3.2	2.5	6.0	4.5	2.2	4.0	3.1	3.9
Zn	mg/kg	20.0	17.3	37.0	28.0	14.9	25.0	22.0	25.0
AMBI	na	4.2	3.5	3.6	2.0	3.4	3.6	2.0	2.0



Drainage channel cut through salt marsh (top) and grazing damage from animals in areas of herbfield (bottom).

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SALT ECOLOGY

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 mud extent), 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 extensions of that approach) within key locations being (from north to south) Kakanui, Shag River, Pleasant River, Waikouaiti, Blueskin Bay, 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 1-2 December 2023 in Waikouaiti Estuary (hereafter Waikouaiti; 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 2006 and 2016. 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.

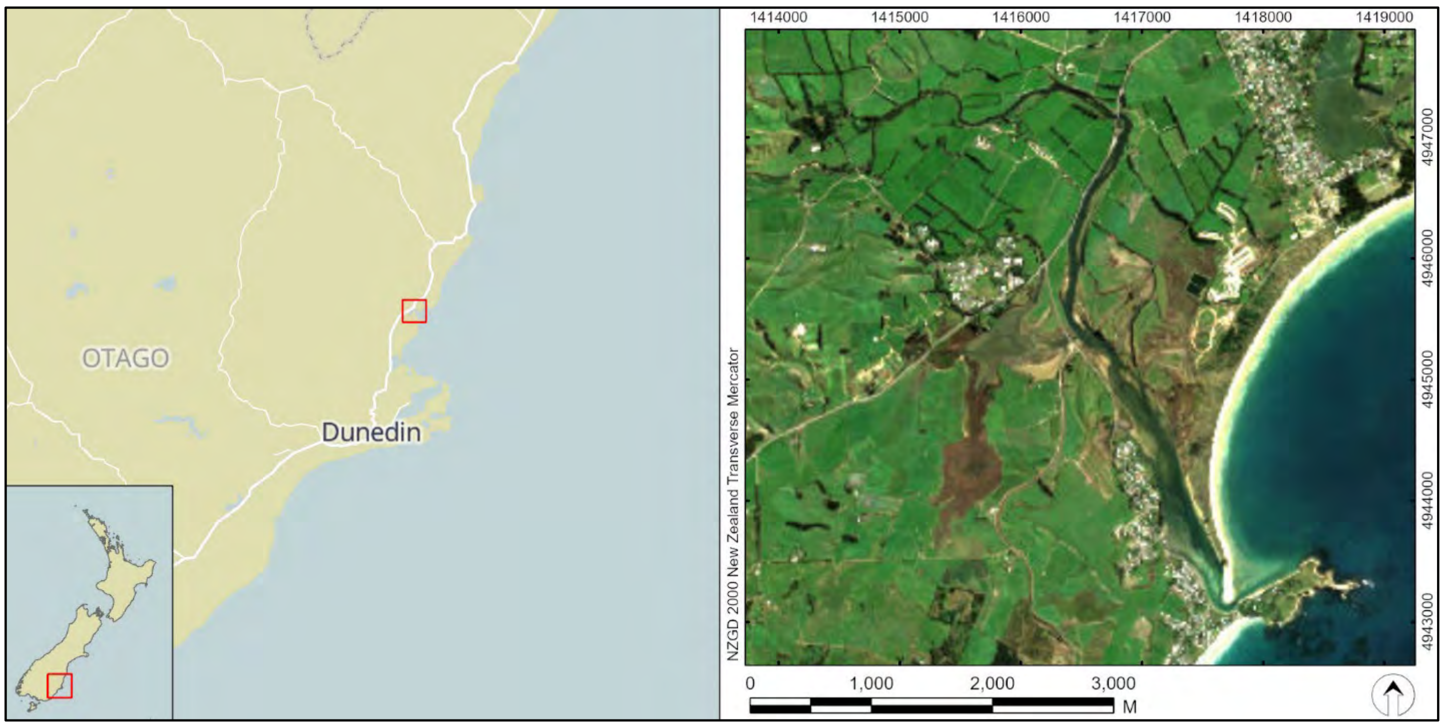


Fig. 1. Location of Waikouaiti Estuary, Otago.

2. OVERVIEW OF WAIKOUAITI

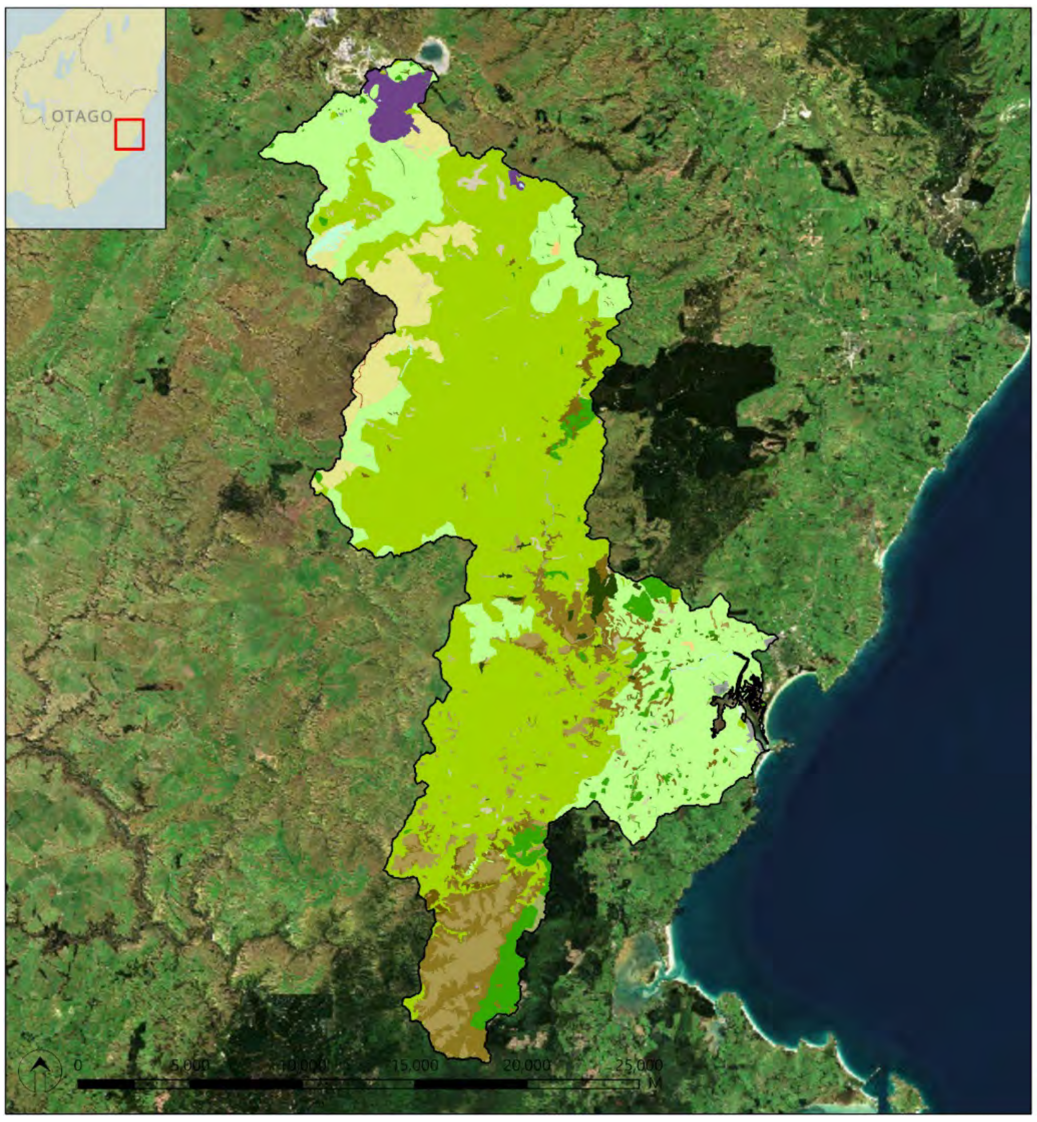
Previous reports (Stewart 2007; ORC 2010; Robertson et al. 2017; Stevens et al. 2017; Rabel 2024 and references therein) present background information on Waikouaiti, which is paraphrased (and expanded in places) below.

Waikouaiti is a medium-sized (~250ha), shallow, intertidally-dominated estuary (SIDE) situated at the mouth of the Waikouaiti River on New Zealand's east coast. The estuary has a central channel which divides two tidal arms dominated by intertidal flats and salt marsh: Merton Arm to the west and East Arm to the east. A sand spit (~1500m) extends along on the eastern margin and separates the estuary from the coast with a single narrow opening. The Waikouaiti River is the dominant freshwater input to the estuary and the tidal influence extends ~5km upstream. The catchment historically included large areas of estuary or flood plain which have subsequently been developed for farming. The township of Karitane is the largest area of urban development, and is on the southwest side of the estuary. It was once the site of the Waikouaiti Whaling Station, and a few fishing vessels remain operating out of the lower estuary.

The surrounding catchment (Fig. 2) is large (42,382km^2) and dominated by high and low producing grassland (75%), with only small areas of exotic plantation forestry (4%). Macraes goldmine (1.5%) is present in the upper catchment, while unmodified areas of the headwaters comprise native tussock grassland (5%). Native bush (~12%) primarily comprised of mānuka and/or kānuka, and broadleaved indigenous hardwoods are present in the southern catchment. Previous monitoring has identified Waikouaiti as being at risk from catchment land use inputs (Stevens et al. 2017; Plew et al. 2018).

Salt marsh is relatively extensive (49% of intertidal area) but much of this habitat type (~45%) has been lost historically through reclamation, drainage and conversion to pasture. These changes have greatly reduced the estuary's ability to filter, dilute, and assimilate catchment nutrient and sediment inputs.

Present day, seagrass beds in the estuary are small, fragmented, and predominantly have sparse cover. However, historically dense meadows of seagrass were



Catchment Land Use in 2018	ha	%
Artificial Surfaces		
Built-up Area (settlement)	78.1	0.2
Surface Mines and Dumps	656.0	1.5
Transport Infrastructure	15.4	0.0
Urban Parkland/Open Space	9.5	0.0
Bare or Lightly Vegetated Surfaces		
Sand and Gravel	2.1	0.0
Landslide	2.3	0.0
Alpine Grass/Herbfield	0	0
Gravel and Rock	47.6	0.1
Water Bodies		
River, Lake or Pond	20.3	0.0
Cropland		
Short-rotation Cropland	33.5	0.1
Orchard Vineyard and Other Perennial Crops	0	0
Grassland, Sedge and Saltmarsh		
High Producing Exotic Grassland	9,848.1	23.2
Low Producing Grassland	21,953.3	51.8
Tall Tussock Grassland	2,149.0	5.1
Depleted Grassland	0	0
Herbaceous Freshwater Vegetation	152.4	0.4
Herbaceous Saline Vegetation	25.7	0.1
Flaxland	0	0
Scrub and Shrubland		
Fernland	101.3	0.2
Gorse and/or Broom	549.7	1.3
Manuka and/or Kanuka	2,376.0	5.6
Broadleaved Indigenous Hardwoods	2,029.5	4.8
Sub Alpine Shrubland	0	0
Mixed Exotic Shrubland	55.1	0.1
Matagouri or Grey Scrub	302.5	0.7
Forest		
Forest Harvested	71.5	0.2
Deciduous Hardwoods	39.0	0.1
Indigenous Forest	262.5	0.6
Exotic Forest	1,601.4	3.8
	42,381.8	100.0

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

widespread across the tidal flats adjacent to the main estuary channel and within Merton Arm (see photo).

Historic imagery from 1958 where dark colouring represents seagrass (left) and unvegetated tidal flats in 2024 (right). These images show significant loss of dense seagrass beds within Merton Arm (source: retrolens.co.nz (left) and Apollo Mapping 11 October 2023 (right)).

Seasonal growths of macroalgae are common in the lower estuary. There are small localised areas of eutrophication in the upper estuary characterised by high cover (≥50%), high biomass growths of macroalgae, entrained in soft, muddy substrate with low sediment oxygen. The ecological significance of these habitat features is detailed in Table 1.

Waikouaiti has Kai Tahu cultural and spiritual values, and a Māori pā once stood on the Huriawa peninsula south of the estuary entrance (Ngāi Tahu Atlas). Waikouaiti River and estuary have been recorded as kāinga mahinga kai (food-gathering place) for inaka (whitebait), tuna (eels), pātiki (flounders), and shellfish like tuaki (cockles) and pipi (Ngāi Tahu Atlas). In 2016, the estuary was granted mātaitai status.

Waikouaiti is identified in the Otago Regional Plan: Coast as a Coastal Protection Area for estuarine values and importance to coastal birds such as the eastern bar-tailed godwit and oystercatchers (ORC 2012). Waikouaiti salt marsh complex is identified as a Regionally Significant Wetland within the Regional Plan: Water for Otago (ORC 2004), and an Area of Significant Indigenous Vegetation and Habitat for Indigenous Fauna within the Waitaki District Plan. The Merton Arm became a Wildlife Management Reserve in 1980 and is identified in the Dunedin City District Plan as an area of significant conservation value with mudflat and succulent herb swamp of regional and local significance. Swamp is a scarce wetland type with less than 15% of swamps remaining in Otago (Ausseil et al. 2008). The shallow sand bar at the estuary entrance also forms a surf break of national significance (NZCPS 2010).

Waikouaiti from the air.

3. METHODS

3.1 OVERVIEW

The survey of Waikouaiti was carried out on 1-2 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. 4 (next page) shows the estuary area surveyed and indicates where the sampling described below was undertaken. The survey approach is summarised below and in Tables 1 and 2, with further detail of sampling methods and analyses provided in Appendix 1.

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 Geographical Information System (GIS) technology. Imagery for Waikouaiti was sourced from Apollo Mapping (Colorado) and consisted of 30cm/pixel colour satellite imagery captured 11 October 2023. Appendix 1 outlines QA/QC procedures, applied through the phases of field data collection, digitising, and GIS data collation.

GIS layers for 2006 and 2016 were run through the same QA/QC procedures. Unfortunately, several errors in the 2006 dataset prevented its use in any temporal comparisons. However, salt marsh and seagrass were re-digitised from imagery and therefore only these two habitat features are discussed.

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 15 representative locations (Fig. 4, next page) used to validate field classifications.
- Vegetation mapping characterised high-value features, namely salt marsh 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. 3. 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).

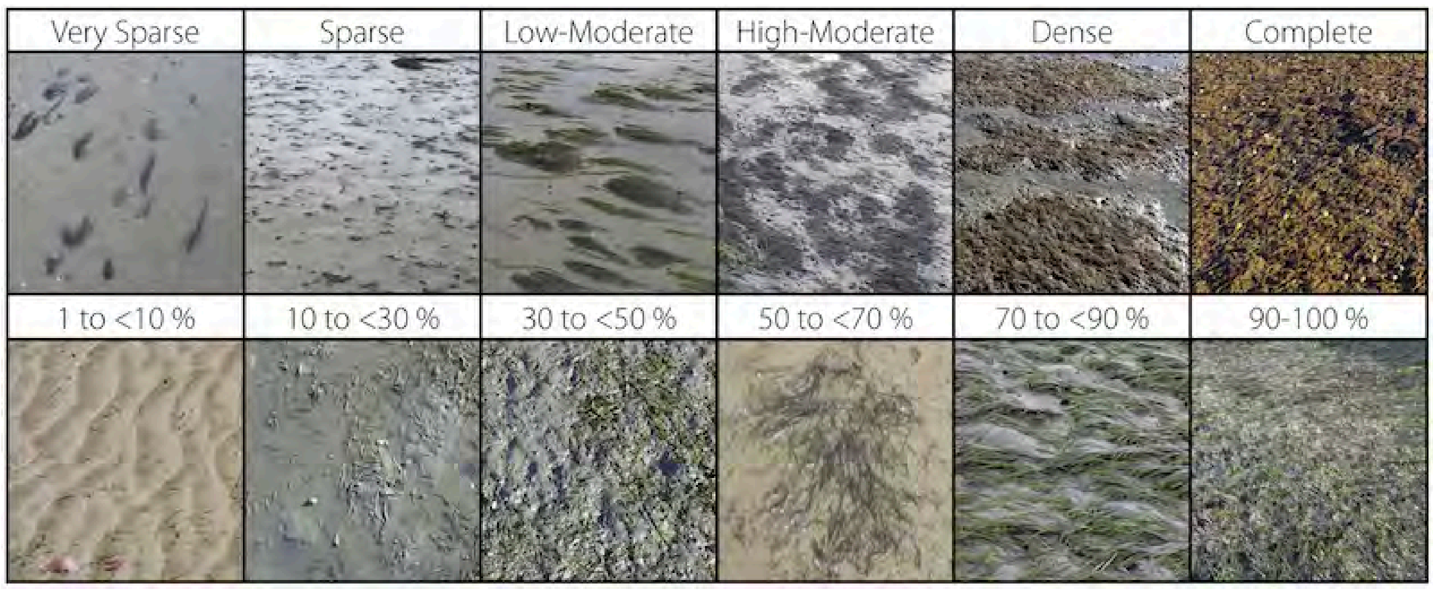


Fig. 3. Visual rating scale for % cover estimates of macroalgae and seagrass. Modified from FGDC (2012).

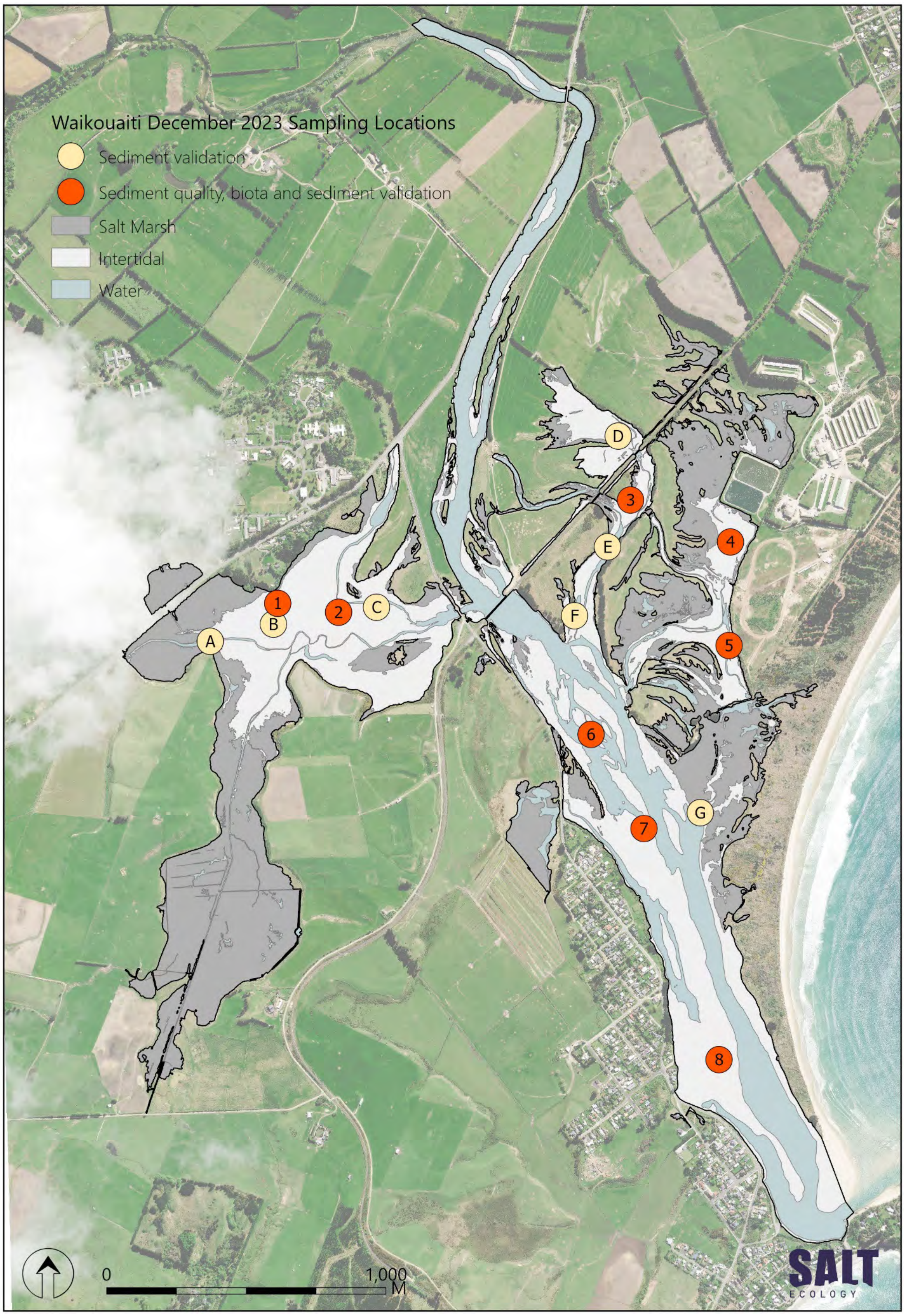


Fig. 4. Location of sites for sediment quality and biota samples (1-8) and sediment validation (1-8 and A-G), Waikouaiti Estuary, December 2023.

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 areal 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 areal 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 areal 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 areal 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 areal 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 areal 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.

Broad scale habitat mapping of Waikouaiti.

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. 4). 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 (aRPD) depth, 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: The focus was on macrofauna, which are small organisms that live within or on the sediment matrix, which 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 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 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 sampling in Waikouaiti, 2023.

Sediment core samples were split vertically to visually assess the depth of sediment oxygenation, as defined by the aRPD.

Estimating percent cover of intertidal vegetation at each site.

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 (aRPD) depth)	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.

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.

There are two broad scale rating indicators (salt marsh and seagrass) that rely on assessment of differences between current state and historic or baseline state.

- To estimate historic salt marsh extent, we assessed LiDAR contours, a 1937 survey map of Waikouaiti District (credit: National Library of New Zealand), and historic aerial imagery captured from 1958, 1969, 1987 (source: retrolens.co.nz), and 2006 (data.linz.govt.nz).

- To estimate historic seagrass extent, we assessed aerial imagery from 1958, 1969, 1987 and 2006.
- Historic imagery was merged, georectified and habitat features digitised as per Section 3.2.

Table 3. Indicators and condition ratings used to assess results in the current report.

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[1] (>50% cover)	% 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. (2016a).
3 Mud-elevated substrate modified from Robertson et al. (2016a) 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 (See Glossary for definitions.)

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. (2016a).
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 of Waikouaiti is provided below, with ground-truthing tracks shown in Appendix 2. Supporting GIS files have been separately supplied 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 (50%) and low producing (16%) exotic grassland. Grassland supports grazing to the estuary edge within East Arm. Built-up areas (~11%) include the settlement of Karitane west of the lower estuary, wastewater treatment infrastructure in the East Arm, and road and rail infrastructure that bisects the northeast upper estuary.

A total of ~12% of the margin was categorised as densely vegetated, which corresponds to a condition rating of 'Poor'. Dense vegetation on the estuary margin primarily comprised of exotic plantation forest (8.1%), some of which had been harvested, and gorse/broom (1.7%). Native vegetation included small patches of broadleaved indigenous hardwoods (1.3%) and herbaceous saline vegetation (1.8%).

Exotic plantation forestry transitioned to native scrub along the northern edge of the Merton Arm, west of the upper estuary.

Dense gorse on the margin of Merton Arm.

Cows fenced and grazing on pasture up to the estuary margin, East Arm.

Fenced high producing grassland adjacent to salt marsh.

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

LCDB5 Class		ha	% Margin
1	Built-up Area (settlement)	47.3	10.8
5	Transport Infrastructure	16.8	3.8
10	Sand or Gravel	2.8	0.6
20	Lake or Pond	2.4	0.6
21	River	0.9	0.2
40	High Producing Exotic Grassland	217.7	49.6
41	Low Producing Grassland	70.0	15.9
410	Duneland[1]	25.5	5.8
46	Herbaceous Saline Vegetation	7.8	1.8
51	Gorse and/or Broom	6.2	1.4
54	Broadleaved Indigenous Hardwoods	5.6	1.3
56	Mixed Exotic Shrubland	0.5	0.1
64	Forest - Harvested	2.7	0.6
71	Exotic Forest	32.9	7.5
Grand Total		**439.3**	**100**
Total dense vegetated margin		**55.8**	**12.7**

[1] Duneland is an additional category to the LCDB classes to help differentiate between "Low Producing Grassland" and "Duneland".
[2] LCDB5 classes 45-71

Herbaceous saline vegetation on the estuary margin occurred in low-lying areas west of Merton Arm, which were historically salt marsh habitat before being drained to provide land for pasture (see Section 4.2). These grazed areas still comprise salt-tolerant species. Further saline vegetation was present southwest of the central estuary, despite tidal flap gates restricting tidal inundation. This area is also recognised as Ellison salt marsh (see Fig. 5), and is a regionally significant wetland (ORC 2004).

Fenced area of grazed herbaceous saline vegetation, with a small drainage channel along the fence line.

Duneland (5.8%) on the coastal sandspit was predominantly introduced marram grass (*Ammophila arenaria*) and the less dominant knobby clubrush (*Ficinia nodosa*). Other exotic species were interspersed throughout the dunes including tree lupin (*Lupinus arboreus*), gorse (*Ulex europaeus*) and wilding pine. Native vegetation included flax (*Phormium tenax*), cabbage tree (*Cordyline australis*), and kohuhu (*Pittosporum tenuifolium*). It should be noted that broad scale mapping of the terrestrial margin recorded dominant cover only and does not represent a comprehensive survey of dune vegetation.

Coastal sandspit vegetated with marram grass.

Vegetation dominated by introduced marram grass interspersed with lupin, gorse, and wilding pine.

Between 2016 and 2023 the area of densely vegetated margin increased from 7.4% to 12.7%, respectively. Since 2016, wilding pines have been removed from the dunes in two areas and gorse has been cleared from long tracts of the margin in Merton Arm. The net increase in densely vegetated areas has been driven by an expansion of forestry south of Merton Arm, and established native restoration planting north of Merton Arm. Additional restoration planting has occurred recently around much of the remaining margin in Merton Arm. These areas have not been included in the dense vegetation metrics of the current survey (see photo); however, this will be captured in future surveys as these plantings become established.

Young pine plantation bordering the estuary south of Merton Arm.

Restoration plantings of native vegetation border Merton Arm.

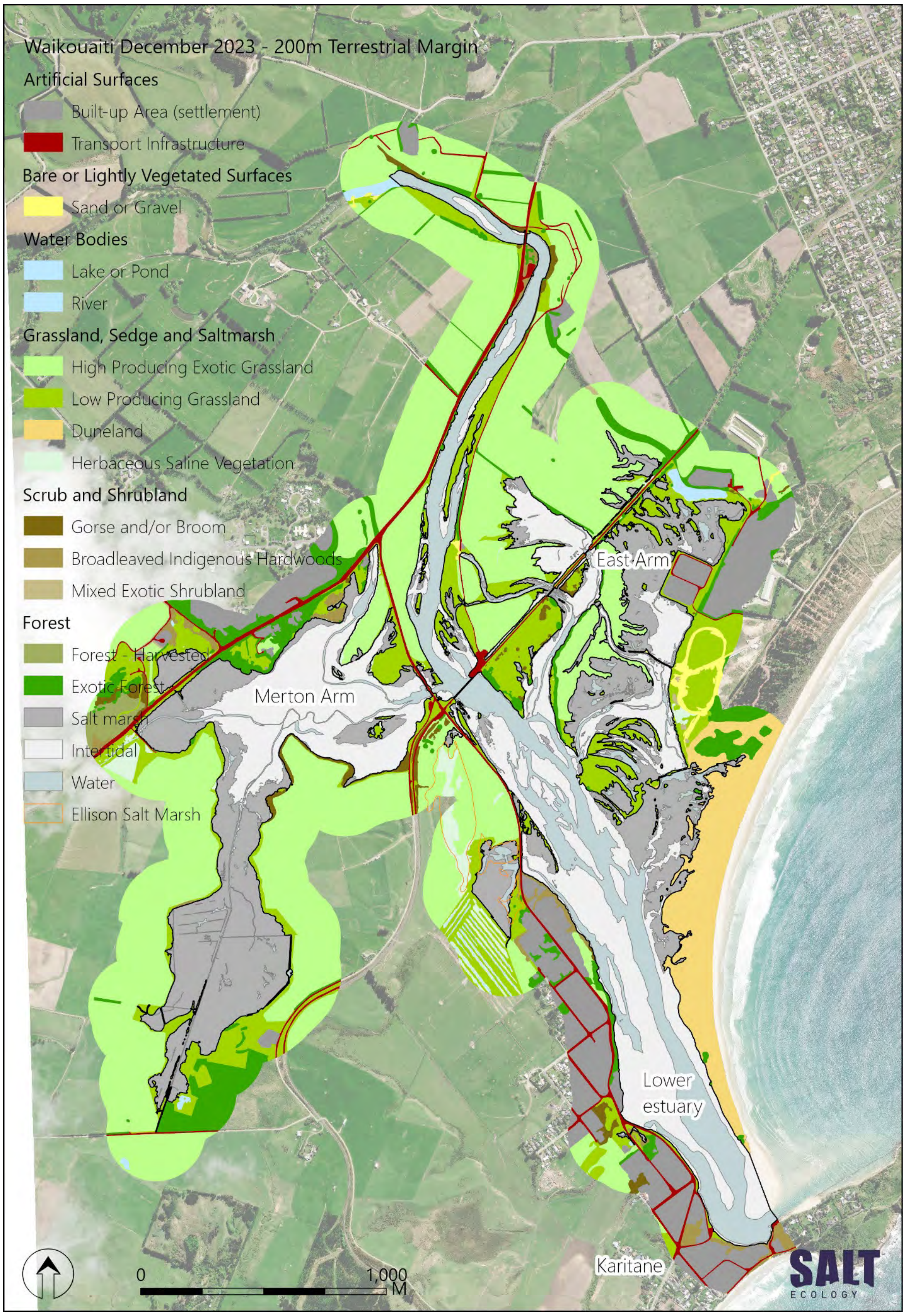


Fig. 5. Map of 200m terrestrial margin land cover, Waikouaiti Estuary, December 2023.

4.2 SALT MARSH

Waikouaiti had 94ha of salt marsh, comprising 49% of the mapped intertidal area (193ha; Table 5, Fig. 6). Dominant species are noted in Table 5, while sub-dominant species are detailed in Appendix 3 and accompanying GIS files.

Salt marsh was widespread in Merton Arm, East Arm, along margins of the main channel, and within an embayment southwest of the mid-estuary (Fig. 6). Salt marsh was dominated (93%) by herbfield (~87ha), and primarily comprised of glasswort (*Sarcocornia quinqueflora*), primrose (*Samolus repens*) and remuremu (*Selliera radicans*). The Merton Arm supported areas of tussockland (~4%) and rushland (~2ha), dominated by jointed wirerush (*Apodasmia similis*), which transitioned to estuarine shrub (0.4ha) in some locations (see bottom inset map in Fig. 6).

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

Salt Marsh Class	Dominant species*	ha	% Intertidal
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.4	0.2
Tussockland	*Puccinella stricta* (Salt grass)	4.1	2.1
Sedgeland	*Schoenoplectus pungens* (Three square)	0.3	0.2
Rushland	*Apodasmia similis* (Jointed wirerush)	2.1	1.1
Reedland	*Spartina alterniflora* (Smooth cord grass)	0.007	0.004
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	87.4	45.4
Total		**94.3**	**49.0**

* See Appendix 3 for additional species in each subclass.

Herbfield dominated by glasswort, primrose and remuremu.

Herbfield and rushland, dominated by jointed wirerush, on the northern margin of Merton Arm.

Invasive cordgrass *Spartina alterniflora* was observed in East Arm. Sparse shoots were present in the south of the arm, below the mapping threshold of $2m^2$. In 2016, cordgrass covered ~1ha in this area, but this large bed has since been eradicated. Dying vegetation around the sparse shoots indicate recent spraying and ongoing management (see photo). Further small patches (<0.01ha) were found in a tidal culvert north of East Arm (see insert Fig. 6) and are a new observation. All locations of cordgrass have been reported to ORC. While cordgrass has been encountered during each survey, it has only been present as individual plants or small, discrete patches and does not appear to be widespread, likely due to the ongoing eradication efforts by ORC and the Department of Conservation.

Cordgrass *Spartina alterniflora* in a tidal culvert north of the railway line (top) and individual plants that have been sprayed as evidenced by the dieback of remuremu, East Arm.

Significant recent physical damage to salt marsh was observed in East Arm due to several activities:

- Areas of salt marsh were fenced and horses and a few cattle were actively grazing and trampling herbfield (see photo below). Gravel had also been spread over herbfields to facilitate vehicle access.
- In ~2020 new drainage channels were cut into salt marsh (information source: Google Earth History and on-site photos; See top right photo; cut salt marsh is visible in the top inset map in Fig. 6).
- A large causeway across the north of the East Arm, initially installed in the late 1980's, was repaired in ~2019 with culverts installed - see centre right photo. Since then, further gravel and concrete debris has been placed for roading (information source: Google Earth History and on-site photos).
- Two other small causeways have been installed across small channels in the last 5 years - see centre right photo. Seawater flows into herbfield areas are now restricted.
- Additionally, vehicles crossing herbfield contributed to damage in both the Merton and East Arms (see lower right photo).

Impacts are also evident from a large causeway installed in the 1970's across the south of the East Arm which limits tidal flushing.

Similar to other estuaries in the region (e.g., Pleasant River), herbfield dieback has also been caused by localised algae smothering. In Waikouaiti, this issue was due to growth of *Vaucheria* sp. on the western margin of Merton Arm (see photo page 25), and filamentous algae growing within shallow pools in herbfield (see Section 4.5). Further physical damage to salt marsh was caused by erosion along the banks of the channels and seaward edge of salt marsh in the central estuary, likely driven by periods of high river flow. Wind and wave driven erosion was also occurring on the seaward edge of salt marsh fringing flats in the tidal arms.

Horses grazing and damaging herbfield with gravel laid over firm sandy mud to reduce stock pugging and allow vehicle access.

New drainage channels dug out of the salt marsh post-2020.

Causeway, with recently (last 5 years) installed culverts restricting tidal inundation in East Arm.

Small causeway installed across a channel of East Arm.

Vehicle damage to herbfield in Merton Arm.

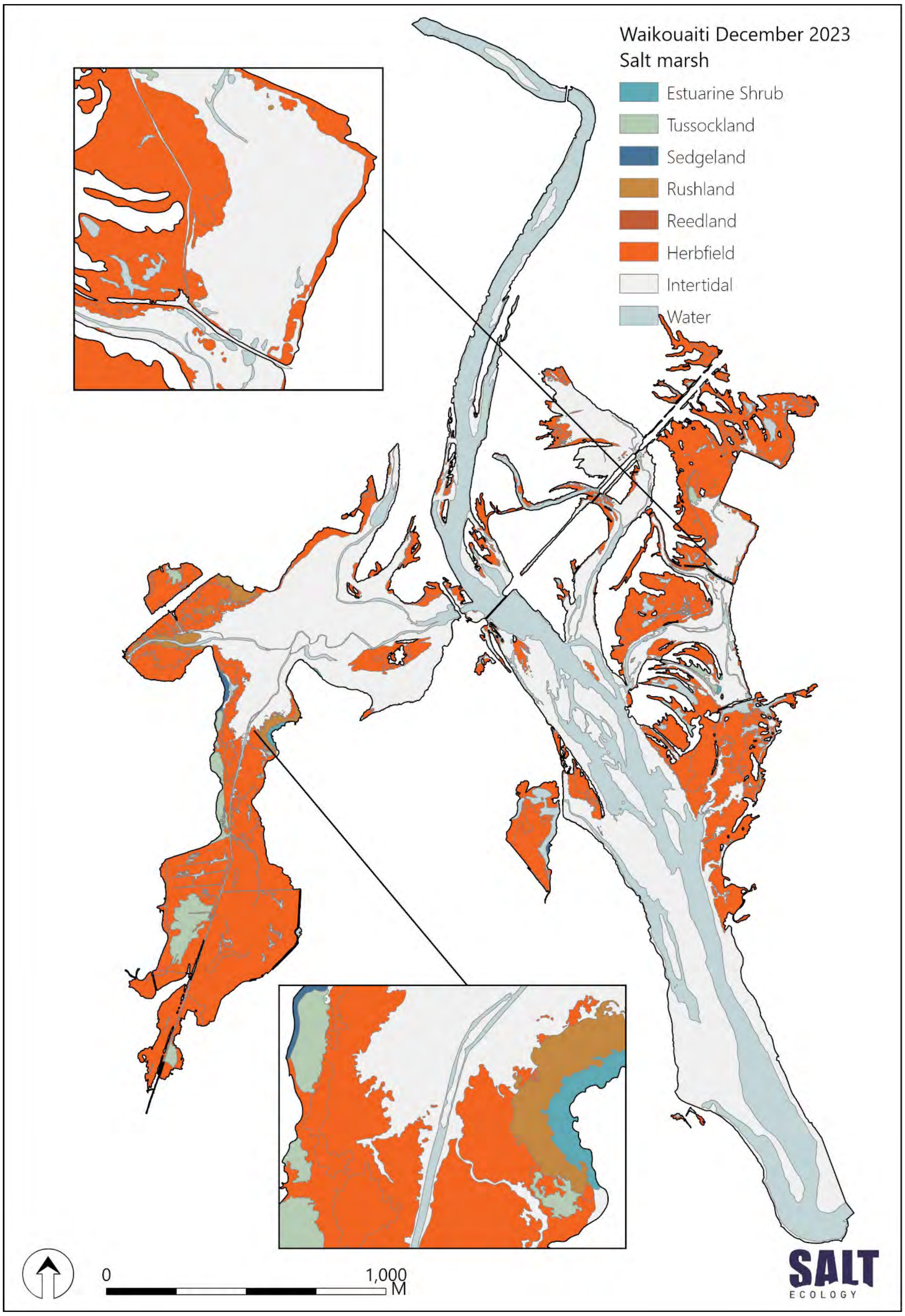


Fig. 6. Salt marsh sub-classes and their distribution, Waikouaiti Estuary, December 2023.

Mats of yellow-green alga *Vaucheria* sp. smother herbfield in Merton Arm.

Erosion on the seaward edge of herbfield in the lower estuary.

Most of the substrate within salt marsh habitat had an elevated mud content (≥25% mud), and comprised 6% firm muddy sand (≥25-50% mud) and 80% firm sandy mud (≥50-90% mud). Remaining areas had lower mud content with 11% of salt marsh in firm muddy sands (≥10-25% mud) bordering the sand dunes south of East Arm, and 1.5% within gravel field in the mid estuary. Substrate details for salt marsh and other vegetated habitats are provided in Appendix 4. As salt marsh habitats play a vital role in retaining fine sediments, they commonly have a high mud content. Therefore, when assessing substrate metrics in Section 4.3, areas of salt marsh habitat are excluded.

Mapped salt marsh increased by 14ha from 80ha in 2016 to 94ha in 2023. This increase was primarily attributed to mapping areas north of the wastewater treatment ponds in the East Arm in 2023, which had not previously been ground-truthed or mapped. The current extent retains a condition rating of 'Very good'.

In December 2023, field observations highlighted that many of the channelised drains around the estuary margin had outfalls fitted with flap gates to restrict tidal inundation (see photo). As discussed in Section 4.1, many of these areas, which were previously salt marsh, retain salt-tolerant species, with some fenced paddocks dominated by herbaceous saline vegetation.

An assessment of the historic salt marsh extent was derived from LiDAR, maps, field observations, and imagery dating back to 1958. The historical (natural) intertidal extent was estimated to be approximately 360ha, including around 171ha of salt marsh, which accounted for 56% of the intertidal area (see Fig. 7; Appendix 5). By 1958, substantial losses (~56ha) were already evident, primarily due to land drainage west of the estuary, and these losses continued through to 1969. Further losses occurred after 1969, caused by additional drainage in the west and reclamation in the eastern arm for the wastewater treatment plant. However, these losses were offset by the expansion of the invasive cordgrass, *Spartina* sp., which was introduced to the estuary in the 1970s and rapidly expanded, particularly in the Merton Arm, by the late 1980s (pers. comm. Pete Ravenscroft). A large-scale eradication project led by the Department of Conservation resulted in the near-complete removal of *Spartina* by the early 2000s. Since then, the extent of the salt marsh has remained relatively stable, although recent modifications pose a threat. Despite past losses, Waikouaiti still retains large areas of salt marsh, and it is estimated that approximately 55% of the historical salt marsh remains, a condition rating of 'Fair'.

Flap gates on culverts prevent tidal inundation.

Native restoration plantings on the grassy margin of a drainage channel with fenced pasture containing herbfield species in the background.

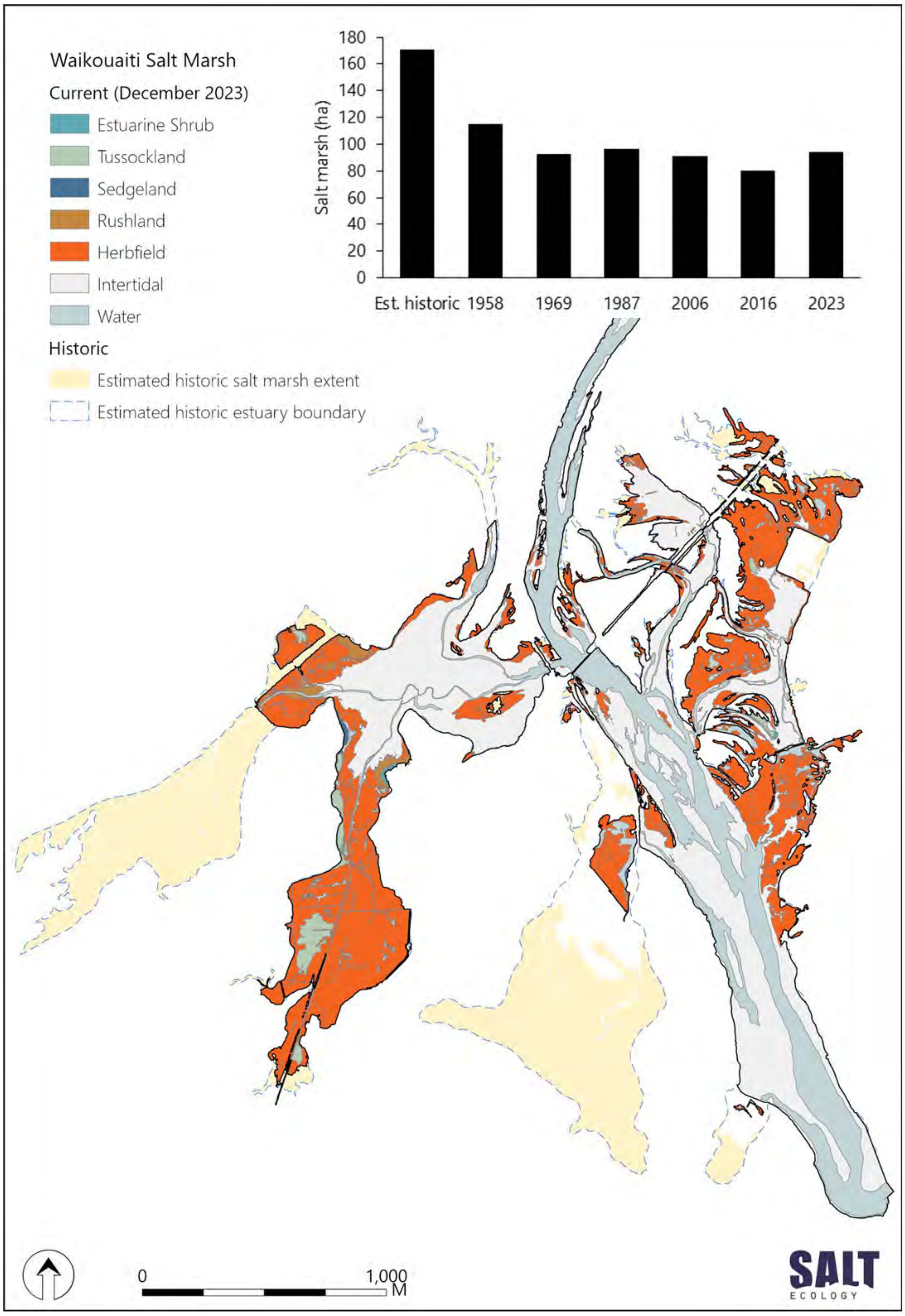


Fig. 7. The historic salt marsh extent (yellow) and historic estuary margin (dashed line) are overlaid with the current salt marsh extent. Inset graph represents salt marsh extent estimated from LiDAR, hand drawn maps and historic imagery in 1958, 1969, 1987 and 2006 and ground-truthed in 2016 and 2021.

4.3 SUBSTRATE

Outside of salt marsh, ~98ha of intertidal substrate was mapped (Table 6, Fig. 8). There was generally good agreement between the subjective sediment classifications applied during mapping and the sediment grain size validation measures (Appendix 6).

Rock field was limited in extent (<0.1%). Artificial boulder walls extended along the western margin of the lower estuary (0.4ha). Gravel field was the predominant coarse substrate within the estuary, comprising ~13% (13ha) of the AIH, with patches primarily located adjacent to the main channel in the upper and mid-estuary. Shell banks and cockle beds were also present within the lower estuary (1.2 and 1.3ha, respectively). Sand (≤10% mud) covered ~29ha (30% of the AIH) within the lower and mid estuary. Firm sand was the most dominant substrate covering ~22ha in the mid estuary, and mobile sands (~6ha) were located towards the estuary entrance and adjacent to the main channel.

Firm muddy sand (≥10-25% mud) covered ~20ha (~20% of the AIH), predominantly across the central flats of Merton Arm and the lower channels of East Arm. Muddy sand (≥25-50% mud) covered ~12ha (~12% of the AIH), with firm muddy sand present on the southern flats of Merton Arm and northern flats of East Arm, and soft substrates on the northern flats of Merton Arm.

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

Substrate Class	Features	ha	% AIH
Bedrock	Rock field	0.002	0.002
Zoogenic	Cockle bed	1.2	1.2
Coarse substrate (>2mm)	Artificial boulder field	0.4	0.4
	Gravel field	12.8	13.1
	Shell bank	1.3	1.3
Sand (0-10% mud)	Mobile sand	6.4	6.5
	Firm sand	22.3	22.7
	Soft sand	0.7	0.8
Muddy Sand (≥10-25% mud)	Firm muddy sand	20.0	20.4
	Soft muddy sand	0.1	0.1
Muddy Sand (≥25-50% mud)	Firm muddy sand	6.2	6.3
	Soft muddy sand	6.0	6.1
Sandy Mud (≥50-90% mud)	Firm sandy mud	9.3	9.4
	Soft sandy mud	10.0	10.2
	Very soft sandy mud	1.5	1.5
Mud (≥90% mud)	Soft mud	0.04	0.04
Total		98.2	100

Artificial boulder wall and gravel on the western margin.

Shell bank and cockle bed in the lower estuary.

Large gravel field in the mid estuary.

Mobile sand (<10% mud) in the lower estuary.

Sandy mud (≥50-90% mud) covered a total area of 21ha, comprising ~21% of the AIH, predominantly on the upper central flats and around salt marsh margins in Merton Arm, and on the upper reaches of northern East Arm. Very soft sandy muds were present in a sheltered embayment with freshwater inflow on the northern margin of Merton Arm and the seaward margins of salt marsh in the north of Merton Arm. This area of very soft sandy mud was also associated with dense beds of *Vaucheria* sp. and entrained *Gracilaria* spp., a species which can promote settling of fine sediments by reducing water flow near the sediment surface. Other areas of very soft sand muds were located in poorly flushed areas of East Arm.

Very soft sandy mud (≥50-90% mud) within an embayment on the northern margin of Merton Arm.

Firm muddy sand (≥10-25% mud) across the central Merton Arm.

Soft muddy sand (≥25-50% mud) in the upper estuary, north Merton Arm.

As a general trend, substrates were muddier on the upper estuary flats of Merton and East Arm. Embayments on the western margin of the central estuary channel and small channels within East Arm also have high mud content, likely attributed to limited water exchange, creating low water movement promoting the deposition of fine sediments. The Waikouaiti River enters the estuary in a well-defined channel that is maintained through to the central estuary and lower estuary toward the entrance. Therefore, hydrodynamics result in little opportunity for fine sediments to settle in the central estuary, and on the outgoing tide nutrients and sediments likely bypass the tidal flats within the Merton and East Arm.

Overall, mud-elevated (≥25-100% mud) sediments covered ~34ha, a condition rating of 'poor'. The extent of mud-elevated substrates has decreased by 2ha since 2016. Although the overall extent has remained relatively consistent, broad scale changes since 2016 include muddier substrates in East Arm, while the central flats of Merton Arm have become sandier.

Mud elevated substrates in East Arm

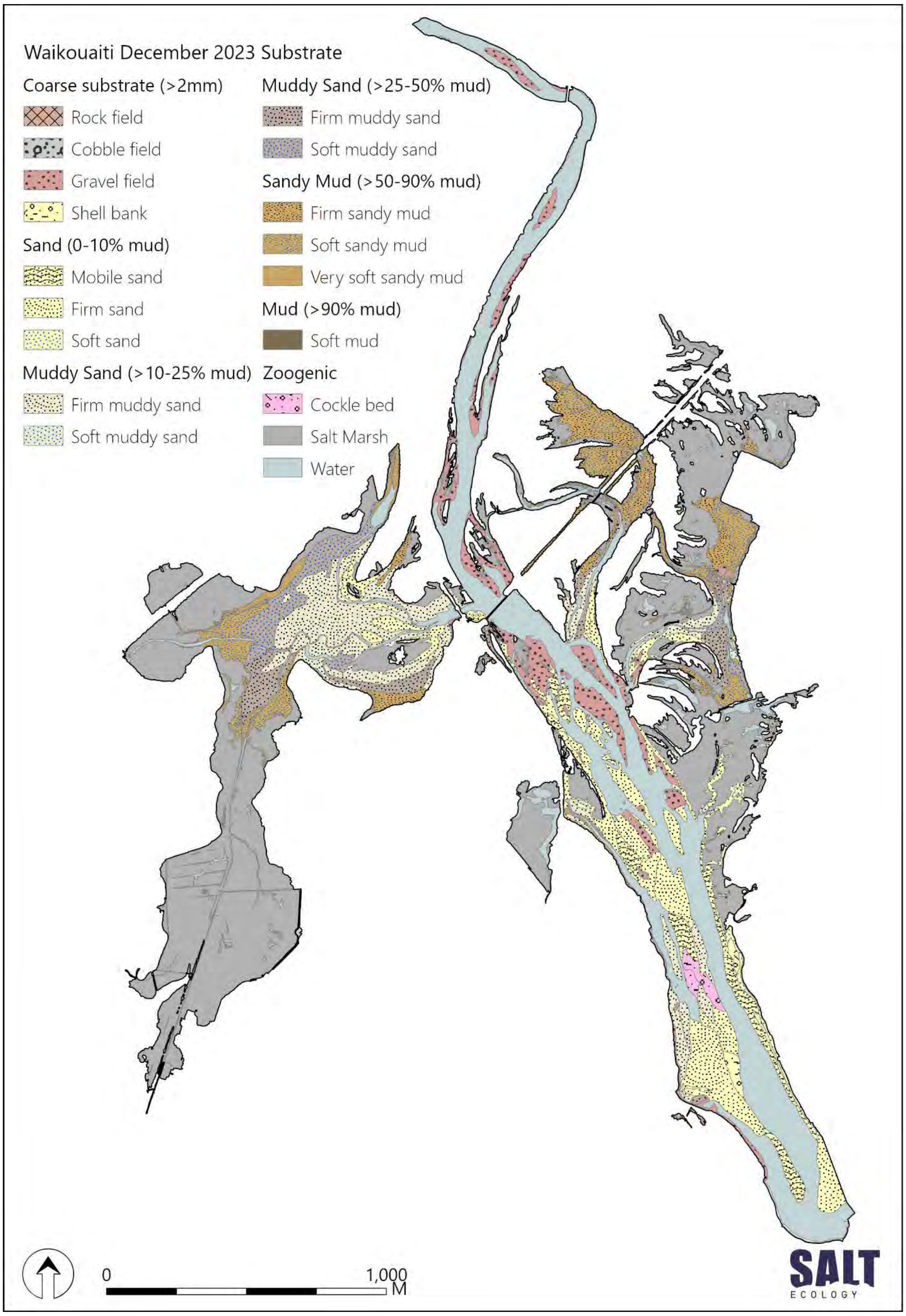


Fig. 8. Dominant intertidal substrate in the AIH (excluding salt marsh), Waikouaiti Estuary, December 2023.

4.4 SEAGRASS

Table 7 and Fig. 9 summarise seagrass (*Zostera muelleri*) percent cover. Seagrass beds were predominantly sparse (10 to <30% cover), small, and fragmented, comprising 1.1% of the AIH. Seagrass was recorded west of the central channel south of the rail bridge bisecting the mid estuary, and one very small patch in a backwater within East Arm. Overall, seagrass appeared healthy, however, there were growths of *Ulva* spp. across the beds on the central flats, and substrate within the beds expressed eutrophic symptoms with poor sediment oxygenation (i.e., shallow aRPD depth).

Table 7. Summary of seagrass cover in the available intertidal area (AIH), Waikouaiti Estuary, December 2023.

Percent cover category	ha	% AIH
Absent or trace (<1%)	97.1	98.9
Sparse (10 to <30%)	0.6	0.6
Low-Moderate (30 to <50%)	0.04	0.04
Moderate-High (50 to <70%)	0.3	0.3
Dense (70 to <90%)	0.1	0.1
Complete (≥90%)	0.02	0.02
Total	98.2	100

Mapped seagrass beds with ≥50% cover decreased from 1.7ha in 2016 to ~0.5ha in 2023, representing a 72% decrease. These losses appeared largely due to physical scouring observed following a flood event in 2018 (Leigh Stevens, Salt Ecology pers. observation).

Ulva spp. growth across seagrass beds.

Poor sediment oxygenation underlying dense seagrass.

Small patches of seagrass within the mid estuary.

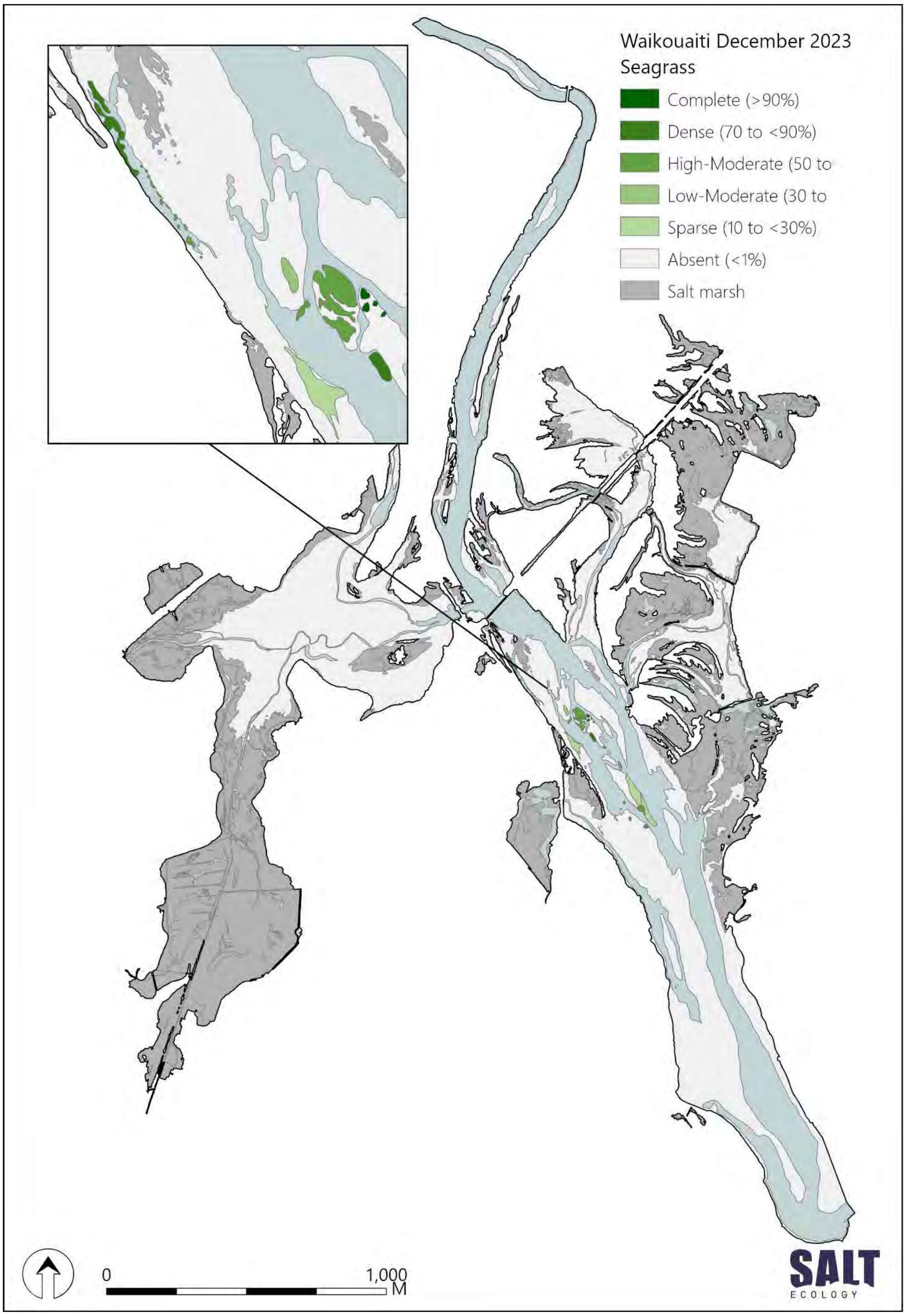


Fig. 9. Distribution and percent cover classes of seagrass, Waikouaiti Estuary, December 2023.

A review of historic imagery shows that seagrass was once extensive (~13ha) across the tidal flats of Merton Arm (Table 8; Fig. 8; Appendix 5). By 1969, the beds had expanded to cover approximately 17ha including beds in Merton Arm and new beds near the main channel in the mid-estuary. However, a significant decline in seagrass was recorded between 1969 and 1975 (visual inspection of imagery from retrolens.co.nz) in the Merton Arm, and by 1987, it had almost completely disappeared from the area. The cause of this large loss of seagrass is uncertain. However, the invasive cord grass, *Spartina* sp. (see Section 4.2), was introduced and became widespread in the Merton Arm during the 1970s, possibly reducing the area where seagrass could grow and altering the hydrology, which may have contributed to the decline. Losses were also likely exacerbated by estuary modification (primarily altered hydrodynamics from causeways and flap gates), and increased catchment sediment inputs.

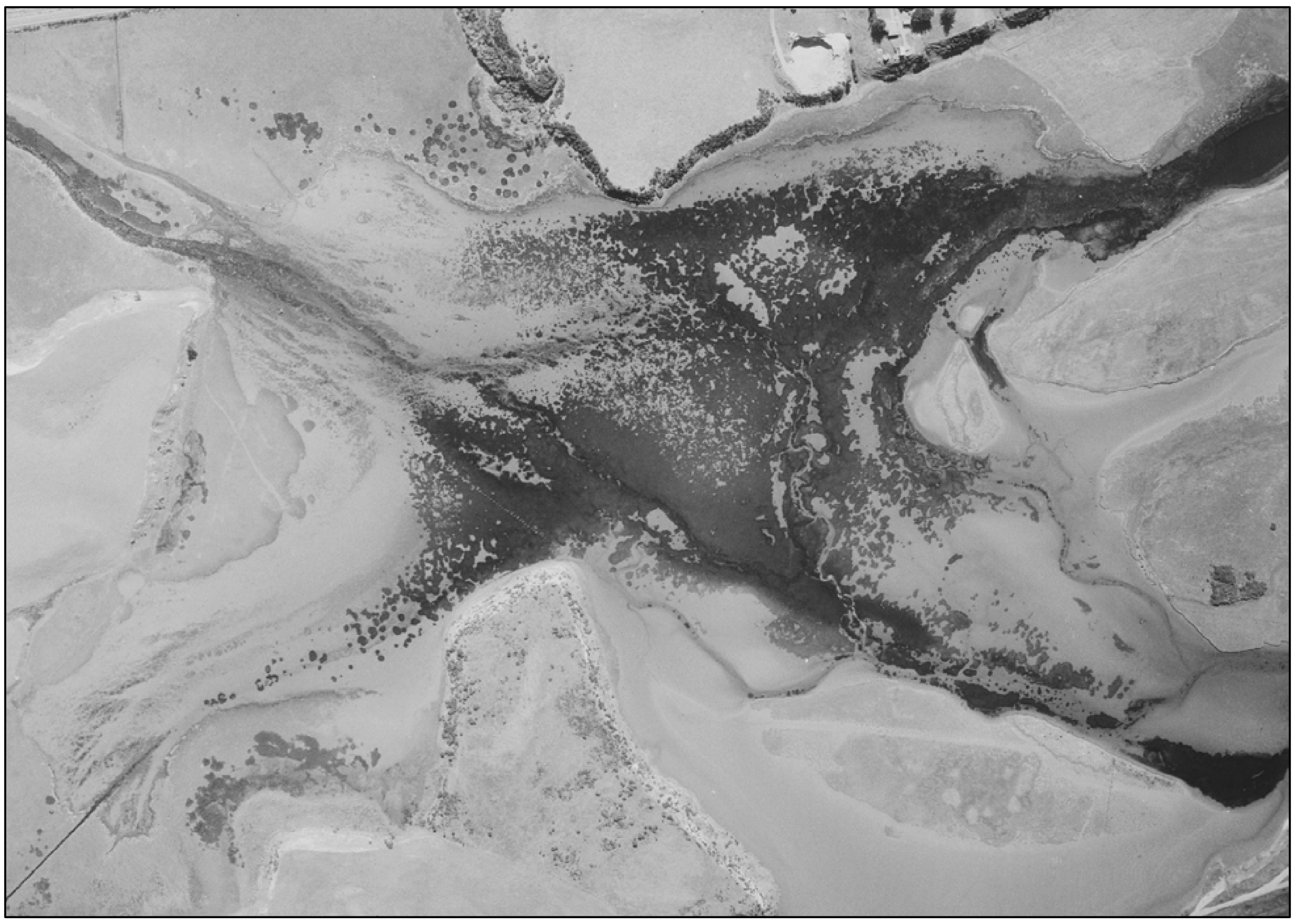
Despite the eradication of *Spartina* sp. no seagrass has been recorded in the Merton Arm since at least 2006. The largest remaining area of seagrass is in the mid-estuary near the main channel (Fig. 9). Overall, between 1958 and 2023, seagrass has declined by over 95%, with the largest losses occurring in the 1970s, a condition rating of 'Poor' (Fig. 10; Appendix 5).

Table 8. Estimated historic seagrass extent.

Year	ha	% AIH	% loss from baseline
1958^	13.1	10.0	*baseline*
1969^*	16.8	15.9	+28.5
1987^	2.9	2.9	-78.0
2006^	2.6	2.7	-79.9
2016	1.7	1.8	-87.0
2023	0.5	0.5	-96.4

^Digitised from historic aerial imagery, no ground-truthing.
*Seagrass expanded to the mid estuary near the main channel.

Seagrass near the main channel in the mid-estuary.



Imagery captured between 1956-1958 showing extensive areas of seagrass (dark colouring) in the Merton Arm.

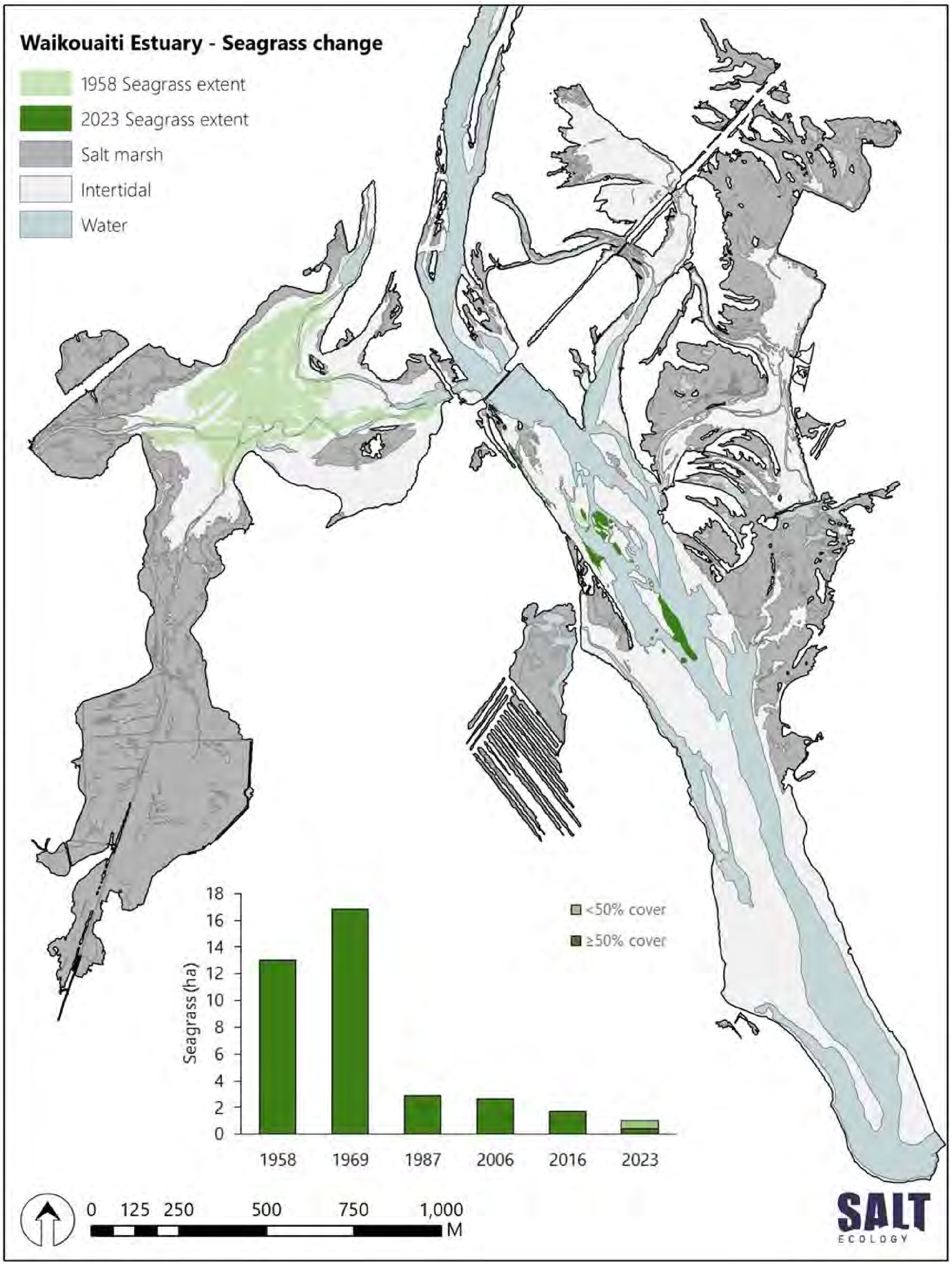


Fig. 10. The 1958 seagrass extent (light green) overlaid with the current mapped seagrass extent. Inset graph represents estimated seagrass cover from historic imagery in 1958, 1969, 1987 and 2006 and ground-truthed seagrass mapped seagrass in 2016 and 2021.

4.5 MACROALGAE

4.5.1 Opportunistic macroalgae

Opportunistic macroalgae species and biomass information is included in Appendix 7, with key results summarised in Table 9 and Fig. 11. Macroalgae comprised the green algae *Ulva* spp., the red algae *Gracilaria* spp., unidentified green filamentous algae, and a mat-forming yellow-green alga identified by NIWA as *Vaucheria* sp.

Macroalgae was mapped as absent or trace (<1% cover) across ~83% of the AIH (intertidal area excluding salt marsh). Sparse macroalgae (10% to <30% cover) was predominantly observed on lower estuary flats (9% of the AIH). Dense/complete growth (3.4ha, 3.5% of the AIH) was located in the upper estuary, and on the estuary margins adjacent to salt marsh in Merton Arm and East Arm.

Table 9. Summary of intertidal macroalgal cover (A) and biomass (B), in the available intertidal area (AIH), Waikouaiti Estuary, December 2023.

A. Percent cover

Percent cover category	ha	% AIH
Absent or trace (<1%)	81.7	83.2
Very sparse (1 to <10%)	0.9	0.9
Sparse (10 to <30%)	8.9	9.1
Low-Moderate (30 to <50%)	1.0	1.0
Moderate-High (50 to <70%)	1.3	1.3
Dense (70 to <90%)	2.9	2.9
Complete (≥90%)	1.5	1.6
Total	98.2	100

B. Biomass

Biomass category (g/m^2)	ha	% AIH
Absent or trace (<1)	81.7	83.2
Very low (1 - 100)	7.1	7.2
Low (101 - 200)	5.5	5.6
Moderate (201 - 500)	1.5	1.5
High (501 - 1450)	1.4	1.5
Very high (>1450)	1.0	1.0
Total	98.2	100

Ulva spp. was isolated to the main channel of the estuary and formed dense (80% cover) beds on islands within the main channel in the upper estuary. Its growth was predominantly sparse in the mid to lower estuary, where it occasionally grew together with sparse *Gracilaria* spp. Dense growth of *Ulva* spp. was also observed subtidally within the main channel (see photo).

Gracilaria spp. was present predominantly as sparse growth across sandy substrates. However, small patches with complete cover (≥90%) were observed in sheltered embayments, where biomass was entrained into soft and very soft sandy mud (≥50-90% mud).

Sparse *Ulva* spp. and *Gracilaria* spp. over firm sand (>10% mud) in the lower estuary (Appendix 7: Patch ID 34).

Ulva spp. growing in shallow water in the mid estuary (subtidal).

Dense *Gracilaria* spp. growing entrained in very soft sandy mud substrate (≥50-90% mud) in a channel north of Merton Arm (Appendix 7: Patch ID 22).

Long-stranded filamentous green algae formed mats over 2ha of sandy mud (≥50-90% mud) on the upper intertidal flats adjacent to salt marsh in Merton Arm.

Vaucheria sp. formed thin mats with very low biomass (20-70g/m), generally over areas of sandy mud (≥50-

90% mud) in the upper tidal flats adjacent to salt marsh in both the Merton and East Arms. Some patches had low to moderate cover (0.6ha), however, most *Vaucheria* sp. (2.9ha) had dense (70 to <90%) or complete (≥90%) cover. Despite the low biomass, the substrate beneath high cover mats of *Vaucheria* sp. was generally enriched and anoxic.

The OMBT-EQR score for Waikouaiti was 0.658, a condition rating of 'Good', and was very similar to the OMBT-EQR score reported in 2016. *Ulva* spp. and *Gracilaria* spp. were the only nuisance macroalgae observed, with high growth (>50% cover) across 5ha. However, the development of high cover of *Vaucheria* sp. mats (2.2ha) and filamentous green algae (1.2ha) in the AIH since 2016 indicates an increase in eutrophication symptoms within the estuary (Table 10; Appendix 7). Overall, the area affected by dense macroalgae remains small (<5% of the AIH, Appendix 7).

Table 10. Opportunistic Macroalgal Blooming Tool (OMBT) Ecological Quality Rating

Year	OMBT-EQR	Rating
2016	0.692	Good
2023	0.658	Good

Dense filamentous green algae and mat-forming yellow-green alga *Vaucheria* sp. over firm muddy sand adjacent to salt marsh (Appendix 7: Patch ID 53 and 44).

4.5.2 Other algae

In addition to opportunistic macroalgal species within the AIH, other algae were also prolific in parts of the estuary (Fig. 12). These species included the following:

- Although microalgae blooms were not widespread within the estuary (0.02ha in the north of the East Arm), in these areas substrate was depleted in oxygen (anoxic).
- Filamentous algae formed abundant growth in ponds within herbfields (0.3ha). Since these growths developed within ponded water and were likely influenced by shallow water temperatures and release of nutrients from salt marsh habitat, they were excluded from the OMBT calculation (the OMBT specifically targets opportunistic species on the main intertidal flats outside of salt marsh areas).
- *Vaucheria* sp., observed smothering a 0.7ha area of salt marsh in the southwest of Merton Arm, was also excluded from the OMBT calculation as it was outside the AIH (see photo below).

Filamentous green algae in ponded water within salt marsh in the Merton Arm.

Vaucheria sp. smothering salt marsh in the upper estuary.

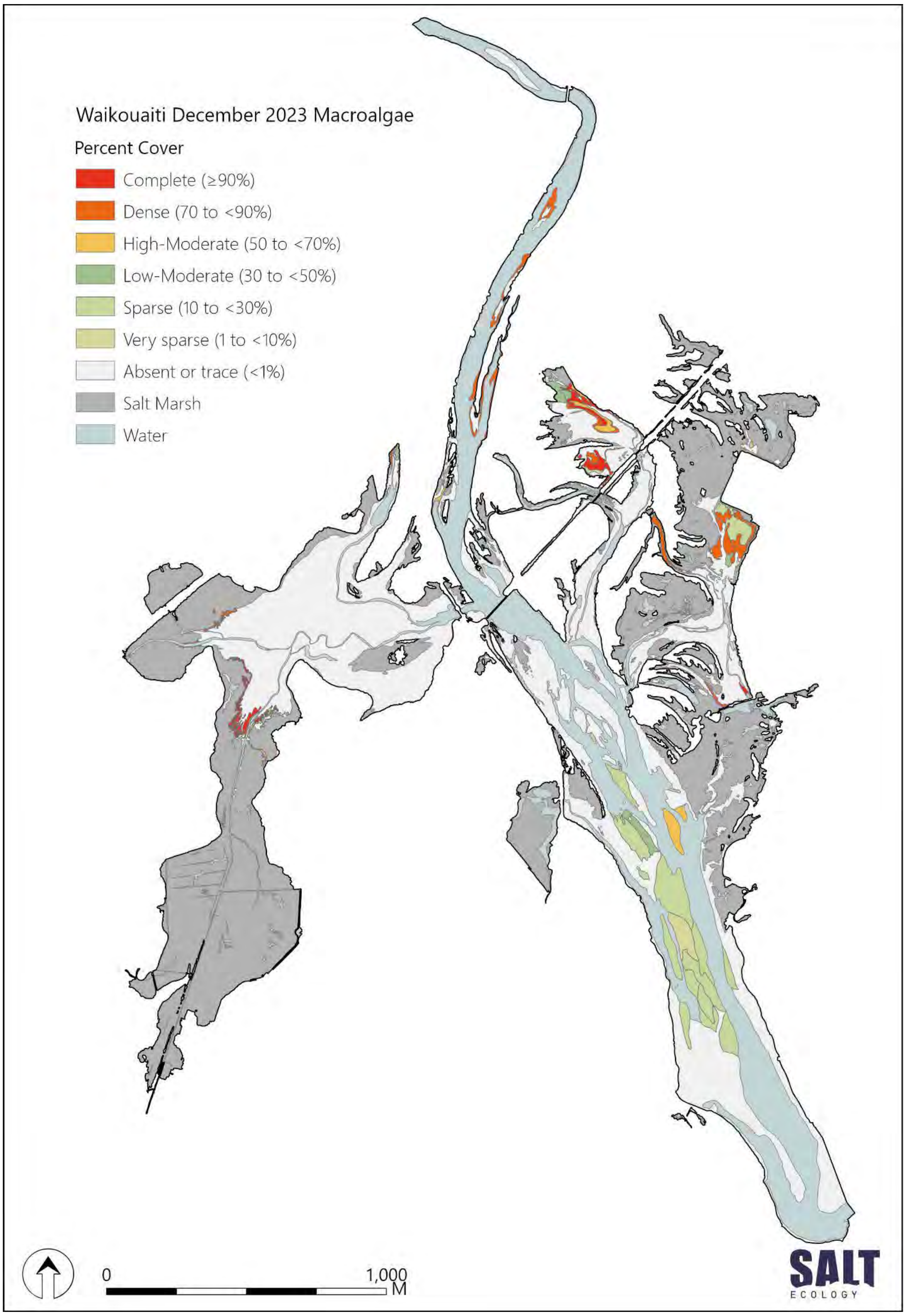


Fig. 11. Distribution and percent cover classes of macroalgae, Waikouaiti Estuary, December 2023.

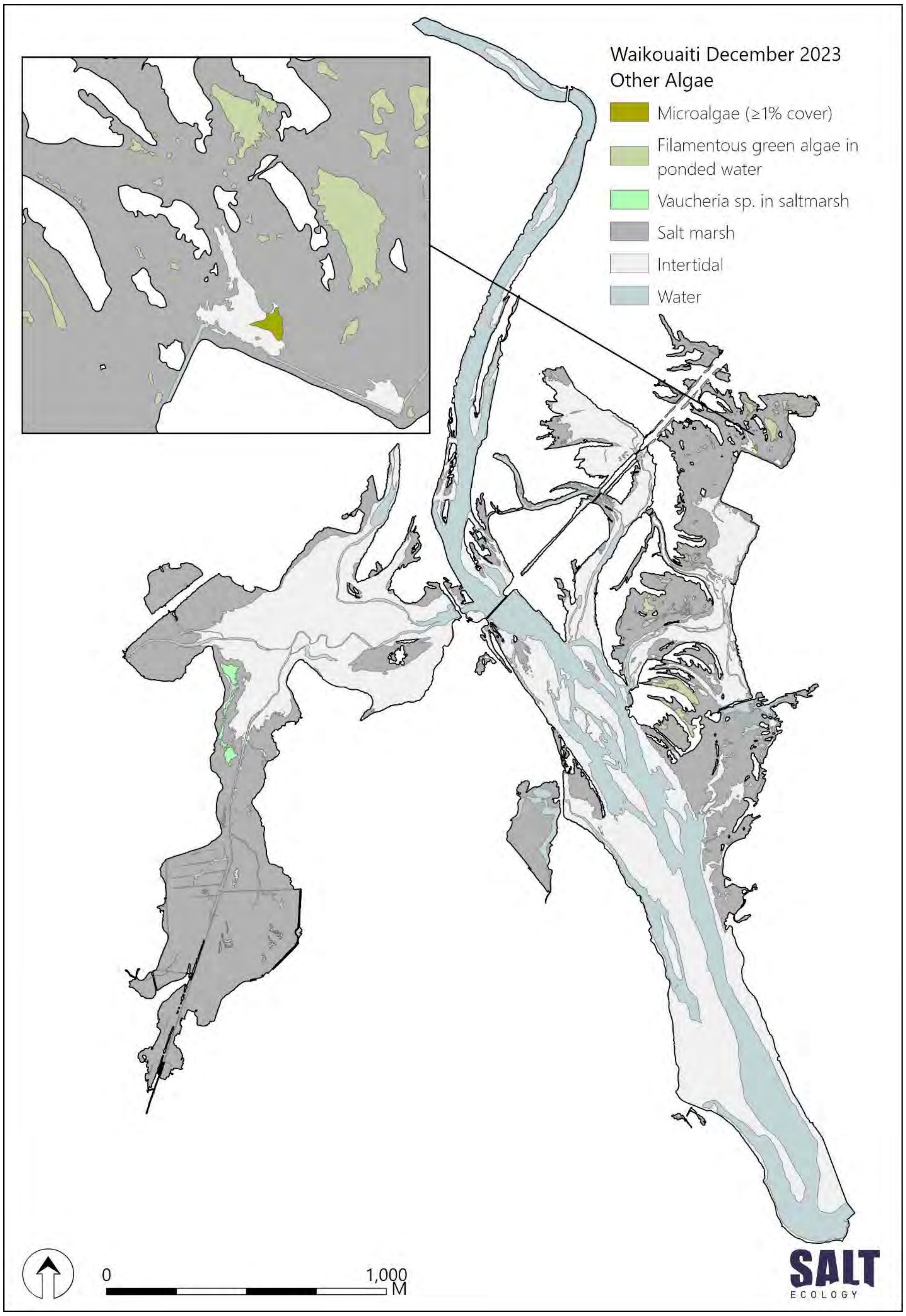


Fig. 12. Distribution of microalgae, filamentous algae in ponded water, and *Vaucheria* sp. growing in salt marsh, Waikouaiti Estuary, December 2023.

4.5.3 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., *Vaucheria* sp., and filamentous species) in areas of ≥50% mud with anoxic sediments with a strong sulfur smell and black colouration. However, the definition was broadened to include areas of blooming microalgal species where growth of these species contributed to the depletion of sediment oxygen. HEC areas covered a total of ~3ha (Table 11; Fig. 13), comprising:

- <0.1ha of *Gracilaria* spp. entrained in sheltered mud-elevated (≥50% mud) embayments of Merton Arm;
- 1.9ha of *Vaucheria* sp. over soft sandy mud on the margin of salt marsh in Merton Arm and East Arm;
- 0.5ha of dense *Ulva* spp. over soft sandy mud adjacent to *Vaucheria* sp. in upper Merton Arm;
- 0.4ha of filamentous green algae species adjacent to *Vaucheria* sp. in upper Merton Arm and East Arm; and
- Blooming microalgal species over 0.02ha in firm sandy muds (≥50-90% mud) in the north of East Arm.

While only small areas in the AIH were displaying HEC, a condition rating of 'Good' (Table 11), this represents a small decline in estuary health since 2016 where no areas of HEC were recorded (condition rating of 'Very good').

As discussed in Section 4.5.2, small areas of other algae also led to sediment degradation and were recorded within salt marsh habitat (therefore excluded from HEC). In the Merton Arm, smothering of salt marsh by *Vaucheria* sp. led to the loss of 0.1ha of salt marsh leaving bare, oxygen-depleted soft sandy muds. This pathway of salt marsh loss, while only small, highlights that nutrient enrichment and resultant macroalgal blooms can have detrimental effects on salt marsh habitat and sediment condition.

Table 11. Summary of High Enrichment Conditions (HEC) in available intertidal habitat (AIH).

Year	ha	% AIH
2016	0	0
2023	2.9	3.0

Condition rating key:

Very Good	Good	Fair	Poor

Vaucheria sp. growing adjacent to salt marsh in the East Arm.

Dense cover of filamentous green algae with black anoxic sediment.

Complete cover of microalgae with black anoxic sediment below, north of the wastewater treatment ponds on the southern margin of East Arm.

Mat-forming *Vaucheria* sp. growing over salt marsh with black anoxic sediment below.

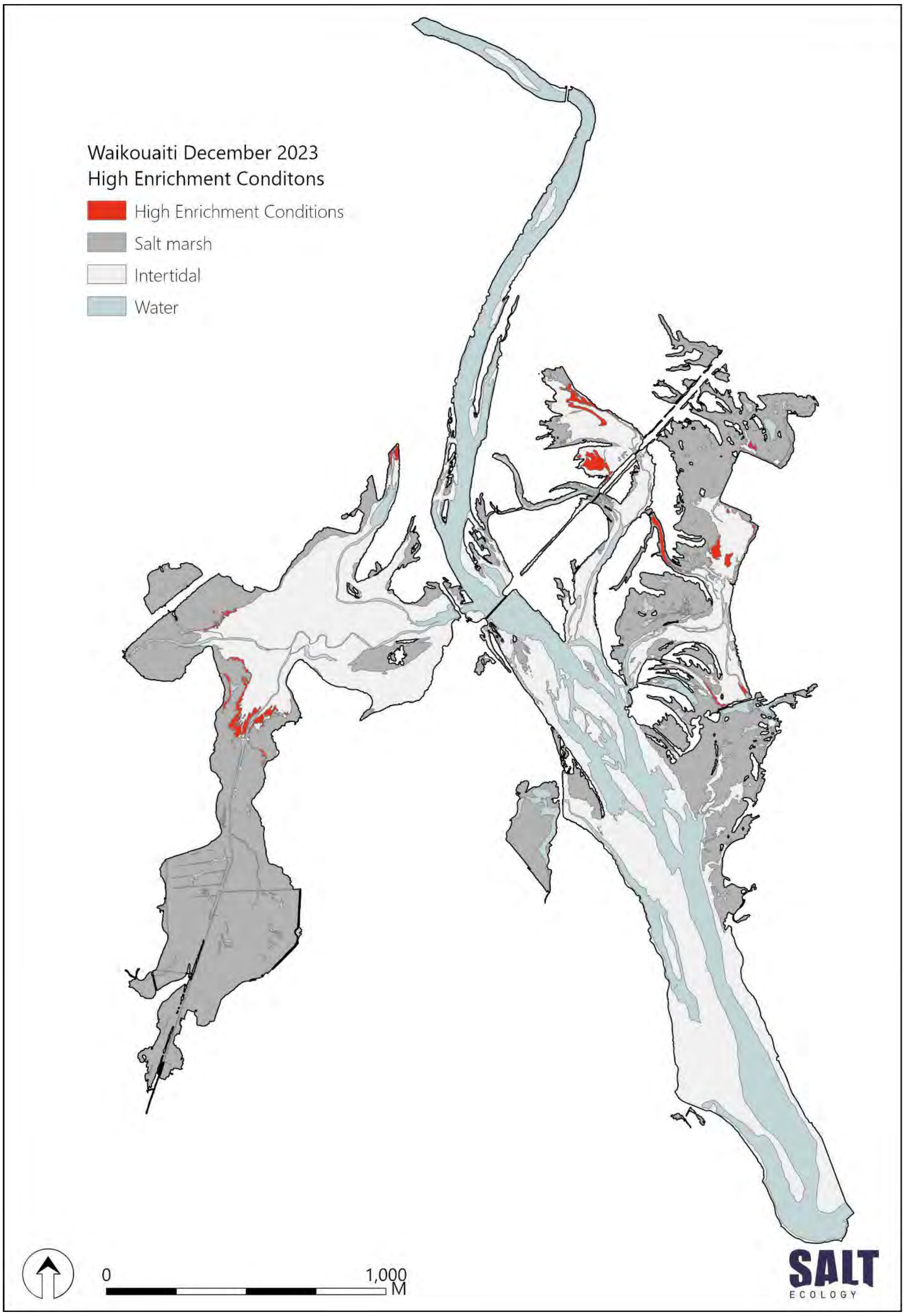


Fig. 13. Distribution of high enrichment conditions, Waikouaiti Estuary, December 2023.

5. SEDIMENT QUALITY AND BIOTA

Fig. 16 &Fig. 17 (following pages) present illustrative photos of Sites 1-8, where sediment quality and biota sampling were undertaken (see Fig. 4 for site locations). Sediment quality and biota sampling aimed to capture a broad range of representative habitat and substrate types and were spread across two sites in Merton Arm (Sites 1 & 2), three sites in East Arm (Sites 3, 4 & 5), and three sites spread between the mid and lower estuary (Sites 6, 7 & 8). Although the side arms of the estuary represent upper-estuary sites, the upper-estuary in the main channel was not sampled because this area is strongly influenced by freshwater (i.e., low salinities), high flows and dynamic substrate movement. Additional estuary substrate grain size samples were collected throughout the estuary to inform substrate mapping validation, as described in Appendix 6 and shown on Fig 4.

5.1 SEDIMENT QUALITY INDICATORS

Sediment sampling confirmed the general broad-scale mapping pattern of decreasing mud content toward the estuary entrance, with upper estuary sites in the two side arms (Sites 1 - 5) having a higher mud content than the mid and lower estuary (Sites 6 - 8; Fig. 14). Strong riverine and tidal currents in the main channel of the mid and lower estuary result in sand-dominated substrates, with a high proportion of gravel and minimal fine sediments (Sites 6, 7 & 8). Elevated-mud sediments (>25% mud) were present in the relatively sheltered Merton Arm (Sites 1 & 2) and the upper reaches of the East Arm (Sites 3 & 4).

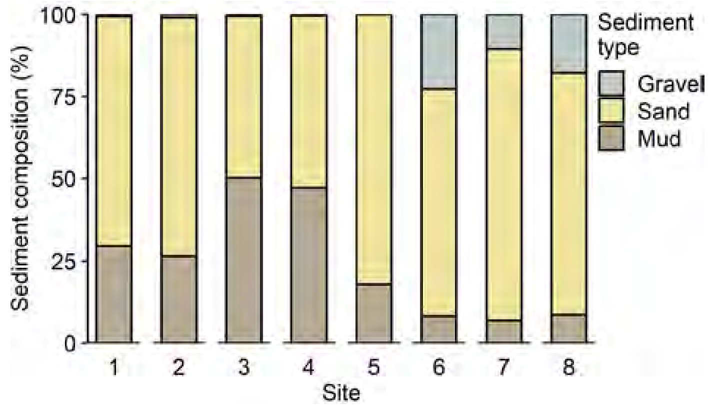


Fig. 14. Sediment grain size composition at sediment quality and biota sites. Size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

Key sediment quality indicators are presented relative to condition rating thresholds in Fig. 15 and Table 12. In summary:

- The mud contents of upper estuary sites within Merton (Sites 1 & 2) and East Arm (Sites 3 &4) were >25% (range 27-50% mud), a condition rating of 'Poor', and above ecological thresholds where significant biological changes due to elevated muddiness are expected. Site 5 within East Arm was sandier than the upper estuary sites, comprising 17% mud, a condition rating of 'Fair'. In 2016, this area

Mid-estuary tidal flats below the railway bridge on the true left bank, had high mud content and beds of *Spartina*. The subsequent eradication of *Spartina* likely released trapped fine sediments and allowed improved flushing of the area reducing its mud content. Mid and lower estuary sites (6, 7 & 8) had low mud content (7-9%), a condition rating of 'Good'.

- In general, Total organic carbon (TOC) and total nitrogen (TN) levels were low, rated 'Very good' and 'Good', respectively. Concentrations of TOC and TN were slightly elevated at the upper sites in East Arm (Sites 3 & 4). Additionally, TN levels were slightly elevated at Site 6 in the mid estuary, possibly due to enriched water flowing over the site or the breakdown of seagrass at this location. These three sites received a condition rating of 'Good', except for TN at Site 4, which was rated 'Fair'. Total phosphorus (TP) showed a similar trend to TN (see Appendix 4).
- Sediments were generally poorly oxygenated (shallow aRPD; Fig. 16, Fig. 17), rated 'Poor' at the upper sites in East Arm (Sites 3 & 4) and Site 6 in the mid estuary (which had seagrass present), and 'Fair' in Merton Arm (Site 1 & 2) and Site 7 in the mid-lower estuary. The lower estuary site (Site 8) had a deeper aRPD, resulting in a condition rating of 'Good'.
- Despite the reduced aRPD, other sediment parameters (TOC, TN and TP) did not indicate sediment enrichment at the monitored sites. Total sulphur (TS) was generally low overall indicating eutrophic conditions were not an issue at these locations (Appendix 4).
- Trace metal concentrations were very low in all samples, a condition rating of 'Very good' (Table 12). This rating represents metal concentrations that are less than half of ANZG (2018) Default Guideline Values (DGV). These results are consistent with previous fine scale monitoring within the estuary (Robertson et al. 2017; O'Connell-Milne et al. 2024).

Sampling sediment quality.

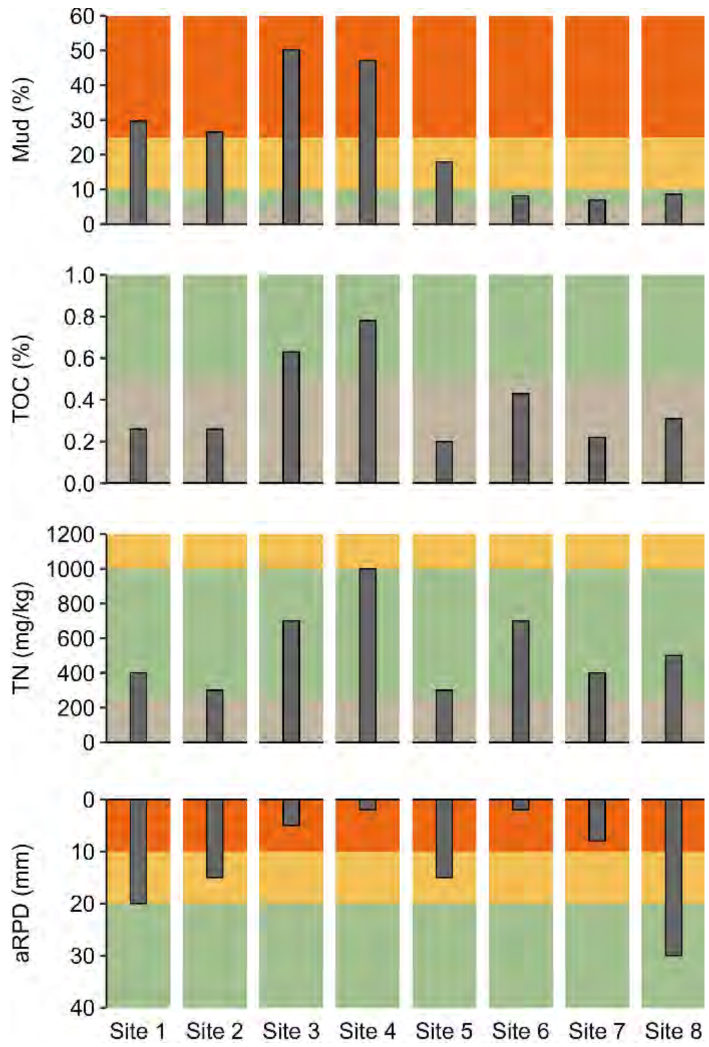


Fig. 15. Grey bars show sediment %mud, total organic carbon (TOC), and total nitrogen (TN) and aRPD depth at sediment quality and biota sites, relative to condition ratings. TN at Sites 2 and 5 was less than method detection limits (MDL), hence half of the MDL value is shown.

Condition rating key:

Very Good	Good	Fair	Poor

Table 12. Trace metal concentrations (mg/kg) relative to ANZG (2018) Default Guideline Values (DGV).

Site	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
1	4.2	0.027	5.5	2.2	0.01	3.4	3.2	20.0
2	3.5	0.018	3.9	2.3	0.01	3.3	2.5	17.3
3	6.3	0.025	7.4	7.6	0.01	8.1	6.0	37.0
4	5.6	0.027	6.3	5.1	0.01	5.6	4.5	28.0
5	3.7	0.014	3.8	2.4	0.01	3.3	2.2	14.9
6	5.6	0.017	5.2	5.0	0.01	6.0	4.0	25.0
7	4.0	0.005	4.3	4.2	0.01	5.0	3.1	22.0
8	6.2	0.019	6.6	4.2	0.01	6.2	3.9	25.0
DGV	20	1.5	80	65	0.15	21	50	200

DGV indicates the concentrations below which there is a low risk of unacceptable effects occurring. Grey shading corresponds to a 'very good' (<0.5 x DGV) condition rating, as shown in Table 3.

Site 1

Site 1 - aRPD

Site 2

Site 2 - aRPD

Site 3

Site 3 - aRPD

Site 4

Site 4 - aRPD

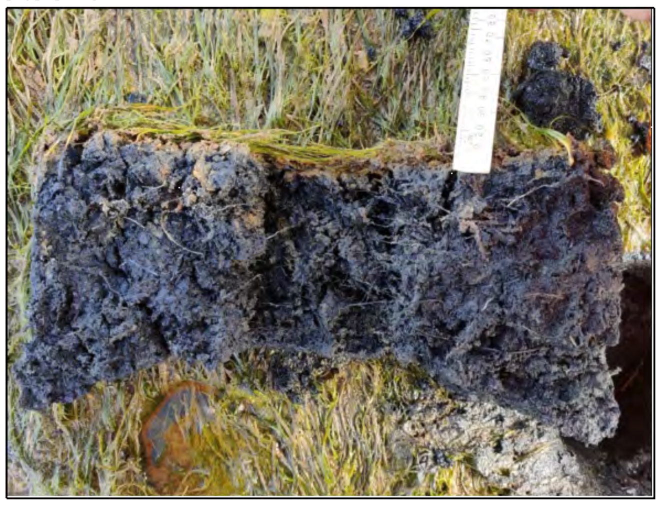
Fig. 16. Illustrative photos of Sites 1-4 (see Fig. 4) where sediment quality and biota sampling were undertaken.

Site 5

Site 5 - aRPD

Site 6

Site 6 - aRPD



Site 7

Site 7 - aRPD

Site 8

Site 8 - aRPD

Fig. 17. Illustrative photos of Sites 5-8 (see Fig. 4) where sediment quality and biota sampling were undertaken.

5.2 BIOTA

Epibiota were reflective of the site sediment characteristics discussed above. Surface-dwelling epifauna were generally sparse, however the elevated mud substrates within the upper estuary at Sites 1, 2, 3 & 5 supported abundant mud snails (*Amphibola crenata*; 10-20/m^2) and the stalk-eyed mud crab *Hemiplax hirtipes*.

Minimal macroalgae or visible surface microalgae was noted at most sampling sites. Site 4 had dense filamentous green algae (75%) and drift *Ulva* spp. present, and Site 7 had *Ulva* spp. present. Site 6 was within a dense (85%) seagrass bed with *Ulva* spp. (25%) growing on the surface of seagrass.

Site 3 in the upper estuary (East Arm) had the highest mud content (50% mud) and abundant mud snails visible on the surface.

Dense seagrass and *Ulva* spp. over anoxic black sediment at Site 6.

All sites had a suite of sediment-dwelling macrofauna in the core samples. A total of 43 species or higher taxa were recorded, representing 14 main organism groups (Appendix 8). Fig. 18 shows the average species richness per site was moderate-high increasing towards the lower estuary (Site 8). Organism abundances generally followed the same trend, except for Site 1 and Site 4 which were elevated due to high amphipod abundances. These observations are consistent with results of previous fine scale monitoring carried out within the estuary (i.e., Sites 1, 6 & 8 which correspond to Fine Scale Sites C, B and A, respectively; Robertson et al. 2017; O'Connell-Milne et al. 2024).

Site 4, located in the East Arm, had the highest abundance, dominated by the amphipod *Paracalliope novizealandiae* (total abundance = 640). This species was scarce at other sites, with the next highest count being 14 individuals at Site 3. Site 1 in Merton Arm also had elevated abundance, driven by the tube-building amphipod *Paracorophium excavatum (*total abundance = 668) which comprised 79-85% of the community and was present in lower numbers (3 - 36) at other mud dominated sites (Fig. 18).

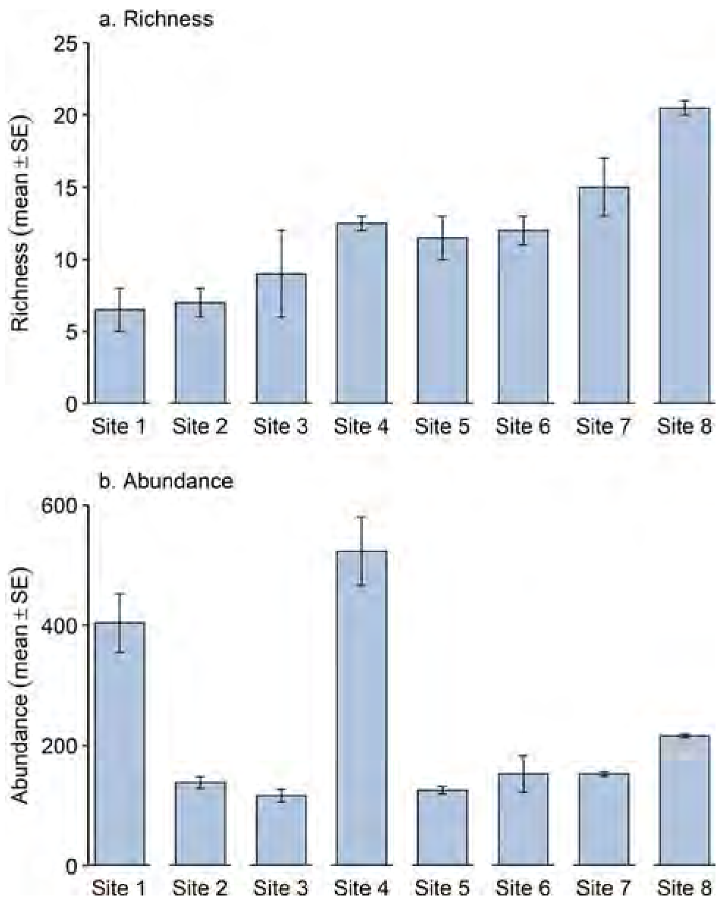
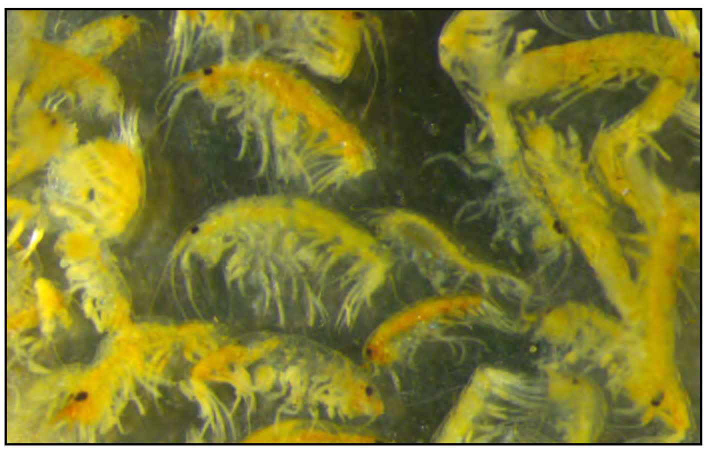
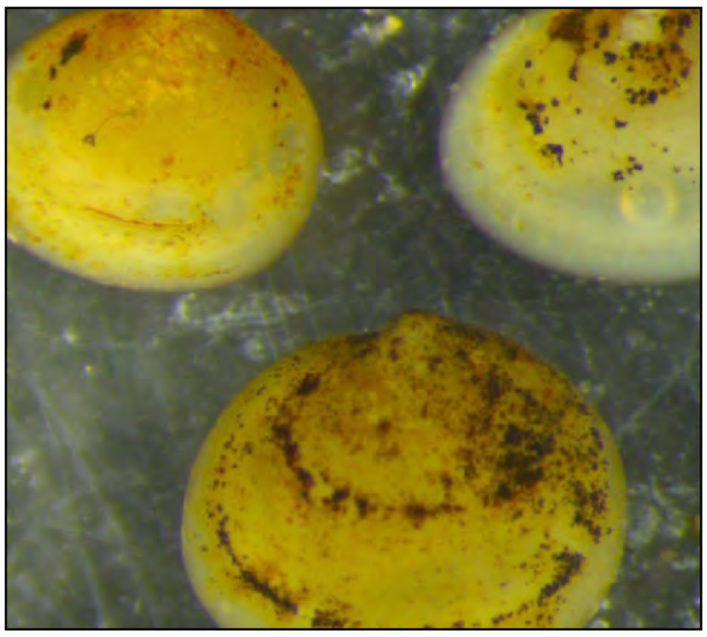


Fig. 18. Mean (± SE) taxon richness and abundance in duplicate core samples.



The amphipod *Paracalliope novizealandiae* was abundant at Site 4 (photo courtesy of NIWA).

Core sampling found an abundance of cockles (*Austrovenus stutchburyi*) in the lower well-flushed parts of the estuary (Site 8), and lower numbers on the mid estuary flats (Sites 6 & 7). The bivalve *Arthritica* sp.5 had an inverse distribution, due to its tolerance for muddy substrates. It was present at all sites other than the sand-dominated mid estuary Site 7, and in very low numbers at Site 8 (n=3; Appendix 8).



Bivalve *Arthritica* sp. 5 was almost ubiquitous across the estuary, absent only from Site 7 (photo courtesy of NIWA).

Table 13 shows that 55% of the dominant macrofauna species are disturbance-tolerant or tolerant of low salinity conditions (eco-groups (EG) III-V), resulting in a relatively hardy suite of species.

For example, the resilient spionid *Scolecolepides benhami* (EG-V) was present across most sites, with reduced numbers in the mid-lower estuary (Site 7) and absent from the lower estuary (Site 8).

This led to elevated AMBI scores (Fig. 19), indicating 'Fair' ecological conditions at upper estuary sites and 'Good' ecological conditions in the mid and lower estuary. Exceptions to this were Site 4, which had a 'Good' rating, and Site 6 in the mid estuary, which had a 'Fair' rating. Due to the abundance of *P. novizealandiae* (EG-I) at Site 4 (upper estuary, East Arm), the AMBI score may not accurately reflect the relatively degraded community present, which includes high numbers of the polychaete *Capitella cf. capitata* (EG-V). Despite *P. novizealandiae* being classified as a sensitive species within EG-I (based on the international eco-group sensitivity for *Paracalliope* sp.) our data indicates this species appears to tolerate sedimentation and muddy habitats and would likely be reclassified to EG-IV.

Site 6 had lower species richness and a relatively degraded AMBI score compared to other sand-dominated sites in the mid and low estuary. This is notable as its location within a seagrass bed would typically be expected to support higher diversity metrics (Rodil et al. 2021). The Site 6 AMBI score reflected relatively high abundances of *S. benhami, Arthritica* sp. 5., and *Capitella cf. capitata*, as well as high abundance of the polychaete *Perinereis vallata*.

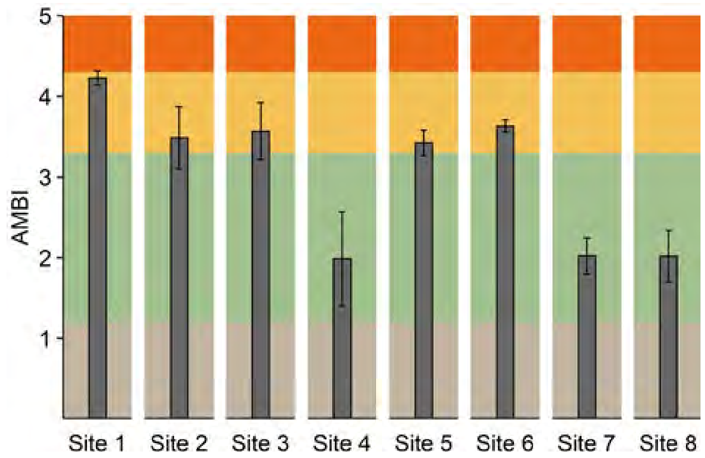


Fig. 19. Mean (± SE) macrofauna AMBI scores in duplicate cores at Site 1-8, relative to condition ratings. *Condition rating key:*

Very Good	Good	Fair	Poor

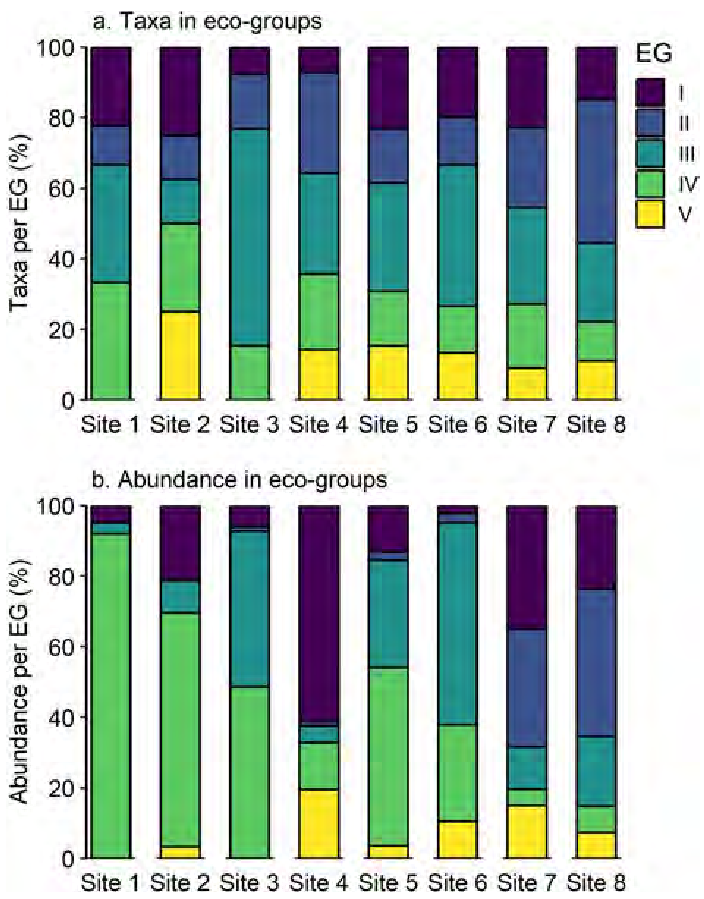


Fig. 20. Percentage of taxa within eco-groups ranging from sensitive (EG-I) to resilient (EG-V) at Site 1-8.

Table 13. Dominant macrofauna at Sites 1-8. Numbers are total abundances summed across duplicate cores.

Main group	Taxa	EG	1	2	3	4	5	6	7	8	Description
Amphipoda	*Paracorophium excavatum*	IV	668	36	3	29	3	1	1	-	Corophioid amphipod that is an opportunistic tube-dweller, tolerant of muddy and low salinity conditions.
Polychaeta	*Scolecolepides benhami*	IV	74	148	110	108	123	83	6	-	A spionid, surface deposit feeder. It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark.
Polychaeta	*Microspio maori*	I	38	57	-	-	21	-	4	-	A small, common, intertidal spionid. Can handle moderately enriched situations. Prey items for fish and birds.
Bivalvia	*Arthritica sp. 5*	III	21	25	91	11	64	54	-	3	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.
Polychaeta	*Prionospio aucklandica*	III	2	-	-	-	-	-	1	64	A surface deposit-feeding spionid common in harbours and estuaries. Associated mainly with muddy sands, but occurs across a range of mud contents (12-50% optimum). Considered tolerant to organic enrichment despite EG II classification.
Amphipoda	*Paracalliope novizealandiae*	I	1	-	14	640	11	2	5	6	Amphipods are shrimp-like crustaceans. This species is common in New Zealand estuaries. It is considered to be indifferent to sedimentation and can tolerate muddy habitats to some extent.
Polychaeta	*Capitella cf. capitata*	V	-	5	-	186	2	29	42	24	Subsurface deposit feeder, occurs down to about 10 cm sediment depth. Common indicator of organic enrichment or other forms of disturbance. Is a dominant inhabitant of sediments polluted heavily with organic matter.
Polychaeta	*Perinereis vallata*	III	-	-	1	15	-	99	24	-	An intertidal omnivorous nereid worm, associated with mud/sand sediments. Prey item for fish and birds. Considered sensitive to high sedimentation.
Polychaeta	*Aonides trifida*	I	-	-	-	-	1	-	88	75	Small surface deposit-feeding spionid polychaete worm that lives throughout the sediment to a depth of 10cm. Considered highly sensitive to sedimentation and mud (mud optimum <15%), but tolerant of organic enrichment despite EG I classification.
Bivalvia	*Austrovenus stutchburyi*	II	-	-	-	-	-	6	4	64	Cockles are suspension feeding bivalves, living near the sediment surface. They can improve sediment oxygenation, increasing nutrient fluxes and influencing the type of macrofauna present. Sensitive to organic enrichment. Important in diet of certain birds, rays and fish.
Polychaeta	*Boccardia syrtis*	II	-	-	-	-	-	2	73	79	A small surface deposit-feeding spionid. Found in a wide range of sand/mud habitats. Lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Sensitive to organic enrichment.

A multivariate analysis of macrofauna community composition is summarised in Fig. 21. It 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. Community composition at Site 1 (upper estuary) and Site 8 (lower estuary) were the most different, reflecting both the presence of species not recorded at other sites, and the absence of certain species common at some or all other sites. The high abundance of *P. excavatum* at upper estuary Site 1, as discussed above, and the localised distribution of cockles and polychaetes *Scoloplos cylindrifer* and *Boccardia syrtis* to lower estuary sites (Site 7 & 8) drive upper to lower (i.e., left-to-right in Fig. 17) estuary site differences. The vertical site separation (i.e., up-down in Fig. 17) was mostly influenced by species present at only one or two sites at low abundance. For example, a single Copepoda was found in cores at Sites 3, 4, 5 and 8, while Sabellidae polychaetes were present at Site 2 and 4. The absence of these species at other sites further contributed to the vertical site differences.

Mud content was the sediment quality attribute which was most closely correlated with the changes in macrofauna community composition, and most strongly explained the upper to lower estuary pattern of compositional change in the macrofauna. Gravel and sand also had a large impact on community composition, potentially reflecting the impact of substrate stability and homogeneity on abundance of disturbance tolerant species (i.e., Site 6), and may be related to higher riverine flow which likely contributes to substrate instability. This is supported by highly variable interannual patterns in sediment deposition and erosion through the main reach of the estuary during fine scale monitoring (O'Connell-Milne et al. 2024). Site 6 is located at fine scale monitoring Site B, which was abandoned in 2019 following a large erosion event due to the proximity of the main channel.

Other unmeasured factors are also likely to be important determinants of macrofauna composition differences, such as substrate stability and effects of wave action in the lower estuary, and the effects of pulses of low-salinity water during flood events, especially adjacent to the central estuary.

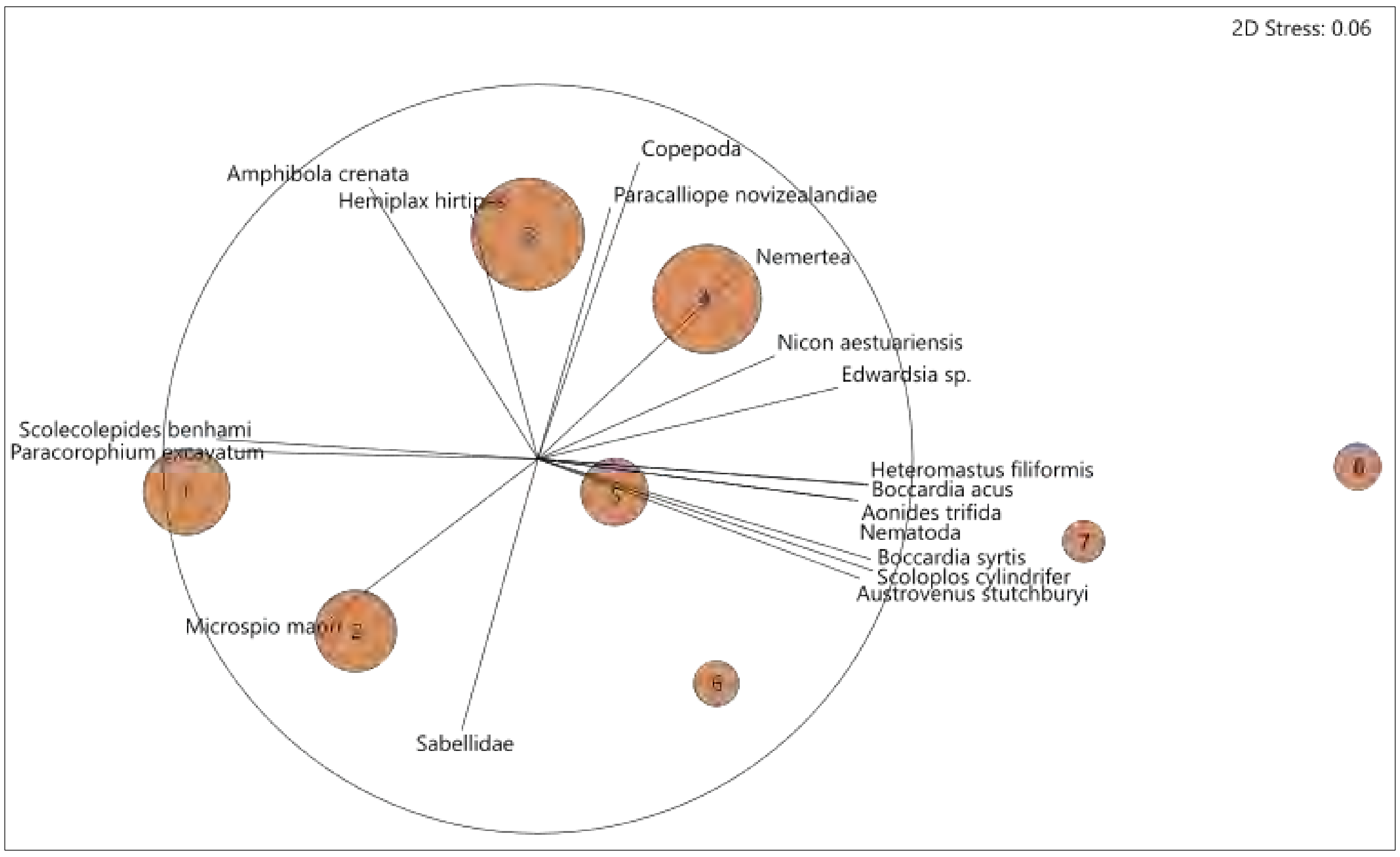


Fig. 21. Non-metric MDS ordination of macrofaunal core samples from each site.

Sites closer to each other are more similar than distant ones in terms of macrofauna composition. This plot has a 2D stress value of 0.06. A 'stress' value of zero indicates that a 2-dimensional plot provides a highly reliable representation of site differences. The vectors show the direction and strength of association (length of lines relative to circle) of grouping patterns for macrofauna species most correlated (>65%) with site differences. Brown circles for each site are scaled to reflect sediment mud content, the environmental variable most strongly correlated with macrofauna composition differences.

6. SYNTHESIS OF KEY FINDINGS

6.1 OVERVIEW

Summaries of key broad scale features, and results relative to broad scale and fine scale condition ratings, are provided in Tables 14, 15, and 16. Additional supporting indicators used to assess and interpret estuary condition were derived from catchment-scale nutrient and sediment models (e.g., CLUES; Hicks et al. 2019) and are presented in Table 17. The 2023 results indicate Waikouaiti is experiencing degradation as a consequence of current and historic human activities within the estuary, and catchment inputs of fine sediment and nutrients.

Table 14. Summary of key broad scale features as a percentage of total estuary, intertidal, available intertidal habitat (AIH) or margin area, Waikouaiti Estuary, December 2023.

a. Area summary	ha	% Estuary
Intertidal Area	192.5	76.2
Subtidal Area	60.3	23.8
Estuary Area	252.7	100
AIH Area	98.2	38.8
b. Key substrate features	**ha**	**% AIH**
Mud-enriched (25 to <50% mud)	12.2	12.4
Mud-dominated (≥50% mud)	20.8	21.2
c. Key habitat features	**ha**	**% Intertidal**
Salt marsh	94.3	49.0
		% AIH
Seagrass (≥50% cover)	0.5	0.5
Macroalgae (≥50% cover)	5.7	5.8
Microalgae (1-100% cover)	0.02	0.02
High Enrichment Conditions	2.9	3.0
d. Terrestrial margin (200m)	**ha**	**% Margin**
200m densely vegetated margin	55.8	12.7

Drainage channels cut through high quality salt marsh habitat.

Bare muddy substrate in Merton Arm, where seagrass historically flourished.

Filamentous green algae growing over seagrass beds in the mid estuary.

Salt marsh damaged due to pugging by livestock in the foreground, with horses grazing in the distance.

Table 16. Summary of broad scale indicator condition ratings for Waikouaiti Estuary, December 2016 and 2023.

Broad Scale Indicators	Unit	2016	2023	2023 Rating
200m terrestrial margin	% densely vegetated	7.4	12.7	Poor
Mud-elevated substrate	% AIH[1] area (≥25% mud)	35.6	33.6	Poor
Macroalgae (OMBT-EQR[2])	Ecological Quality Rating (EQR)	0.692	0.658	Good
Seagrass (≥50% cover)[3]	% decrease from baseline	87.0	96.4	Poor
Salt marsh extent (current)	% of intertidal area	45.4	49.0	Very good
Historical salt marsh extent[4]	% of historical remaining	47.0	55.2	Fair
High Enrichment Conditions	ha	0	2.9	Good
High Enrichment Conditions	% of estuary	0	3.0	Good
Modelled Estuary-wide Indicators				
Sedimentation rate	CSR:NSR[5] ratio	na	1.8	Good
Sedimentation rate	mm/yr	na	8.1	Poor

[1]Available Intertidal Habitat excludes salt marsh area; [2]Opportunistic Macroalgal Blooming Tool (OMBT) scores have been updated following Stevens et al. (2022); [3]Seagrass baseline 1958 (Appendix 5); [4]Estimated from historic aerial imagery; [5]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling). na = not applicable. See Table 3 for colour bands and definitions.

Table 15. Synoptic sampling sites (1-8) and indicator condition ratings for sediment quality and macrofauna AMBI, 2023.

Parameter	Unit	1	2	3	4	5	6	7	8
Mud	%	29.6	26.5	50.2	47.1	17.9	8.1	6.9	8.6
aRPD	mm	20	15	5	2	15	2	8	30
TN	mg/kg	400	300	700	1000	300	700	400	500
TP	mg/kg	480	580	690	680	380	550	400	530
TOC	%	0.26	0.26	0.63	0.78	0.20	0.43	0.22	0.31
TS	%	0.11	0.07	0.12	0.20	0.11	0.09	0.40	0.50
As	mg/kg	4.2	3.5	6.3	5.6	3.7	5.6	4.0	6.2
Cd	mg/kg	0.027	0.018	0.025	0.027	0.014	0.017	0.005	0.019
Cr	mg/kg	5.5	3.9	7.4	6.3	3.8	5.2	4.3	6.6
Cu	mg/kg	2.2	2.3	7.6	5.1	2.4	5.0	4.2	4.2
Hg	mg/kg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ni	mg/kg	3.4	3.3	8.1	5.6	3.3	6.0	5.0	6.2
Pb	mg/kg	3.2	2.5	6.0	4.5	2.2	4.0	3.1	3.9
Zn	mg/kg	20.0	17.3	37.0	28.0	14.9	25.0	22.0	25.0
AMBI	na	4.2	3.5	3.6	2.0	3.4	3.6	2.0	2.0

See Glossary for abbreviations. < values below lab detection limit. See Table 3 for colour bands and definitions.

6.2 DIRECT IMPACTS TO SALT MARSH

Waikouaiti salt marsh is recognised as a regionally and locally significant wetland because of its high degree of naturalness and scarcity (<15% remaining) in the Otago region. Under the draft Otago Land and Water Regional Plan, this designation means that within the regionally significant wetland boundary, activities such as drainage, digging artificial ponds, and diversion or damming of water are either prohibited or require resource consent. Stock access must not cause pugging or damage to fauna or New Zealand native flora in regionally significant wetlands under regional rules (note that horses are currently not considered 'stock' under these rules). While the regionally significant wetland boundary does not cover all salt marsh, remaining areas are treated as 'natural wetlands' which have the same restrictions around activities.

Despite the importance of this habitat, human activities have resulted in a loss of ~45% salt marsh when compared to 'natural' state, attributed primarily to historic reclamation and drainage for pasture in the west and southwest of the estuary (Fig. 7). Other historical losses include reclamation for infrastructure (road, rail, wastewater treatment plant) and as a consequence of reduced flushing due to the installation of causeways.

Salt marsh losses from human activities are ongoing. Horses and cattle fenced within herbfield in the East Arm have caused significant recent damage to vegetation and soil structure due to grazing and pugging. Further, vehicle tracking and gravel access roads are common in this part of the estuary (see photos below). Vehicle damage was also observed in the Merton Arm. Vehicles compact the soil, damage vegetation, and create ruts which can alter water flow and increase erosion, further degrading salt marsh.

Vehicle tracks in areas of herbfield accessed via a causeway across East Arm (top; source: 2018 imagery from LINZ Data Service). The same area in December 2023 with both vehicle and horse damage observed within herbfield (bottom).

Vehicle tracks through herbfield in Merton Arm.

Another significant contributor to salt marsh loss in recent decades is the restriction of water flow by causeways. While the two largest causeways in the East Arm were installed in the 1970-1980's, the one closest to the wastewater treatment ponds was reinstated with concrete fill and gravel in ~2019 after it had eroded away. Although two large culverts are present, water flow is severely restricted to the upper estuary. Two smaller causeways have also been installed in recent years in the same arm. The restriction of tidal flows into these areas has led to salt marsh loss and exacerbated the expansion of mud-elevated sediments and symptoms of nutrient enrichment.

Of particular concern were newly cut (~2020) drainage channels through herbfield in the East Arm close to the boundary of the regionally significant wetland area and within the 'natural' wetland area. These unconsented drainage channels will cause further losses of salt marsh in the upper estuary areas.

Relatively recent drainage channels were also observed in the Merton Arm. Other minor losses of salt marsh had occurred following dumping of sediment and/or vegetation cuttings over herbfield, as well as from localised erosion of salt marsh on some channel edges.

Newly cut (~2020) drainage channels in herbfield, East Arm.

Most historical losses of salt marsh occurred prior to an appreciation of their high value in terms of biodiversity and ecosystem services including erosion protection, flood mitigation, sediment stabilisation, nutrient assimilation and carbon sequestration.

Maintaining and improving the health of salt marsh habitat is essential for regulating estuary conditions and ensuring the overall ecological integrity of the area, especially with the imminent threat of further losses due to sea level rise (see Section 6.5).

Contemporary losses within, and adjacent to, areas designated for protection are therefore highly concerning in light of current knowledge of salt marsh value, and regional scarcity due to extensive past losses. The cumulative effects of past losses, and the recent impacts described above, have significantly reduced the health of Waikouaiti Estuary. It is considered a high priority to prevent ongoing damage of salt marsh, to prioritise protection and enhancement efforts, and to remedy or mitigate recent salt marsh damage.

Table 17. Supporting data to assess estuary ecological condition in Waikouaiti Estuary, December 2023.

Supporting Condition Measure	Waikouaiti
Mean freshwater flow (m^3/s)[1]	1.6
Catchment Area (Ha)[1]	42382
Catchment nitrogen load (TN/yr)[2]	65.3
Catchment phosphorus load (TP/yr)[2]	12.1
Catchment sediment load (KT/yr)[1]	35.1
Estimated N areal load in estuary ($mg/m^2/d$)[2]	70.8
Estimated P areal load in estuary ($mg/m^2/d$)[2]	13.1
CSR:NSR ratio[1]	1.8
Trap efficiency (sediment retained in estuary)[1]	87%
Estimated rate of sedimentation (mm/yr)[1]	8.1

[1] Hicks et al. (2019) & Oldham (2022).

[2] CLUES version 10.8 (LCBD5); Run date: April 2024.

6.3 VULNERABILITY TO MUDDY SEDIMENTS

In 2023, mud-elevated (≥25-100% mud) sediments covered 33ha (~34% of the AIH, a rating of 'Poor') and continue to be one of the most significant pressures on estuary health. Mud-elevated sediments are likely attributable to a combination of historic land clearance, contemporary catchment inputs, and reduced trapping efficiency through significant salt marsh loss (see Section 6.2).

Catchment modelling predicts a Current to Natural Sedimentation Rate (CSR:NSR) ratio of 1.8, a condition rating of 'Good' (Table 17; Hicks et al. 2019) suggesting contemporary inputs are not significantly elevated above natural rates. However, present-day loads are likely underestimated by Hicks et al. (2019) because land cover was based on LCDB3 (2008), the modelling does not account for variable intensification of land uses (e.g., intensive dairying or winter grazing), and erosion susceptibility is considered independently from land use (Hicks et al. 2019). More contemporary and refined estimates are needed to assess true sediment loads to the estuary.

Elevated contemporary loads are expected as a high proportion of the catchment and margin is in land uses known to generate high sediment loads such as farming (75% of catchment area is pasture) and exotic forestry (4% of catchment area). It has been estimated that 44% of the soil that enters New Zealand rivers is from pasture, and these sediments are deposited in estuaries or the marine environment (MfE 2019). Plantation forestry is recognised as a significant source of sediment with disproportionately high sediment loss during harvest and in the post-harvest period before replanted forest reaches a closed canopy state (e.g., Gibbs et al. 2019). Lags in sediment inputs post-harvest are also likely as disturbed sediment can continue to be mobilised and flushed through the catchment in ongoing pulses. Plantation forestry on the estuary margin (~8%) also presents a potential future sediment source directly to the estuary during harvest.

Sediment deposition varies spatially in the estuary due to the range of physical environments present. For example, the main reach of the estuary is channelised, with river-dominated hydrodynamics contributing to high flushing, in contrast to the limited flow and flushing characteristics of the adjacent side arms. The dynamic movement of substrates in the main reach of the estuary is reflected in the substrate type (i.e., sands and gravels) and the highly variable interannual patterns of sedimentation (Rabel 2024).

In terms of biota, sites with mud-elevated sediments in the upper estuary were generally characterised by a macrofaunal community of hardy taxa that are resilient to elevated mud and most forms of disturbance. The river-dominated sites subject to highly variable flows and salinities also had high numbers of species commonly found in disturbed environments (e.g., *P. excavatum*). Accordingly, the macrofauna AMBI scores had a condition rating of 'Fair' (Table 16). In the East Arm muddy sediments were also coincident with reduced sediment oxygenation and marginally elevated levels of TOC (Table 16).

Between 2016 and 2023, there was an increase in the extent of muddy substrates in the East Arm, with substrate shifting from muddy-sand to mud-dominated substrates, likely influenced by the relatively sheltered environment and low flows promoting settling of fine particles.

Merton Arm retains large areas of muddy substrate; however, improvements were evident with a reduction in the extent of muddy substrates since 2016 and concurrent erosion of -2.4mm/y recorded at sediment plate monitoring Site 1 (Fine Scale Site C) in the upper tidal flats of Merton Arm (Rabel 2024).

The extent of soft mud-elevated substrates increased in the East Arm between 2016 and 2023.

In 2023, seagrass was primarily localised to a small area (1.1ha) in firm sands in the well-flushed main reach of the estuary. Historical aerial imagery shows that the estuary previously supported much larger areas of seagrass (13ha), particularly in the Merton Arm. It is possible that the introduction of *Spartina* sp. in the late 1970s, in addition to estuary modification (primarily altered hydrodynamics from causeways and flap gates), and increased catchment sediment inputs, potentially caused the significant seagrass losses observed.

The current extent of muddy sediments, presence of mud-tolerant biota, and historical seagrass losses show the estuary is vulnerable to catchment derived fine sediment inputs. Any increases in sediment loads, will likely result in expansion of mud-elevated sediments which are likely to have negative consequences for the overall health of the estuary. It will be particularly important to manage activities known to contribute elevated sediment losses from the catchment (i.e., intensive grazing, exotic forest harvesting).

6.4 VULNERABILITY TO NUTRIENT ENRICHMENT AND EUTROPHICATION

In 2023, symptoms of eutrophication were localised and are a minor feature, although there has been an increase in areas of macroalgae, an increase in the number of species of opportunistic algae present, and development of small patches of high enrichment conditions since 2016 (Table 15). Sediment indicators of eutrophication (i.e., aRPD, TN, TP, and TS) throughout the estuary were generally rated 'Good'. However, substrate oxygenation (i.e., aRPD) was reduced at several sites, and rated 'Poor'.

Consistent with the current 'Good' state of nuisance macroalgae (i.e., OMBT score; Table 14), the modelled nitrogen (N) areal load for Waikouaiti is 70.8mg/m^2/d (Table 17), which is below the ~100mgTN/m^2/d threshold at which nuisance macroalgae problems are predicted to occur in intertidally-dominated estuaries (Robertson et al. 2017). However, the estuary is assessed as having a high susceptibility (i.e., high flushing potential, low dilution potential) to nutrient problems driving macroalgae growth (Plew et al. 2018). The estuary's short residence time (<3 days; Plew et al. 2018) and channelised hydrodynamics (the main channel bypasses between the tidal flats of Merton and East Arm) suggest most riverine nutrient inputs are very likely to be rapidly washed out to sea, particularly on the outgoing tide. Equally, the constrained nature of the two main tidal arms may result in localised retention of nutrients inputs from adjacent pastural land, which is further exacerbated by restricted flow (e.g., causeways in the East Arm), increasing their susceptibility to nutrient issues.

Dense mat of *Vaucheria* sp. growing over mud elevated substrate in the upper reaches of the East Arm.

Chlorophyll-*a* is an indicator of phytoplankton growth in the water column and is used as proxy for phytoplankton biomass to assess eutrophic symptoms in response to nutrient inputs. Estuaries with a flushing time of ~4 days or less have a low susceptibility to phytoplankton growth in response to increasing concentrations of nitrogen (Plew et al. 2020). Because the estimated flushing time of Waikouaiti Estuary is ~2.9 days, it is considered unlikely to support regular phytoplankton growth (Plew et al. 2018).

However, phytoplankton blooms have previously been observed in the deeper bottom waters of the main reach of the upper estuary (Leigh Stevens, pers. obs.), supporting additional observations that the estuary does occasionally stratify, forming isolated bottom waters where nutrients accumulate (ORC 2010). This susceptibility likely increases during summer when lower river flows extend the residence time and reduce flushing. More detailed and event-based water quality monitoring is needed to confirm this, but is not considered a priority based on current results. Regular water column monitoring is not undertaken in the Waikouaiti River or estuary.

Overall, eutrophic symptoms (i.e., areas of algal growth, HEC) were not widespread, but had increased slightly since 2016. This change, and potential episodic phytoplankton blooms, suggest that Waikouaiti may be under moderate pressure due to nutrient-driven degradation. Although a specific tipping point beyond which rapid and difficult to reverse change is uncertain, maintaining or reducing current catchment nutrient inputs is recommended to ensure that the health of the estuary is maintained and/or improved.

6.5 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 Waikouaiti, 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

The 2023 results show that Waikouaiti is expressing symptoms of degradation related to catchment derived sediments, and to a lesser extent nutrients, with salt marsh being adversely impacted by localised grazing, vehicle and reclamation activities.

As discussed in Section 6.3, a large percentage (80%) of the Waikouaiti catchment is in land uses known to generate high rates of sediment and nutrient run-off to waterways (e.g., pasture, plantation forestry).

In a management context it would be prudent to assess erosion susceptibility in the Waikouaiti catchment and consider this when consenting land use activities (e.g., conversion of pasture to plantation forestry, increasing stock numbers, or forest harvesting). Further, non-regulatory options could be considered such as larger grazing buffer zones on river margins and riparian planting, examples of which are already occurring within the catchment (e.g., the Halo Project) and around much of the margin in Merton Arm (e.g., planting days with Kāti Huirapa ki Puketeraki, Hawksbury Lagoon Group, East Otago Catchment Group, East Otago Taiapure Committee, DoC Conservation Corps, and River-Estuary Care: Waikouaiti-Karitane).

Without management actions to reduce loads, further expansion of mud-elevated sediments can be expected, alongside an increase in eutrophic symptoms (e.g., nuisance macroalgal blooms, sediment degradation). These issues will be exacerbated by any further deterioration or losses of salt marsh habitat.

Salt marsh protection and enhancement also presents an opportunity to increase the natural ability of the estuary to assimilate catchment derived sediments and nutrients, in addition to other benefits such as enhanced biodiversity, erosion control, carbon sequestration, flood and storm surge buffering, and cultural and recreational services. There is very good potential for increasing ecological restoration initiatives currently underway throughout most of the Merton Arm. Further enhancement of marginal habitat and riparian planting should be considered to minimise or offset potential impacts on the estuary.

The recent degradation of ecologically significant salt marsh could be prevented by simple management practices, such as stock and vehicle exclusion, and weed control. Identifying and removing barriers, such as causeways and tidal flap gates, to allow tidal flushing in low-lying areas, will facilitate the maintenance of existing salt marsh and allow migration of estuarine species and potential future salt marsh expansion in response to sea level rise (SLR). Salt marsh expansion would be most effective in areas of historic salt marsh loss where saline species persist within low-lying land identified through SLR inundation modelling undertaken recently by Stevens (2023) for ORC.

7. RECOMMENDATIONS

Based on the 2023 survey, it is recommended ORC consider the following recommendations:

Monitoring

- Undertake broad scale monitoring ~5-yearly 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.
- When undertaking annual sediment plate monitoring (see Rabel 2024), keep a watching brief on areas of macroalgae and HEC. If expansion is observed, undertake targeted nuisance macroalgae monitoring to facilitate timely management actions and track long-term changes.
- Utilise estuary monitoring data to review the SOE programme and assess monitoring needs in Waikouaiti alongside priorities for other estuaries regionally.
- Advocate for development of New Zealand specific eco-group information to inform community sensitivity within a local context.

Management

- Ensure activities in the coastal area comply with ORC plan requirements. Support landowners and managers with guidance on best practices and regulations (i.e., MPI stock rules for grazing within low lying areas), and the significance and vulnerability of salt marsh habitat.
- Continue work to identify and prioritise salt marsh areas for ecological restoration, protection, and resilience to sea level rise, e.g., exclusion of grazing animals, compliance monitoring of physical damage and drainage, planting, improving or reinstating tidal flushing, and facilitating retreat and expansion.
- 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. Also explore historical land use changes to assess causes of previous seagrass loss.
- Improve estimates of sediment and nutrient loads to the estuary, determine potential sources, and investigate options for reducing inputs where loads exceed guidance thresholds, or adverse impacts are identified.
- Evaluate the need for water quality monitoring in the terminal reach of Waikouaiti River to better assess loads, and investigate options for a reduction of inputs where loads exceed guidance thresholds (e.g., Plew & Dudley 2018).
- Include Waikouaiti Estuary in 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.

Restoration planting bordering the salt marsh on the northern margin of the estuary.

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.

Ausseil AG, Newcome P, Johnson P 2008. Wetland Mapping in the Otago Region. Landcare Research Contract Report prepared for the Otago Regional Council.

Gibbs M, Swales A 2019. Historical sediment source apportionment in the Waimea Estuary: Continuation of the Waimea and Moutere River study. Prepared for TDC by NIWA. Report number: 2002012HN. 44p.

Ministry for the Environment & Stats NZ 2019. New Zealand's Environmental Reporting Series: Environment Aotearoa 2019.

O'Connell-Milne S, Forrest BM, Rabel HD 2024. Waikouaiti Estuary Intertidal Fine-Scale Monitoring Data Summary. Salt Ecology Report 131, prepared for Otago Regional Council, June 2024. 22p.

Otago Regional Council 2004. Regional Plan: Water for Otago.

Otago Regional Council 2010. Otago estuaries state of environment report 2010.

Otago Regional Council 2012. Regional Plan: Coast for Otago.

Plew D, Dudley B, Shankar U, Zeldis J 2018. Assessment of the eutrophication susceptibility of New Zealand Estuaries. NIWA report prepared for Ministry for the Environment.

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.

Rabel H 2024. Waikouaiti Estuary: 2023/2024 Intertidal Sediment Monitoring Summary. Salt Ecology Short Report 047 prepared for Otago Regional Council, May 2024. 2p.

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 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 BM, Robertson BP, Stevens LM 2017. Waikouaiti Estuary: Fine Scale Monitoring 2016/17. Prepared for Otago Regional Council. 37p.

Rodil IF, Lohrer AM, Attard KM, Hewitt JE, Thrush SF, Norkko A 2021. Macrofauna communities across a seascape of seagrass meadows: environmental drivers, biodiversity patterns and conservation implications. Biodiversity and Conservation. 30:3023–3043.

Stevens LM 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. Waikouaiti Estuary - Broad Scale Habitat Mapping 2016/17. Report prepared by Wriggle Coastal Management for Otago Regional Council. 36p.

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 2007. Mapping of the Waikouaiti and Shag River Estuaries: Otago Regional Council State of the Environment Report. Prepared for the ORC by Ryder Consulting Ltd. 55p.

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 1. SAMPLING METHODS, WAIKOUAITI, 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 (0-10%), firm shell/sand (0-10%), firm sand (0-10%),

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:

- Forest (woody plants >10 cm density at breast height - dbh) and scrub (woody plants <10cm dbh) are considered terrestrial and mapped using LCDB codes as outlined in Table A1.
- Introduced weeds: Weeds are a common margin feature occasionally extending into upper intertidal areas and have been added to broad salt marsh structural classes.
- Estuarine shrubland: Woody plants <10 cm dbh growing in intertidal areas (e.g., mangroves, salt marsh 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 in ArcMap (currently v10.8) 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

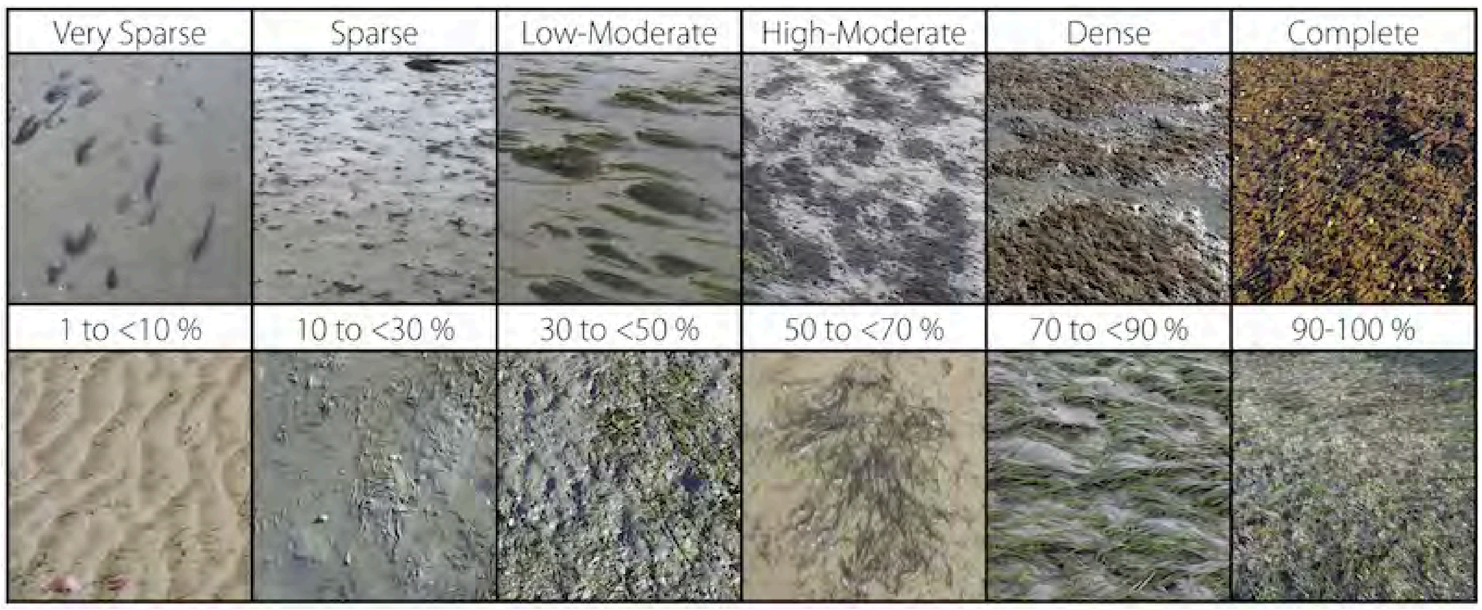


Fig. A1. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

broad scale surveys, historic imagery, supported by anecdotal reports of seagrass presence, can be georeferenced in ArcMap (v10.8) 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 ArcMAP (v10.8) 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 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 ArcMap (v10.8) 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 ArcMap, 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 ArcMap 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 RJ Hill Laboratories 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.

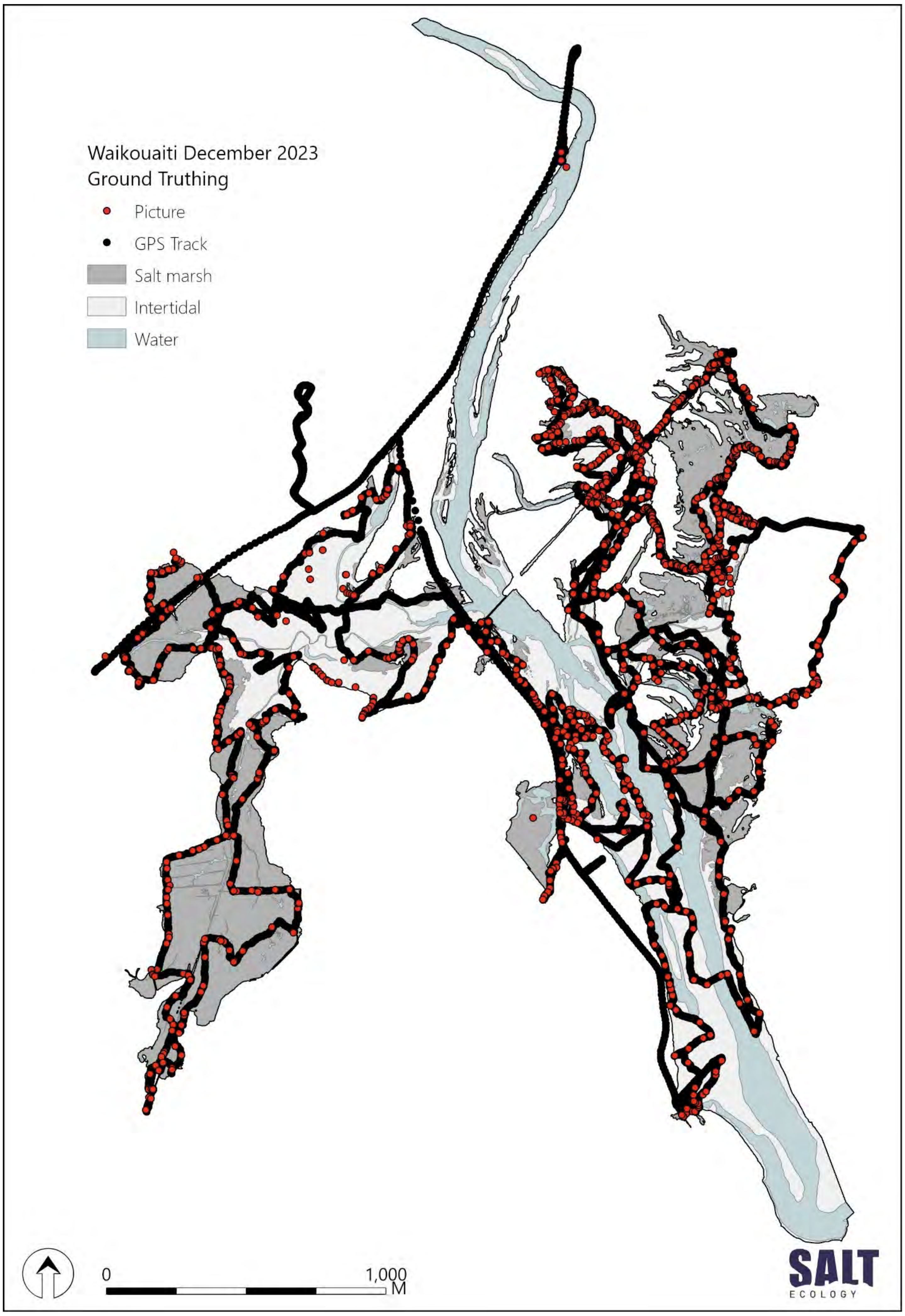
Stevens LM, Robertson BM 2014. Havelock Estuary 2014: Broad scale habitat mapping. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

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

SubClass	Dominant Species	Sub-dominant species	Sub-dominant species 2	Sub-dominant species 3	Area (ha)	% Salt marsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)				0.3	0.3
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)			0.05	0.05
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Disphyma australe* (NZ Ice Plant, Horokaka)			0.03	0.03
Tussockland	*Carex litorosa* (Sea sedge)				0.002	0.002
Tussockland	*Carex litorosa* (Sea sedge)	*Juncus gerardii* (Salt marsh rush)			0.0003	0.0004
Tussockland	*Poa cita* (Silver tussock)				0.002	0.002
Tussockland	*Puccinella stricta* (Salt grass)				0.2	0.2
Tussockland	*Puccinella stricta* (Salt grass)	*Samolus repens* (Primrose)	*Cotula coronopifolia* (Bachelor's button)		0.03	0.03
Tussockland	*Puccinella stricta* (Salt grass)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	0.2	0.2
Tussockland	*Puccinella stricta* (Salt grass)	*Sarcocornia quinqueflora* (Glasswort)			2.7	2.8
Tussockland	*Puccinella stricta* (Salt grass)	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)		0.01	0.01
Tussockland	*Puccinella stricta* (Salt grass)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)		0.2	0.2
Tussockland	*Puccinella stricta* (Salt grass)	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	0.5	0.5
Tussockland	*Puccinella stricta* (Salt grass)	*Suaeda novaezelandiae* (Sea blite)	*Sarcocornia quinqueflora* (Glasswort)		0.2	0.3
Sedgeland	*Eleocharis sphacelata* (Bamboo spike sedge)				0.04	0.05
Sedgeland	*Schoenoplectus pungens* (Three square)				0.01	0.01
Sedgeland	*Schoenoplectus pungens* (Three square)	*Apodasmia similis* (Jointed wirerush)	*Cotula coronopifolia* (Bachelor's button)	*Samolus repens* (Primrose)	0.3	0.3
Rushland	*Apodasmia similis* (Jointed wirerush)				2.1	2.2
Rushland	*Juncus gerardii* (Salt marsh rush)				0.04	0.04
Herbfield	*Cotula coronopifolia* (Bachelor's button)				0.09	0.10
Herbfield	*Cotula coronopifolia* (Bachelor's button)	*Puccinella stricta* (Salt grass)	*Thyridia repens* (New Zealand musk)		0.4	0.4
Herbfield	*Disphyma australe* (NZ Ice Plant, Horokaka)				0.2	0.2
Herbfield	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Poa cita* (Silver tussock)			0.003	0.003
Herbfield	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Sarcocornia quinqueflora* (Glasswort)			0.003	0.003
Herbfield	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)		0.01	0.01
Herbfield	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Sarcocornia quinqueflora* (Glasswort)	0.2	0.2
Herbfield	*Samolus repens* (Primrose)	*Cotula coronopifolia* (Bachelor's button)			0.02	0.02
Herbfield	*Samolus repens* (Primrose)	*Cotula coronopifolia* (Bachelor's button)	*Puccinella stricta* (Salt grass)	*Selliera radicans* (Remuremu)	0.08	0.09
Herbfield	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	*Thyridia repens* (New Zealand musk)	*Cotula coronopifolia* (Bachelor's button)	1.5	1.5
Herbfield	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)			0.1	0.1
Herbfield	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	*Sarcocornia quinqueflora* (Glasswort)	0.09	0.09
Herbfield	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Cotula coronopifolia* (Bachelor's button)	0.1	0.1
Herbfield	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)		0.4	0.4
Herbfield	*Samolus repens* (Primrose)	*Suaeda novaezelandiae* (Sea blite)	*Sarcocornia quinqueflora* (Glasswort)		0.06	0.06
Herbfield	*Sarcocornia quinqueflora* (Glasswort)				22.8	24.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)			0.04	0.04
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)	*Puccinella stricta* (Salt grass)		0.2	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)	*Puccinella stricta* (Salt grass)	*Suaeda novaezelandiae* (Sea blite)	0.3	0.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Cotula coronopifolia* (Bachelor's button)	*Suaeda novaezelandiae* (Sea blite)	*Puccinella stricta* (Salt grass)	0.5	0.5
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Disphyma australe* (NZ Ice Plant, Horokaka)			0.5	0.5
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		0.07	0.07
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Poa cita* (Silver tussock)	*Suaeda novaezelandiae* (Sea blite)	0.02	0.02
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	0.3	0.4
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	0.2	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Selliera radicans* (Remuremu)	*Suaeda novaezelandiae* (Sea blite)	0.003	0.003
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Suaeda novaezelandiae* (Sea blite)		0.07	0.07
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Festuca arundinacea* (Tall fescue)			0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Lycium ferocissimum* (Boxthorn)	*Selliera radicans* (Remuremu)		0.2	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Plagianthus divaricatus* (Salt marsh ribbonwood)			0.02	0.02
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Plantago coronopus* (Buck's horn plantain)			0.02	0.02
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)			25.3	26.9
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Cotula coronopifolia* (Bachelor's button)		0.6	0.6
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Festuca arundinacea* (Tall fescue)	*Ulex europaeus* (Gorse)	0.01	0.02
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Samolus repens* (Primrose)	*Cotula coronopifolia* (Bachelor's button)	1.2	1.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Selliera radicans* (Remuremu)		0.4	0.4
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)	*Selliera radicans* (Remuremu)	*Disphyma australe* (NZ Ice Plant, Horokaka)	0.03	0.03
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)			0.8	0.9
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	*Cotula coronopifolia* (Bachelor's button)	0.07	0.07
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)		0.6	0.6
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)		1.8	1.9
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	0.4	0.4
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Suaeda novaezelandiae* (Sea blite)	0.1	0.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Suaeda novaezelandiae* (Sea blite)		0.4	0.4
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Schoenoplectus pungens* (Three square)	*Cotula coronopifolia* (Bachelor's button)	*Samolus repens* (Primrose)	0.04	0.04
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Schoenoplectus pungens* (Three square)	*Puccinella stricta* (Salt grass)	*Selliera radicans* (Remuremu)	0.03	0.03
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)			2.2	2.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Cotula coronopifolia* (Bachelor's button)		1.1	1.1
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	*Puccinella stricta* (Salt grass)	0.05	0.05
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	*Suaeda novaezelandiae* (Sea blite)	0.2	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Disphyma australe* (NZ Ice Plant, Horokaka)		0.2	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Lycium ferocissimum* (Boxthorn)	*Suaeda novaezelandiae* (Sea blite)	0.4	0.4
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Puccinella stricta* (Salt grass)	0.01	0.01
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)		0.4	0.4
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	*Cotula coronopifolia* (Bachelor's button)	0.8	0.8
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Puccinella stricta* (Salt grass)	*Samolus repens* (Primrose)	0.06	0.06
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)		2.2	2.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	0.09	0.10
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)	0.05	0.05
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	1.2	1.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Suaeda novaezelandiae* (Sea blite)		0.6	0.7
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)			2.1	2.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Cotula coronopifolia* (Bachelor's button)	*Puccinella stricta* (Salt grass)	0.2	0.2
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Disphyma australe* (NZ Ice Plant, Horokaka)		1.4	1.5
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Disphyma australe* (NZ Ice Plant, Horokaka)	*Selliera radicans* (Remuremu)	0.07	0.07
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Puccinella stricta* (Salt grass)	*Poa cita* (Silver tussock)	0.06	0.06
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	0.7	0.7

SubClass	Dominant Species	Sub-dominant species	Sub-dominant species 2	Sub-dominant species 3	Area (ha)	% Salt marsh
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	0.3	0.3
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Selliera radicans* (Remuremu)		0.06	0.06
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Selliera radicans* (Remuremu)	*Disphyma australe* (NZ Ice Plant, Horokaka)	5.4	5.7
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	0.3	0.4
Herbfield	*Selliera radicans* (Remuremu)				0.7	0.7
Herbfield	*Selliera radicans* (Remuremu)	*Festuca arundinacea* (Tall fescue)			0.01	0.02
Herbfield	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)			0.08	0.08
Herbfield	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	1.2	1.3
Herbfield	*Selliera radicans* (Remuremu)	*Isolepis cernua* (Slender clubrush)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.06	0.06
Herbfield	*Selliera radicans* (Remuremu)	Samolus repens (Primrose)			0.07	0.07
Herbfield	*Selliera radicans* (Remuremu)	Samolus repens (Primrose)	*Cotula coronopifolia* (Bachelor's button)		0.06	0.07
Herbfield	*Selliera radicans* (Remuremu)	Samolus repens (Primrose)	*Isolepis cernua* (Slender clubrush)		0.3	0.3
Herbfield	*Selliera radicans* (Remuremu)	Samolus repens (Primrose)	*Sarcocornia quinqueflora* (Glasswort)		1.0	1.0
Herbfield	*Selliera radicans* (Remuremu)	Samolus repens (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	*Thyridia repens* (New Zealand musk)	0.06	0.06
Herbfield	*Selliera radicans* (Remuremu)	Samolus repens (Primrose)	*Schoenoplectus pungens* (Three square)		0.0	0.0
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)			0.4	0.5
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Apium prostratum* (Native celery)		0.5	0.5
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Festuca arundinacea* (Tall fescue)		0.1	0.1
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	*Puccinella stricta* (Salt grass)	0.4	0.4
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Lycium ferocissimum* (Boxthorn)		0.04	0.04
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)		1.6	1.7
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	*Cotula coronopifolia* (Bachelor's button)	0.04	0.04
Herbfield	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Puccinella stricta* (Salt grass)	0.6	0.7
Herbfield	*Selliera radicans* (Remuremu)	*Schoenoplectus pungens* (Three square)			0.01	0.01
Reedland	*Spartina alterniflora* (Smooth cord grass)				0.007	0.008
Total					94.3	100

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	
SubClass	Feature	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Bedrock	Rock field	0.002	0.001	0.002	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coarse substrate (>2mm)	Artificial boulder field	0.4	0.2	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cobble field	0.006	0.003	0.0	0.0	0.01	0.01	0.0	0.0	0.0	0.0	0.0	0.0
	Gravel field	14.2	7.4	12.8	13.1	1.4	1.5	0.1	12.2	1.6	9.6	0.0	0.0
	Shell bank	1.3	0.7	1.3	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sand (0-10% mud)	Mobile sand	6.4	3.3	6.4	6.5	0.0	0.0	0.0	0.0	1.2	6.8	0.0	0.0
	Firm sand	22.4	11.6	22.3	22.7	0.1	0.1	0.9	87.1	4.9	28.8	0.0	0.0
	Soft sand	0.7	0.4	0.7	0.8	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Muddy Sand (>10-25% mud)	Firm muddy sand	30.3	15.7	20.0	20.4	10.3	10.9	0.0	0.0	2.0	11.7	0.0	0.0
	Soft muddy sand	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Muddy Sand (>25-50% mud)	Firm muddy sand	12.3	6.4	6.2	6.3	6.2	6.5	0.0	0.0	0.1	0.4	0.0	0.0
	Soft muddy sand	6.0	3.1	6.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sandy Mud (>50-90% mud)	Firm sandy mud	84.9	44.1	9.3	9.4	75.6	80.2	0.0	0.0	1.1	6.5	0.0	0.0
	Soft sandy mud	10.7	5.5	10.0	10.2	0.7	0.7	0.0	0.0	5.0	29.1	0.0	0.0
	Very soft sandy mud	1.5	0.8	1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	100.0
Mud (>90% mud)	Soft mud	0.04	0.02	0.04	0.04	0.0	0.0	0.0	0.0	0.04	0.2	0.0	0.0
Zoogenic	Cockle bed	1.2	0.6	1.2	1.2	0.0	0.0	0.0	0.0	1.2	6.9	0.0	0.0
Total		192.5	100.0	98.2	100.0	94.3	100.0	1.1	100.0	17.2	100.0	0.0	100.0

Hills Laboratories sediment analytical results from Site 1 – 8.

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Dry Matter of Sieved Sample	g/100g as rcvd	80	79	72	66	79	79	81	82
Total Recoverable Phosphorus	mg/kg dry wt	480	580	690	680	380	550	400	530
Total Sulphur	g/100g dry wt	0.11	0.07	0.12	0.2	0.11	0.09	0.4*	0.5*
Total Nitrogen	g/100g dry wt	0.04	0.03	0.07	0.1	0.03	0.07	0.04	0.05
Total Organic Carbon	g/100g dry wt	0.26	0.26	0.63	0.78	0.2	0.43	0.22	0.31
Total Recoverable Arsenic	mg/kg dry wt	4.2	3.5	6.3	5.6	3.7	5.6	4	6.2
Total Recoverable Cadmium	mg/kg dry wt	0.027	0.018	0.025	0.027	0.014	0.017	< 0.010	0.019
Total Recoverable Chromium	mg/kg dry wt	5.5	3.9	7.4	6.3	3.8	5.2	4.3	6.6
Total Recoverable Copper	mg/kg dry wt	2.2	2.3	7.6	5.1	2.4	5	4.2	4.2
Total Recoverable Lead	mg/kg dry wt	3.2	2.5	6	4.5	2.2	4	3.1	3.9
Total Recoverable Mercury	mg/kg dry wt	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Total Recoverable Nickel	mg/kg dry wt	3.4	3.3	8.1	5.6	3.3	6	5	6.2
Total Recoverable Zinc	mg/kg dry wt	20	17.3	37	28	14.9	25	22	25

*High TS results anticipated to be unreliable due to relatively well-oxygenated sand dominated substrates, and low TOC and TN. This concentration of TS is more reflective of extremely degraded areas with high enrichment conditions, such as seen within Pleasant River Estuary (Roberts et al. 2022).

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 1958, 1969, 1987 (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. 7.

Table of historic salt marsh extent (ha).

Year	Estuary (ha)	Intertidal (ha)	Subtidal (ha)	Salt marsh (ha)	% Intertidal
Estimated natural	358.3	303.4	54.9	170.7	56.3
1958	298.6	245.3	53.3	115.0	46.9
1969	254.7	197.6	57.1	92.3	46.7
1987	247.6	195.6	52.0	96.7	49.4
2006	243.6	188.3	55.3	91.4	48.5
2016	229.1	176.9	52.2	80.3	45.4
2023	252.8	192.6	60.2	94.3	49.0

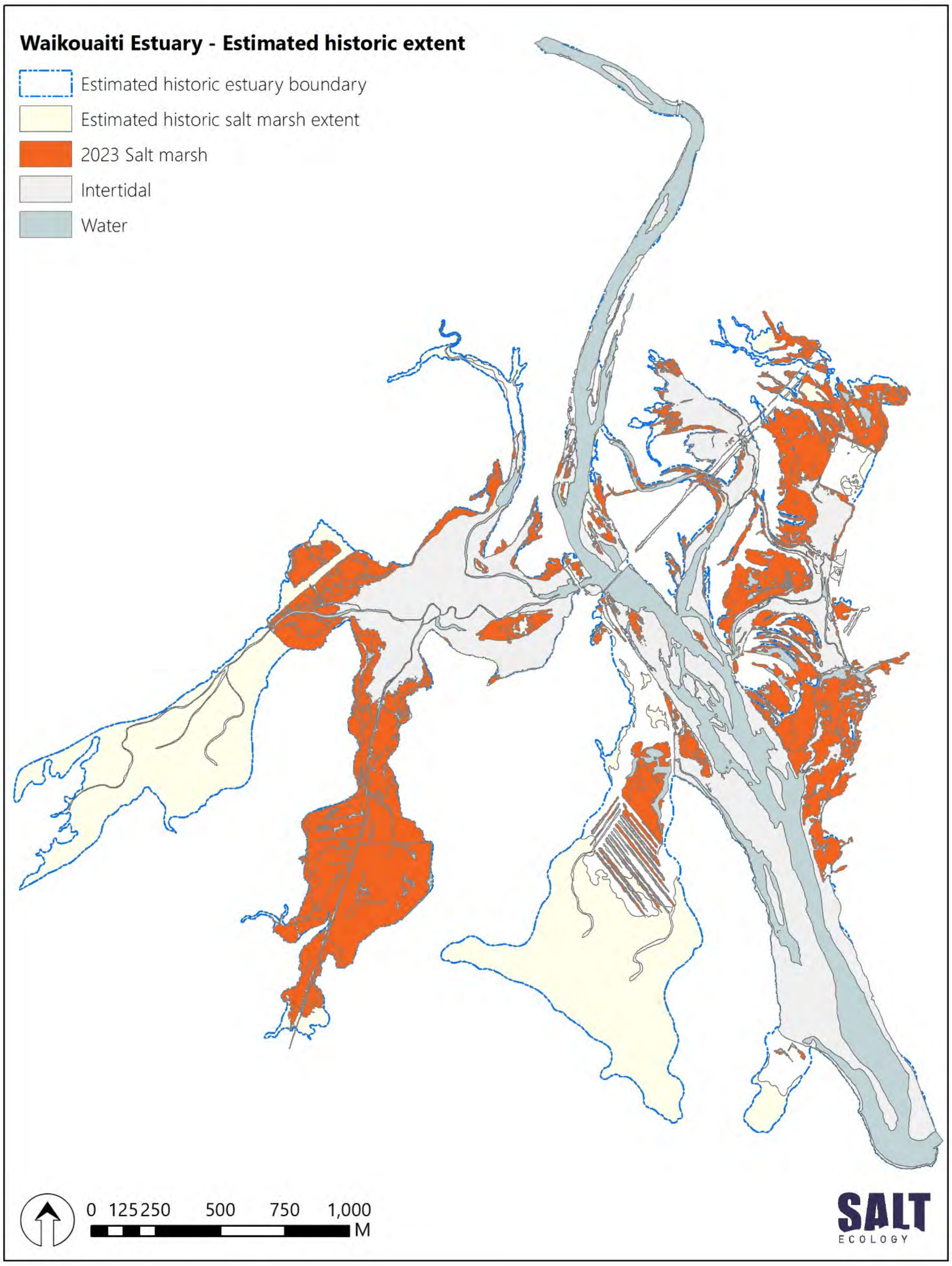
To estimate historic seagrass extent, we assessed current mapped layers and historic aerial imagery captured in 1958, 1969, 1987 (source: retrolens.co.nz), and 2006 (data.linz.govt.nz). Where required, imagery was merged and georectified to digitise the seagrass area and inform historic extent. Historic 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).

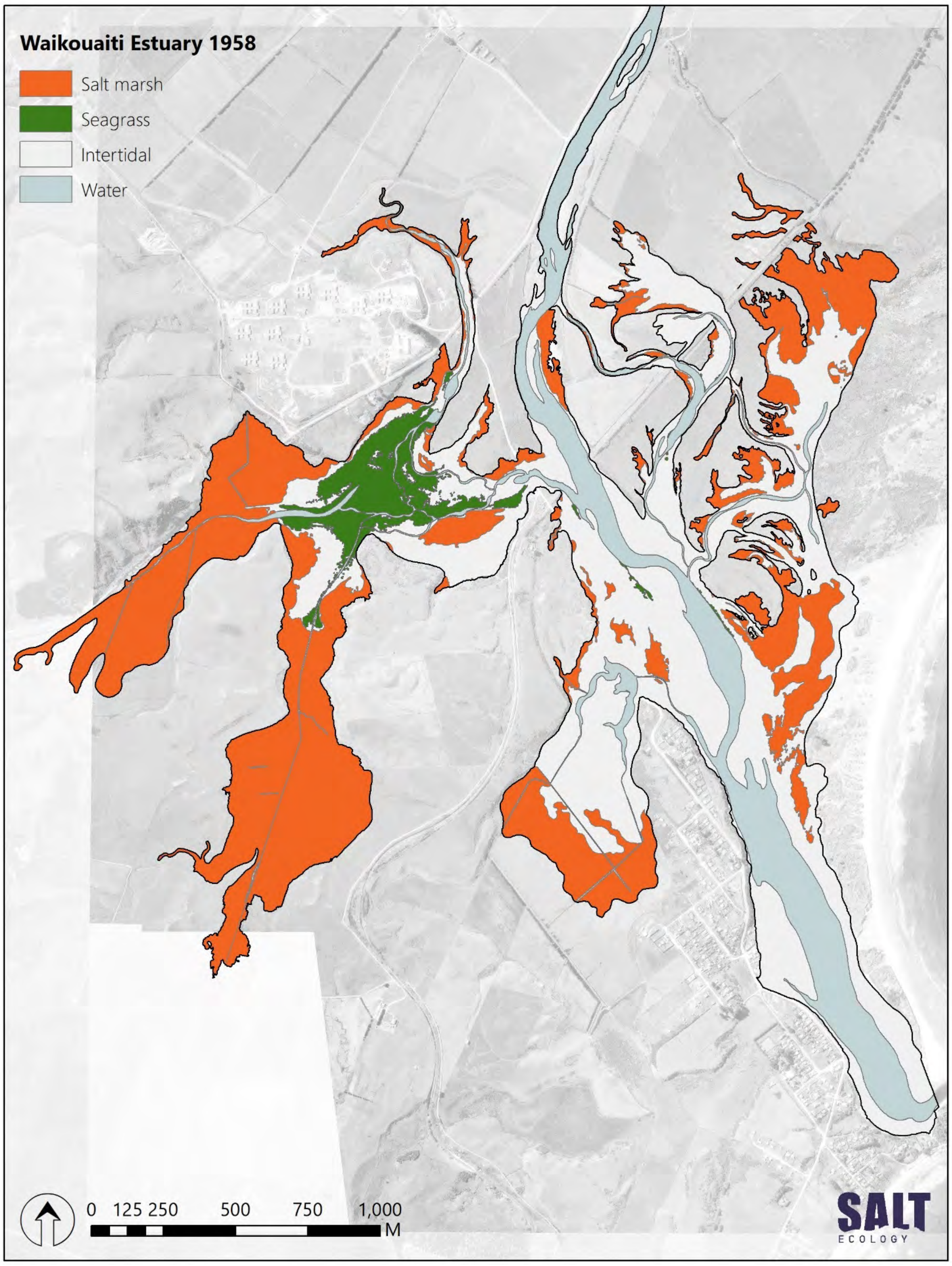
Year	Estuary (ha)	Intertidal (ha)	Subtidal (ha)	AIH* (ha)	Seagrass (ha) (>1-100% cover)	Seagrass (ha) (≥50% cover)	% AIH (≥50% cover)	% decline from baseline
1958	298.6	245.3	53.3	130.3		13.1	10.0	*baseline*
1969	254.7	197.6	57.1	105.3		16.8	15.9	+28.5
1987	247.6	195.6	52.0	98.9		2.9	2.9	-78.0
2006	243.6	188.3	55.3	96.9		2.6	2.7	-79.9
2016	229.1	176.9	52.2	96.6		1.7	1.8	-87.0
2023	252.7	192.5	60.3	98.2	1.1	0.5	0.5	-96.4

*Available intertidal habitat

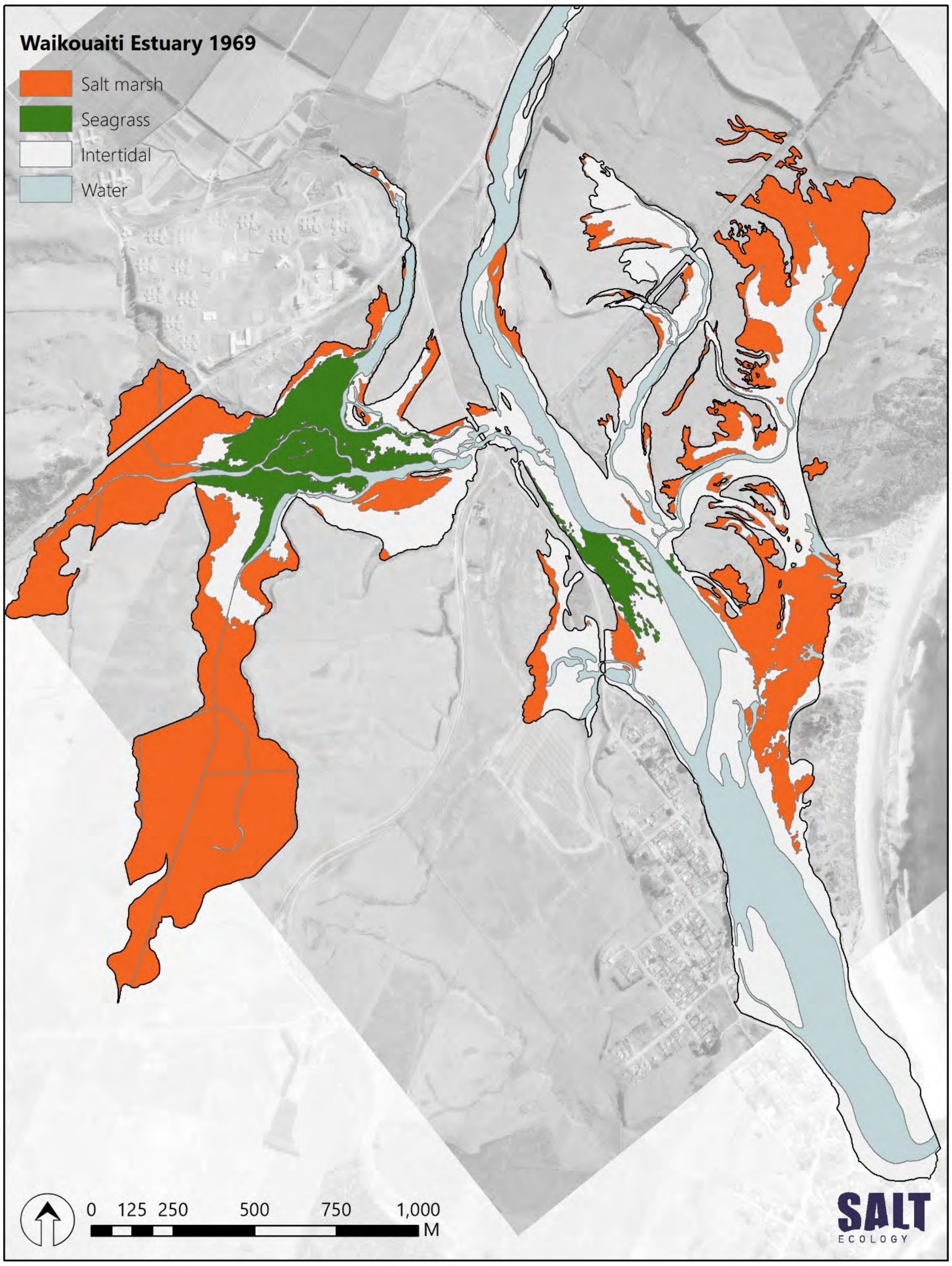
Estimated historic extent of salt marsh compared to 2023 measured extent.



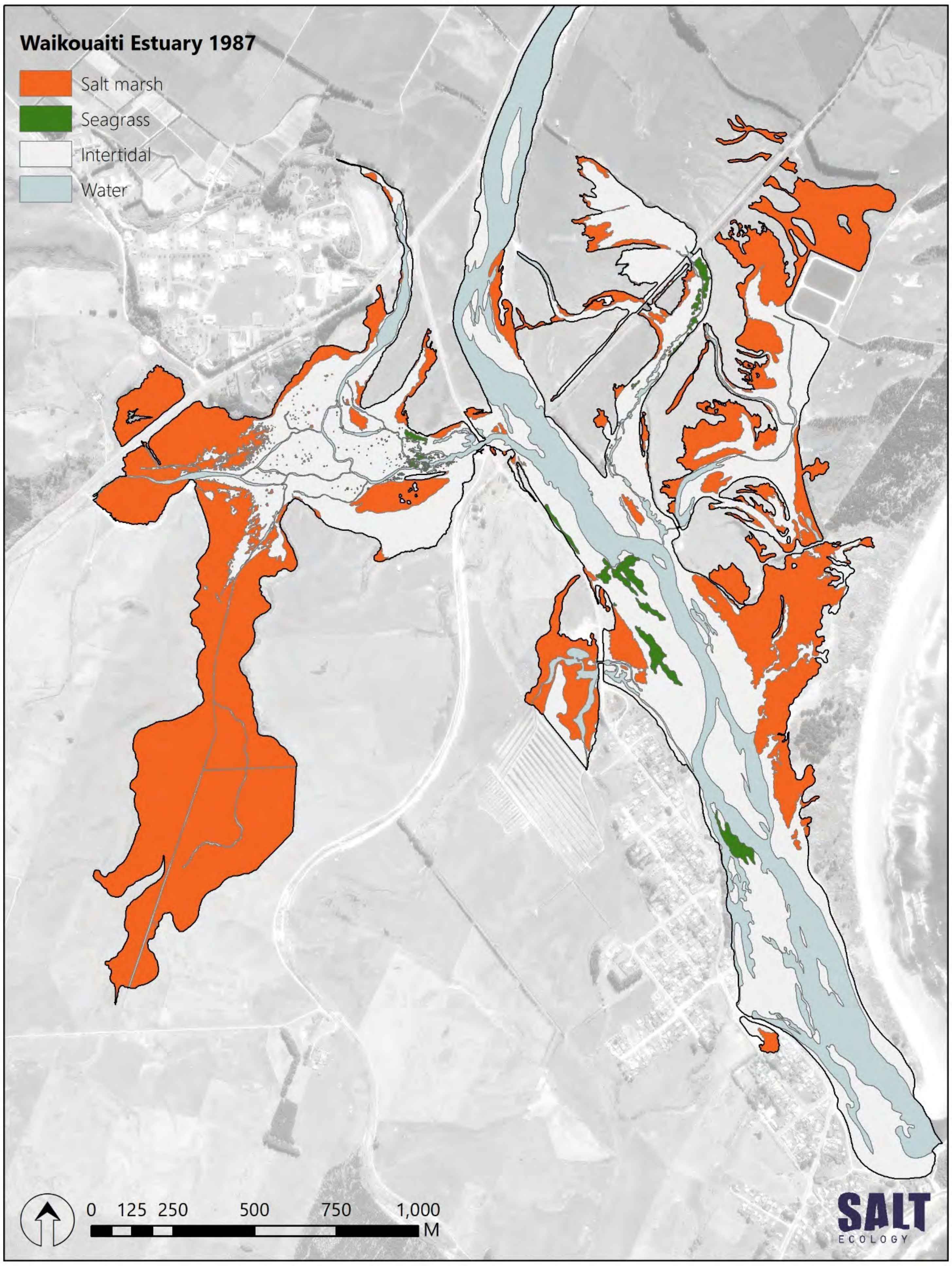
1958 salt marsh and seagrass extent based on imagery (no ground-truthing)



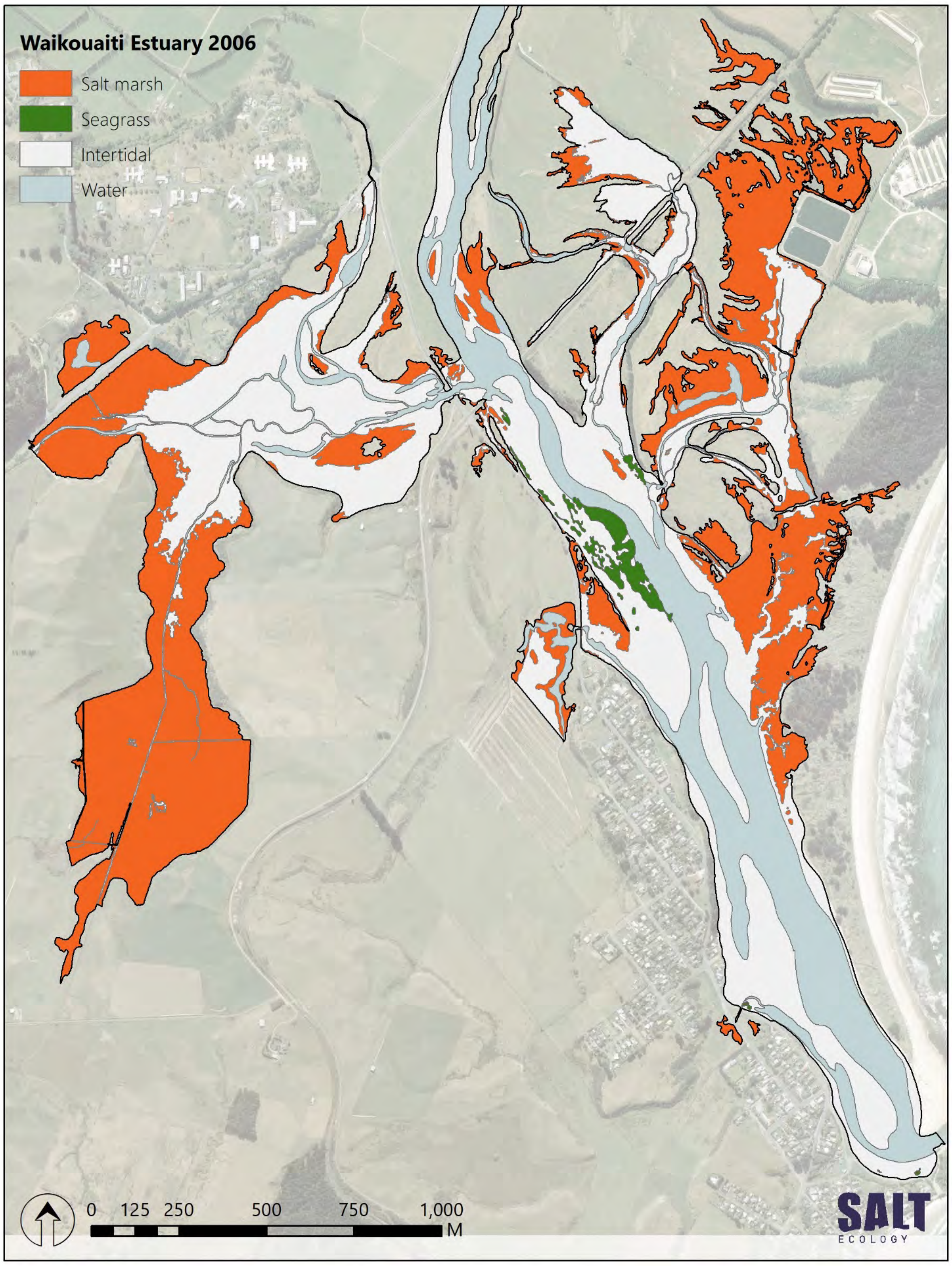
1969 salt marsh and seagrass extent based on imagery (no ground-truthing)



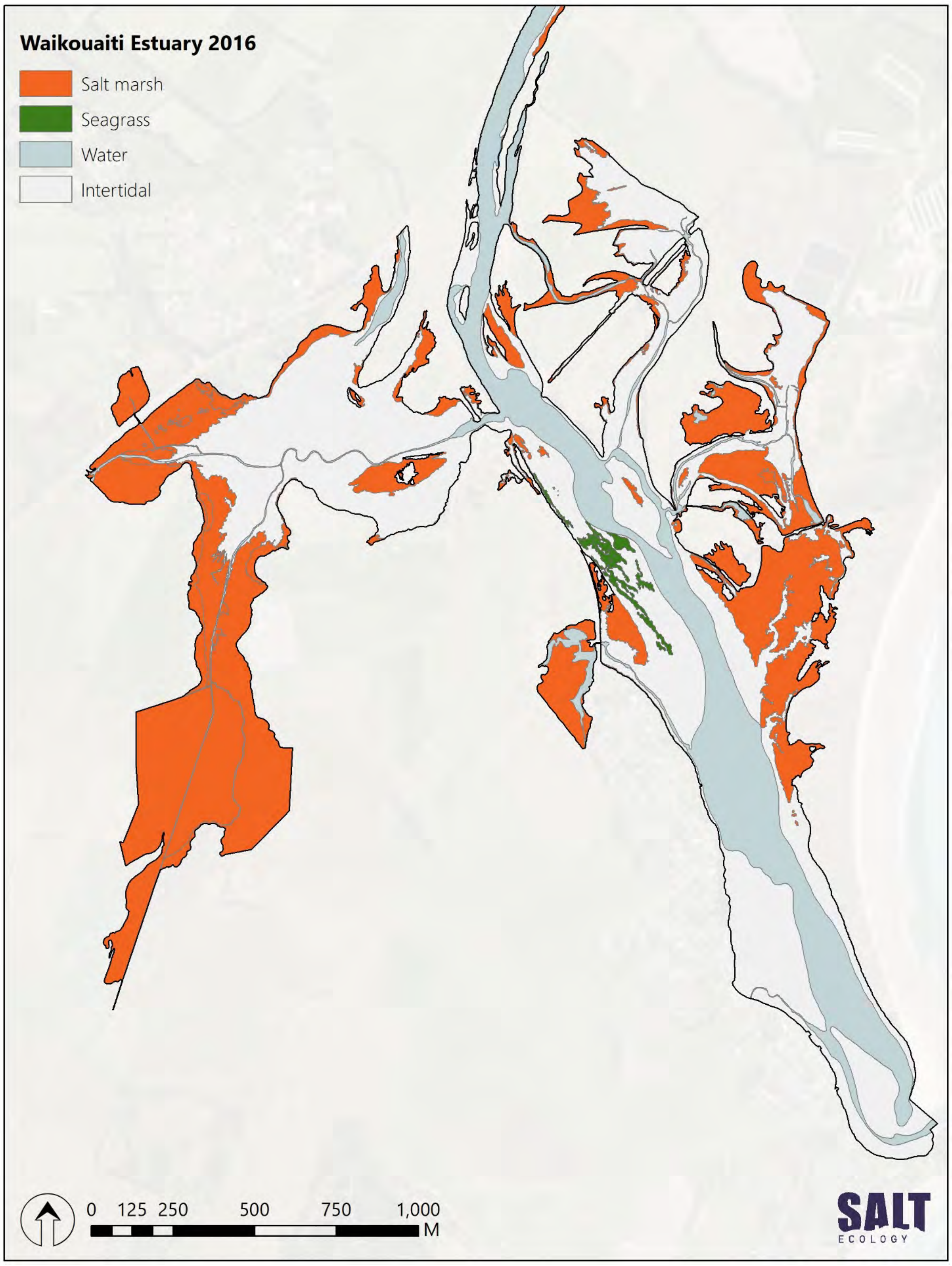
1987 salt marsh and seagrass extent based on imagery (no ground-truthing)



2006 salt marsh and seagrass extent based on imagery (no ground-truthing)



2016 salt marsh and seagrass extent based on imagery (no ground-truthing)



APPENDIX 6. SEDIMENT VALIDATION

Sampling was undertaken at fifteen 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 nine of the fifteen samples (no shading), while four samples were within ±5% of the subjective classification (light green shading). The two sites with differences >5% are shown in red (light yellow shading). Site 5 and B were adjusted down, with the likely cause for the difference due to an overestimation based on the soft sediment texture.

Site	NZTM Easting	NZTM Northing	Sediment firmness	Field code	Subjective % mud	Mud (%)	Sand (%)	Gravel (%)	aRPD (mm)	Updated classification*
Site 1	1415756.9	4945357.5	soft	MS25_50	25 to <50%	29.6	69.8	0.6	20	-
Site 2	1415974.7	4945325.6	firm	MS10_25	10 to <25%	26.5	72.6	0.9	15	No change
Site 3	1417020.3	4945727.1	soft	SM50_90	50 to <90%	50.2	49.3	0.5	5	-
Site 4	1417377.9	4945577.2	soft	SM50_90	50 to <90%	47.1	52.6	0.2	2	No change
Site 5	1417372.6	4945206.2	soft	MS25_50	25 to <50%	17.9	82	0.1	15	MS10_25
Site 6	1416878.6	4944888.3	firm	S0_10	<10%	8.1	69.2	22.7	2	-
Site 7	1417068.0	4944551.1	firm	S0_10	<10%	6.9	82.6	10.5	8	-
Site 8	1417336.9	4943724.3	firm	S0_10	<10%	8.6	73.7	17.7	30	-
Site A	1415515.4	4945221.2	very soft	SM50_90	50 to <90%	49.1	50.5	0.4	9	-
Site B	1415741.2	4945282.7	very soft	SM50_90	50 to <90%	44.6	55.3	0.1	15	MS25_50
Site C	1416110.6	4945343.2	firm	S0_10	<10%	10.9	88.8	0.2	30	No change
Site D	1416975.6	4945956.1	firm	SM50_90	50 to <90%	63.9	36	0.1	-	-
Site E	1416937.9	4945559.3	soft	MS25_50	25 to <50%	29.3	67.7	3	10	-
Site F	1416819.4	4945313.0	firm	MS10_25	10 to <25%	25.4	74.5	0.2	10	No change
Site G	1417269.8	4944608.0	firm	MS10_25	10 to <25%	13.5	86.5	0.05	5	-

*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. 1. Elevation estimated from LiDAR 10cm contours with correction of -0.3 to calculate height relative to mean sea level.

Site 1

Site 1 - aRPD

Site 2

Site 2 - aRPD

Site 3

Site 3 - aRPD

Site 4

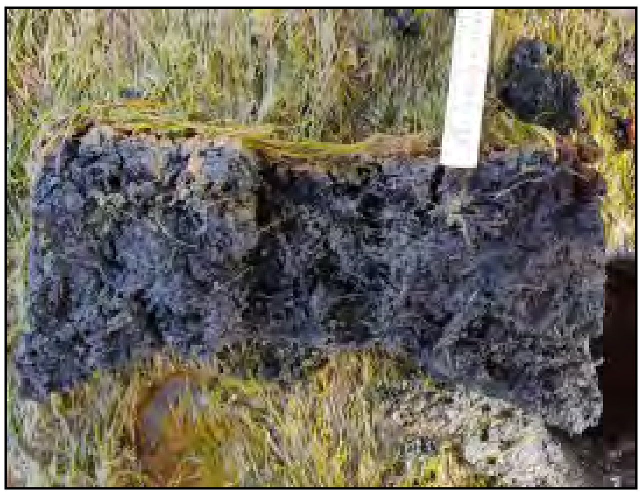
Site 4 - aRPD

Site 5

Site 5 - aRPD

Site 6

Site 6 - aRPD



Site 7

Site 7 - aRPD

Site 8

Site 8 - aRPD

Site A

Site A - aRPD

Site B

Site B - aRPD

Site C

Site C - aRPD

Site D

Site D – aRPD

Site E

Site E - aRPD

Site F

Site F – aRPD no photo available

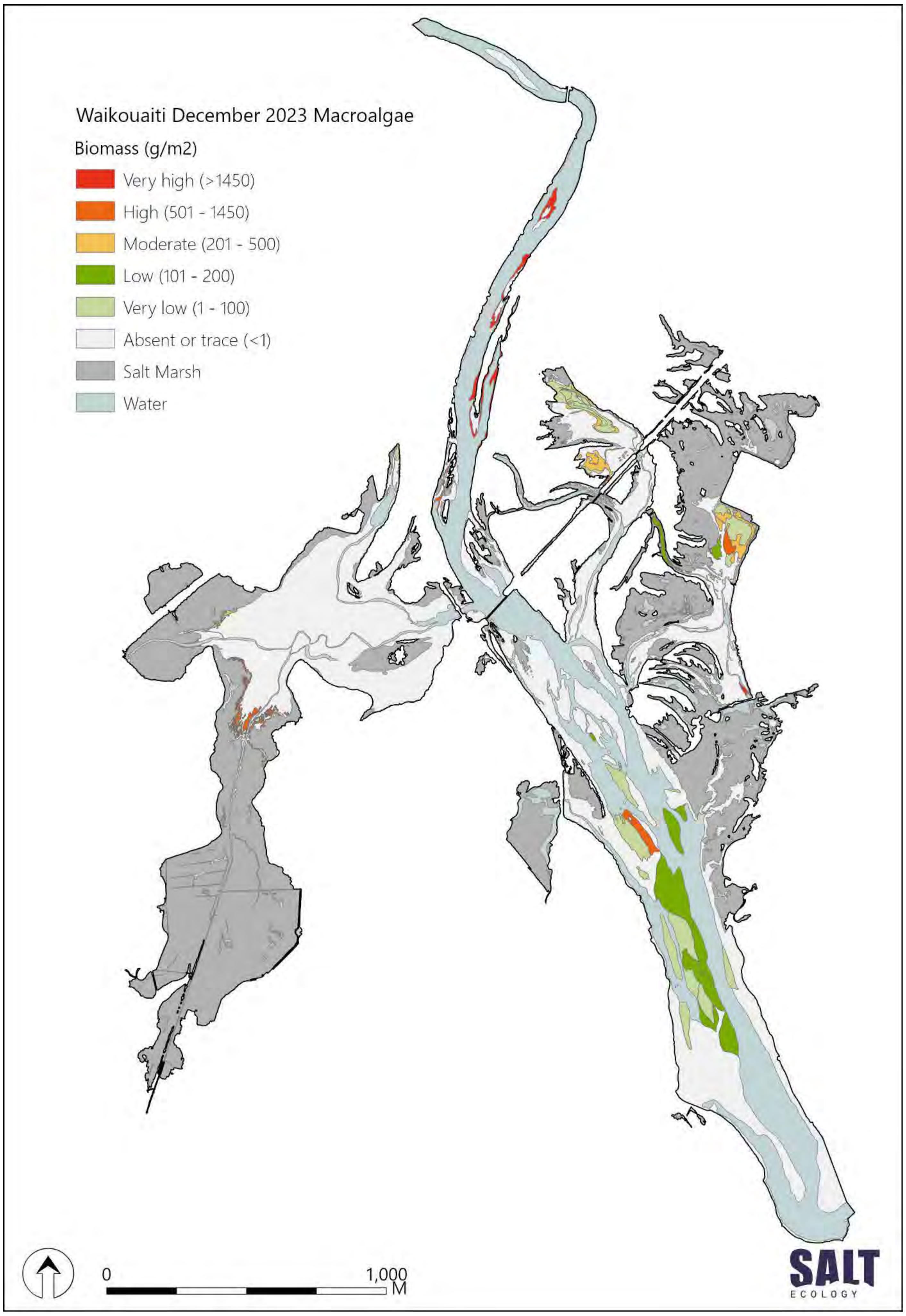
Site G

Site G - aRPD

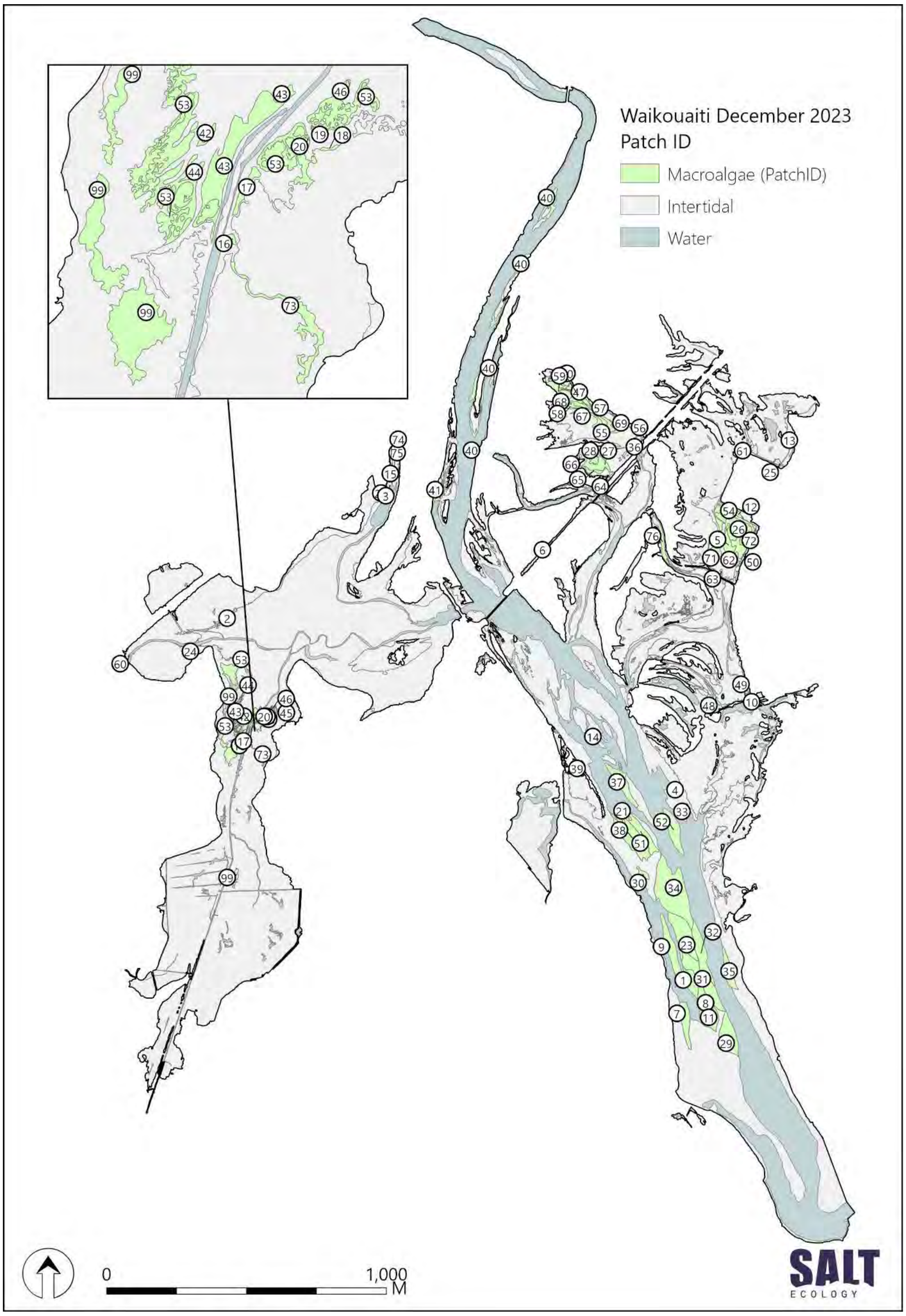

Waikouaiti December 2023 Sampling Locations
Sediment validation
Sediment quality, biota and sediment validation
Salt Marsh
Intertidal
Water
A
B
C
D
E
F
G
1
2
3
4
5
6
7
8
0
1,000
M
SALT
ECOLOGY

APPENDIX 7. MACROALGAE BIOMASS AND PATCH INFORMATION

A. Biomass



B. Macroalgae patch ID



C. Macroalgae Patch data and OMBT input data

Patch ID	Dominant Species	Sub-dominant species	% Cover	Percent Cover Category	Biomass (g/m2)	Biomass Category	Entrained	Substrate	Area (ha)
1	*Agarophyton* spp. (Agar weed)		15	Sparse (10 to <30%)	75	Very low (1 - 100)	1	CKLE fMS10 Shel	0.3
2	Filamentous green algae	*Vaucheria* sp.	80	Dense (70 to <90%)	500	Moderate (201 - 500)	0	fSM	0.1
3	Filamentous green algae		100	Complete (>=90%)	1000	High (501 - 1450)	0	vsSM	0.01
4	*Agarophyton* spp. (Agar weed)	*Ulva* spp. (Sea lettuce)	16	Sparse (10 to <30%)	100	Very low (1 - 100)	0	fMS25	0.03
5	Filamentous green algae		75	Dense (70 to <90%)	560	High (501 - 1450)	0	fSM	0.2
6	Filamentous green algae	*Vaucheria* sp.	60	Moderate-High (50 to <70%)	500	Moderate (201 - 500)	0	fSM	0.01
7	*Agarophyton* spp. (Agar weed)		10	Sparse (10 to <30%)	60	Very low (1 - 100)	1	fMS10	0.4
8	*Agarophyton* spp. (Agar weed)		15	Sparse (10 to <30%)	80	Very low (1 - 100)	1	fMS10 GF	0.4
9	*Agarophyton* spp. (Agar weed)		10	Sparse (10 to <30%)	50	Very low (1 - 100)	1	fMS10 GF	0.6
10	*Agarophyton* spp. (Agar weed)		100	Complete (>=90%)	3500	Very high (>1450)	1	sSM	0.04
11	*Agarophyton* spp. (Agar weed)	*Ulva* spp. (Sea lettuce)	20	Sparse (10 to <30%)	120	Low (101 - 200)	1	fS CKLE	0.3
12	Filamentous green algae		70	Dense (70 to <90%)	500	Moderate (201 - 500)	0	fSM	0.05
13	Filamentous green algae		100	Complete (>=90%)	800	High (501 - 1450)	0	fSM	0.002
14	*Ulva* spp. (Sea lettuce)		15	Sparse (10 to <30%)	200	Low (101 - 200)	0	fS GF	0.04
15	Filamentous green algae		80	Dense (70 to <90%)	250	Moderate (201 - 500)	0	sSM	0.02
16	Filamentous green algae		25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	sSM	0.003
17	Filamentous green algae		25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	sSM	0.02
18	Filamentous green algae		25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	sSM	0.003
19	Filamentous green algae		25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	sSM	0.002
20	Filamentous green algae		25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	sSM	0.1
21	*Agarophyton* spp. (Agar weed)	*Ulva* spp. (Sea lettuce)	10	Sparse (10 to <30%)	50	Very low (1 - 100)	1	fS GF	0.03
22	*Agarophyton* spp. (Agar weed)		100	Complete (>=90%)	800	High (501 - 1450)	1	vsSM	0.003
23	*Ulva* spp. (Sea lettuce)		5	Very sparse (1 to <10%)	30	Very low (1 - 100)	0	mS GF	0.9
24	Filamentous green algae		70	Dense (70 to <90%)	250	Moderate (201 - 500)	0	sM90	0.04
25	Filamentous green algae		90	Complete (>=90%)	450	Moderate (201 - 500)	0	sSM	0.002
26	Filamentous green algae		10	Sparse (10 to <30%)	80	Very low (1 - 100)	0	sSM	0.8
27	Filamentous green algae	*Ulva* spp. (Sea lettuce)	50	Moderate-High (50 to <70%)	400	Moderate (201 - 500)	0	sSM	0.02
28	*Vaucheria* sp.	Filamentous green algae	70	Dense (70 to <90%)	500	Moderate (201 - 500)	0	sSM	0.1
29	*Ulva* spp. (Sea lettuce)		20	Sparse (10 to <30%)	120	Low (101 - 200)	0	fS CKLE	0.7
30	*Ulva* spp. (Sea lettuce)		10	Sparse (10 to <30%)	60	Very low (1 - 100)	0	GF fS	0.1
31	*Ulva* spp. (Sea lettuce)	*Agarophyton* spp. (Agar weed)	20	Sparse (10 to <30%)	120	Low (101 - 200)	0	CKLE mS GF	0.8
32	*Ulva* spp. (Sea lettuce)	*Agarophyton* spp. (Agar weed)	20	Sparse (10 to <30%)	130	Low (101 - 200)	0	fMS10	0.6
33	*Ulva* spp. (Sea lettuce)	*Agarophyton* spp. (Agar weed)	55	Moderate-High (50 to <70%)	200	Low (101 - 200)	0	fS GF	0.1
34	*Ulva* spp. (Sea lettuce)	*Agarophyton* spp. (Agar weed)	20	Sparse (10 to <30%)	120	Low (101 - 200)	0	fS GF	1.9
35	*Ulva* spp. (Sea lettuce)	*Agarophyton* spp. (Agar weed)	15	Sparse (10 to <30%)	100	Very low (1 - 100)	0	mS	0.3
36	*Ulva* spp. (Sea lettuce)		90	Complete (>=90%)	2000	Very high (>1450)	0	sSM	0.003
37	*Ulva* spp. (Sea lettuce)		10	Sparse (10 to <30%)	100	Very low (1 - 100)	0	fS GF	0.5
38	*Ulva* spp. (Sea lettuce)		10	Sparse (10 to <30%)	60	Very low (1 - 100)	0	fS GF	0.9
39	*Ulva* spp. (Sea lettuce)		10	Sparse (10 to <30%)	100	Very low (1 - 100)	0	GF	0.01
40	*Ulva* spp. (Sea lettuce)		80	Dense (70 to <90%)	1500	Very high (>1450)	0	GF	1.0
41	*Ulva* spp. (Sea lettuce)		50	Moderate-High (50 to <70%)	1000	High (501 - 1450)	0	GF	0.1
42	*Ulva* spp. (Sea lettuce)		100	Complete (>=90%)	750	High (501 - 1450)	0	sSM	0.01
43	*Ulva* spp. (Sea lettuce)		100	Complete (>=90%)	750	High (501 - 1450)	0	sSM	0.1
44	*Ulva* spp. (Sea lettuce)		100	Complete (>=90%)	750	High (501 - 1450)	0	sSM	0.3
45	Filamentous green algae		25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	sSM	0.01
46	Filamentous green algae		25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	sSM	0.1
47	Filamentous green algae		60	Moderate-High (50 to <70%)	300	Moderate (201 - 500)	0	sSM	0.1
48	Filamentous green algae		75	Dense (70 to <90%)	80	Very low (1 - 100)	1	sSM	0.1
49	*Agarophyton* spp. (Agar weed)		100	Complete (>=90%)	3360	Very high (>1450)	1	sSM	0.01
50	Filamentous green algae		75	Dense (70 to <90%)	450	Moderate (201 - 500)	0	sSM	0.6
51	*Ulva* spp. (Sea lettuce)		45	Low-Moderate (30 to <50%)	720	High (501 - 1450)	0	GF	0.5
52	*Ulva* spp. (Sea lettuce)	*Agarophyton* spp. (Agar weed)	55	Moderate-High (50 to <70%)	200	Low (101 - 200)	1	fS	0.5
53	*Vaucheria* sp.		100	Complete (>=90%)	70	Very low (1 - 100)	0	sSM	0.2
54	*Vaucheria* sp.		80	Dense (70 to <90%)	60	Very low (1 - 100)	0	fSM	0.05
55	*Vaucheria* sp.	Filamentous green algae	70	Dense (70 to <90%)	400	Moderate (201 - 500)	0	sSM	0.1
56	*Vaucheria* sp.		60	Moderate-High (50 to <70%)	40	Very low (1 - 100)	0	fSM	0.02
57	*Vaucheria* sp.		90	Complete (>=90%)	65	Very low (1 - 100)	0	fSM	0.1
58	*Vaucheria* sp.	Filamentous green algae	70	Dense (70 to <90%)	400	Moderate (201 - 500)	0	sSM	0.03
59	*Vaucheria* sp.		90	Complete (>=90%)	65	Very low (1 - 100)	0	sSM	0.1
60	*Vaucheria* sp.		70	Dense (70 to <90%)	55	Very low (1 - 100)	0	fSM	0.01
61	*Vaucheria* sp.		60	Moderate-High (50 to <70%)	35	Very low (1 - 100)	0	fSM	0.03
62	*Vaucheria* sp.		40	Low-Moderate (30 to <50%)	35	Very low (1 - 100)	0	fSM	0.1
63	*Vaucheria* sp.		60	Moderate-High (50 to <70%)	45	Very low (1 - 100)	0	GF fS	0.01
64	*Vaucheria* sp.	Filamentous green algae	100	Complete (>=90%)	700	High (501 - 1450)	0	sSM	0.02
65	*Vaucheria* sp.		10	Sparse (10 to <30%)	10	Very low (1 - 100)	0	sSM	0.1
66	*Vaucheria* sp.	Filamentous green algae	90	Complete (>=90%)	220	Moderate (201 - 500)	0	sSM	0.3
67	*Vaucheria* sp.		90	Complete (>=90%)	70	Very low (1 - 100)	0	sSM	0.3
68	*Vaucheria* sp.		40	Low-Moderate (30 to <50%)	40	Very low (1 - 100)	0	sSM	0.1

Patch ID	Dominant Species	Sub-dominant species	% Cover	Percent Cover Category	Biomass (g/m2)	Biomass Category	Entrained*	Substrate	Area (ha)
69	*Vaucheria* sp.		50	Moderate-High (50 to <70%)	45	Very low (1 - 100)	0	sSM	0.3
70	*Vaucheria* sp.		40	Low-Moderate (30 to <50%)	40	Very low (1 - 100)	0	fSM	0.3
71	*Vaucheria* sp.	Filamentous green algae	80	Dense (70 to <90%)	150	Low (101 - 200)	0	fSM	0.2
72	*Vaucheria* sp.		40	Low-Moderate (30 to <50%)	35	Very low (1 - 100)	0	fMS25	0.03
73	*Vaucheria* sp.		60	Moderate-High (50 to <70%)	50	Very low (1 - 100)	0	sSM	0.1
74	*Vaucheria* sp.		70	Dense (70 to <90%)	55	Very low (1 - 100)	0	sSM	0.04
75	*Vaucheria* sp.		40	Low-Moderate (30 to <50%)	35	Very low (1 - 100)	0	sSM	0.1
76	*Vaucheria* sp.	Filamentous green algae	80	Dense (70 to <90%)	150	Low (101 - 200)	0	sSM	0.2

*Entrainment is scored as 1 (entrained) or 0 (not entrained)

December 2023 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	6.2	0.775	Good
Average biomass (g/m^2) in AIH	42.9	0.914	High
Average biomass (g/m^2) in AA	256.7	0.562	Moderate
%entrained in AA	16.5	0.446	Moderate
Worst of AA (ha) and AA (% of AIH)		0.590	Moderate
AA (ha)	16.5	0.768	Good
AA (% of AIH)	16.7	0.590	Moderate
Survey EQR		0.658	'Good'

December 2016 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	6.2	0.745	Good
Average biomass (g/m^2) in AIH	42.9	0.763	High
Average biomass (g/m^2) in AA	256.7	0.395	Moderate
%entrained in AA	16.5	1.000	Moderate
Worst of AA (ha) and AA (% of AIH)		0.557	Moderate
AA (ha)	16.5	0.741	Good
AA (% of AIH)	16.7	0.557	Moderate
Survey EQR		0.692	'Good'

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating. 2016 metrics recalaculated in 2024 following the methods in Stevens et al. (2022).

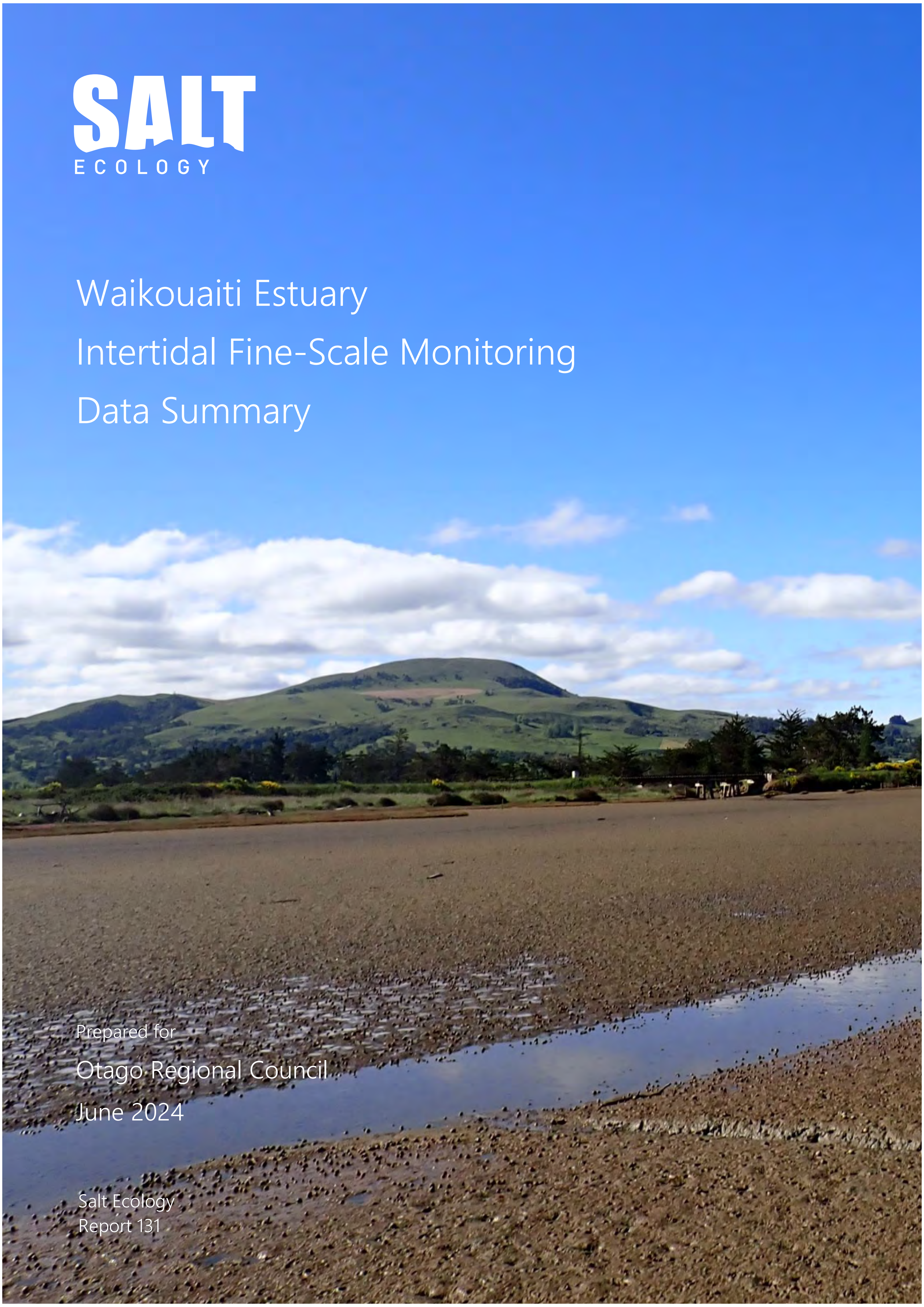
APPENDIX 8. MACROFAUNA RAW DATA

Main group	Taxa	Habitat	EG	Site 1a	Site 1b	Site 2a	Site 2b	Site 3a	Site 3b	Site 4a	Site 4b	Site 5a	Site 5b	Site 6a	Site 6b	Site 7a	Site 7b	Site 8a	Site 8b
Amphipoda	*Josephosella awa*	Infauna	II	-	-	-	1	1	-	2	-	3	2	-	-	4	-	-	-
Amphipoda	*Paracalliope novizealandiae*	Infauna	I	-	1	-	-	14	-	240	400	6	5	1	1	3	2	1	5
Amphipoda	*Paracorophium excavatum*	Infauna	IV	389	279	21	15	2	1	12	17	2	1	-	1	1	-	-	-
Anthozoa	*Edwardsia sp.*	Epibiota	II	-	-	-	-	-	-	1	7	-	-	-	-	18	2	7	5
Bivalvia	*Arthritica sp. 5*	Infauna	III	11	10	20	5	54	37	1	10	40	24	38	16	-	-	1	2
Bivalvia	*Austrovenus stutchburyi*	Infauna	II	-	-	-	-	-	-	-	-	-	-	4	2	-	4	39	25
Bivalvia	*Macomona liliana*	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Bivalvia	*Paphies australis*	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Chironomidae	*Chironomidae*	Infauna	III	-	-	-	-	-	-	-	-	-	1	12	7	-	-	-	-
Copepoda	Copepoda	Infauna	II	-	-	-	-	1	1	-	1	-	1	-	-	-	-	-	1
Cumacea	*Colurostylis lemurum*	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-
Decapoda	*Halicarcinus whitei*	Infauna	III	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-
Decapoda	*Hemiplax hirtipes*	Infauna	III	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	*Amphibola crenata*	Epibiota	III	-	2	-	-	1	-	3	1	-	-	-	-	-	-	-	-
Gastropoda	*Cominella glandiformis*	Epibiota	III	-	-	-	-	-	2	-	-	-	-	-	-	-	-	1	1
Gastropoda	*Micrelenchus huttonii*	Epibiota	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Gastropoda	*Notoacmea scapha*	Epibiota	II	1	-	-	-	-	-	-	-	-	-	-	-	-	-	9	3
Gastropoda	*Potamopyrgus estuarinus*	Epibiota	IV	-	1	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Gastropoda	*Zeacumantus subcarinatus*	Epibiota	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Isopoda	*Omonana sp.*	Infauna	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
Mysida	Mysida	Infauna	II	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Nematoda	Nematoda	Infauna	III	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-
Nemertea	Nemertea	Infauna	III	-	-	-	-	1	-	-	20	-	2	1	-	1	-	-	2
Oligochaeta	Oligochaeta	Infauna	V	-	-	2	2	-	-	2	16	1	6	1	2	4	-	5	-
Polychaeta	*Abarenicola sp.*	Infauna	I	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Polychaeta	*Aonides trifida*	Infauna	I	-	-	-	-	-	-	-	-	-	1	-	-	34	54	46	29
Polychaeta	*Aphelochaeta sp.*	Infauna	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Polychaeta	*Barantolla lepte*	Infauna	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Polychaeta	*Boccardia acus*	Infauna	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	4
Polychaeta	*Boccardia syrtis*	Infauna	II	-	-	-	-	-	-	-	-	-	-	2	-	32	41	28	51
Polychaeta	*Capitella cf. capitata*	Infauna	V	-	-	3	2	-	-	137	49	1	1	24	5	25	17	7	17
Polychaeta	*Euchone sp.*	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Polychaeta	*Hemipodia simplex*	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Polychaeta	*Heteromastus filiformis*	Infauna	IV	-	-	-	-	-	-	-	-	-	-	-	-	-	6	11	16
Polychaeta	*Levinsenia gracilis*	Infauna	III	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
Polychaeta	*Microphthalmus riseri*	Infauna	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	2
Polychaeta	*Microspio maori*	Infauna	I	15	23	13	44	-	-	-	-	10	11	-	-	-	4	-	-
Polychaeta	*Nicon aestuariensis*	Infauna	III	-	-	-	-	4	1	-	-	5	4	-	-	-	8	2	11
Polychaeta	*Perinereis vallata*	Infauna	III	-	-	-	-	1	-	6	9	-	-	64	35	16	8	-	-
Polychaeta	*Prionospio aucklandica*	Infauna	III	-	2	-	-	-	-	-	-	-	-	-	-	-	1	27	37
Polychaeta	*Sabellidae*	Infauna	I	-	-	-	1	-	-	-	-	-	-	2	2	-	-	-	-
Polychaeta	*Scolecolepides benhami*	Infauna	IV	37	37	70	78	46	64	60	48	50	73	32	51	1	5	-	-
Polychaeta	*Scoloplos cylindrifer*	Infauna	I	-	-	-	-	-	-	-	-	-	-	1	-	8	1	18	2
Abundance				453	355	129	148	127	106	466	580	120	132	183	123	149	157	213	219
Richness				5	8	6	8	12	6	12	13	10	13	13	11	13	17	20	21

Environmental Science and Policy Committee - 4 December 2024

SALT ECOLOGY

Waikouaiti Estuary
Intertidal Fine-Scale Monitoring
Data Summary



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Salt Ecology
Report 131

Cover and back photo: Northern upper mud flats of Waikouaiti Estuary, December 2023.

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SALT ECOLOGY

For the People
Mō ngā tāngata

Waikouaiti Estuary Intertidal Fine-Scale Monitoring Data Summary

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for

Otago Regional Council
June 2024

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For the environment
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GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of Environment (Monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
Zn	Zinc

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SALT ECOLOGY

For the People
Mō ngā tāngata

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TABLES

1. INTRODUCTION

Between December 2016 and February 2019, Otago Regional Council (ORC) undertook three ecological and sediment quality surveys in Waikouaiti River Estuary (hereafter Waikouaiti). A report was produced on the first survey (Robertson et al. 2017) but data from the two subsequent surveys were archived. This report provides a high-level summary of the data for all three surveys to support a planned review of ORC's estuary State of the Environment (SOE) monitoring programme.

2. METHODS

The survey methods are described in Robertson et al. (2017) and were based on the 'fine-scale' approach in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). Monitoring was conducted at three sites (Fig. 1). Different providers have undertaken the surveys, namely Wriggle Coastal Management (December 2016), Ryder Associates (December 2017) and Salt Ecology (February 2019). Monitoring indicators and methods are described in Appendix 1, and were as follows:

Sediment quality indicators: Included sediment mud content, oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients and organic content, and selected trace contaminants. Sediment aRPD was measured in the field. For the other variables, three samples (each composited from 3-4 sub-samples of the surface 20mm of sediment) were collected and sent to Hill Laboratories for analysis.

Biotic indicators: Included surface-dwelling snails and macroalgae, and benthic macrofauna. Macrofauna sampling was undertaken using cores (130mm diameter, 150mm deep, ~2L volume, sieved to 0.5mm). Macrofauna species taxonomy and counts were made by Ryder Associates in December 2017, and by Coastal Marine Ecology Consultants for the other two surveys. For reporting purposes, macrofauna naming differences among surveys have been standardised to the extent feasible.

The data analysis methods are described in Appendix 2. Macrofauna assessment included calculation of scores for the international biotic health index 'AMBI'. To assess estuary health, results for most indicators are evaluated against 'condition ratings' described in Appendix 3.

Fig. 1. Location of the three fine-scale monitoring sites in Waikouaiti Estuary. The schematic depicts the sediment sample and macrofauna core collection. Information on site GPS positions and other location information is provided in Robertson et al. (2017).

3. KEY FINDINGS

An overall summary of results, with condition ratings applied where available, is provided in Table 2.

3.1 SEDIMENT QUALITY

Sediment quality data are collated in Appendix 4. Sediments were primarily comprised of sand at Site A and B, and muddy sand at Site C (Fig. 1). The amount of mud at each site has remained relatively stable in consecutive years. However, mud reduced slight at Site A, from 11% in 2016 to 7.3% in 2017 and 6.7% in 2019, representing an improvement in rating from 'fair' to 'good' (Table 2). Substrate mud content at Site B also reduced in 2017, resulting in a temporary rating change from 'good' to 'very good'.

Site A and B are located on well flushed flats near the main channel in the lower estuary. This dynamic hydrological environment limits the deposition of muds. Site C has had a consistently high mud content with a 'poor' rating, which reflects the sheltered location of this site in the upper estuary.

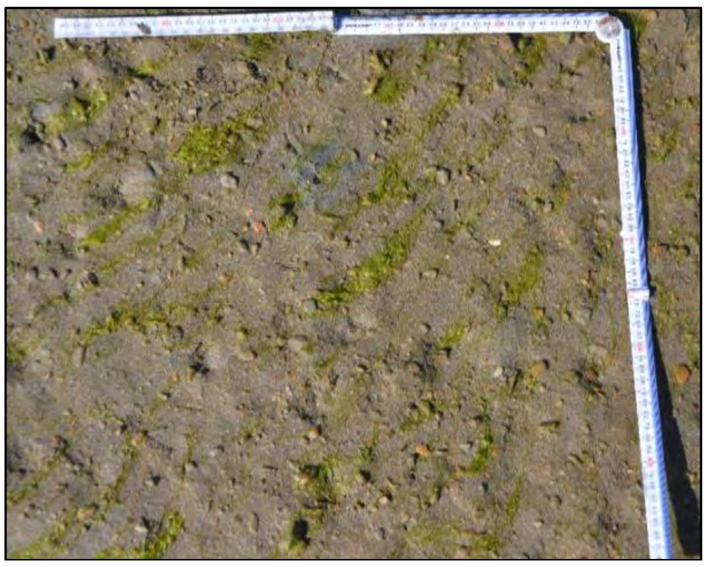
Table 1. Summary of mean values of key indicators at fine-scale monitoring sites in Waikouaiti Estuary. Values are rated against condition scores of ecological health, where available (Appendix 3). No rating criteria exist for total phosphorus (TP), macrofauna richness (Rich.), or macrofauna abundance (Abun.). See Glossary for definition of indicators.

Site	Year	Mud	aRPD	TN	TP	TOC	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Rich.	Abun.	AMBI
		%	mm	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	na	na	na
A	Dec-16	11.9	3	700	487	0.50	7.9	0.026	6.4	5.0	0.01*	6.9	4.4	26.7	7	31	1.3
	Dec-17	7.3	-	333*	503	0.29	5.9	0.016	5.3	4.4	< 0.02	5.7	3.8	26.3	24	437	1.4
	Feb-19	6.7	28	< 500	563	0.27	5.7	0.017	5.2	4.2	< 0.02	5.1	3.6	23.7	12	97	2.1
B	Dec-16	8.0	5	< 500	683	0.20	4.0	< 0.010	3.9	3.4	< 0.01	4.5	2.8	18.0	4	15	2
	Dec-17	4.0	-	< 500	627	0.21	3.9	0.007*	4.4	4.0	< 0.02	4.9	3.1	22.3	13	531	4.5
	Feb-19	7.6	24	< 500	573	0.30	4.5	0.013	5.3	4.5	< 0.02	5.3	3.8	23.3	9	122	4.4
C	Dec-16	30.9	0	633	463	0.41	4.1	0.049	5.3	3.3	0.01	3.9	3.5	22.0	4	34	4.3
	Dec-17	30.3	-	< 500	540	0.30	4.1	0.039	4.9	2.7	< 0.02	3.3	3.3	21.7	6	200	4.5
	Feb-19	28.3	18	< 500	517	0.33	4.3	0.033	5.1	2.6	< 0.02	3.3	3.3	20.5	5	131	4.4

** Sample mean includes values below lab detection limits.*

< All values below lab detection limit.

Very Good	Good	Fair	Poor



Site B had sandy substrate with gravel present, as pictured here in 2016.

Site C had soft substrate with elevated-mud content, as pictured here in 2019.

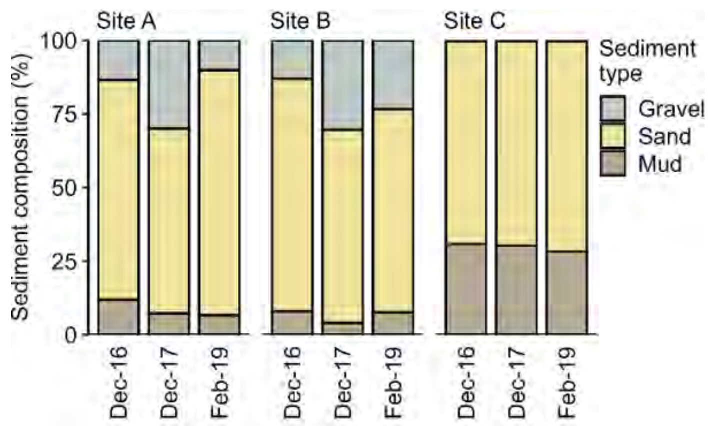


Fig. 1. Sediment particle grain size analysis showing percentage composition of mud (<63μm), sand (<2mm to ≥63μm) and gravel (≥2mm) from composite samples (n=3) at fine-scale sites.

These site characteristics are reflected in data from annual sedimentation monitoring between 2016 and 2022 (Rabel 2024). Both lower estuary sites (Sites A & B) had highly variable interannual patterns of sedimentation which reflect the dynamic movement of sand by water currents within the main reach of the estuary. Site B was abandoned in 2019 following a large erosion event due to the proximity of the main channel. Site C in the upper estuary has a relatively stable pattern of sediment erosion (average rate of -2.4mm/yr, respectively), with a rating of 'very good'.

Sediment oxygenation assessed by the aRPD method was 'poor' across all sites in the 2016 survey and was not assessed in 2017. This indicator had a rating of 'good' at Site A and B, and 'fair' at site C in the 2019 survey (Table 2, Fig. 2). The core photos below illustrate the change in aRPD transition in 2019 between brown surface sediment and deeper oxygen-depleted sediment. There were no signs of excessive sediment enrichment, such as an intense black colour throughout the depth profile or a strong sulphide ('rotten egg') odour when the sediment was disturbed. Due to the lack of site descriptions and photos from the 2016 and 2017 monitoring, the earlier aRPD values cannot be verified, hence reasons for the marked difference between 2016 and 2019 are unable to be determined.

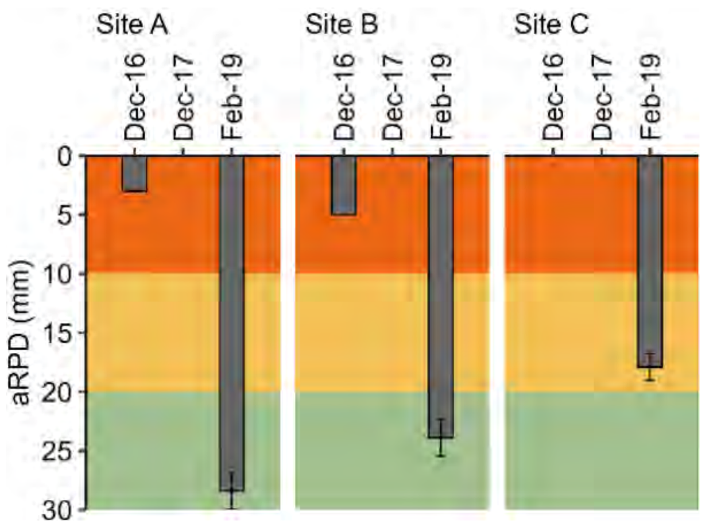
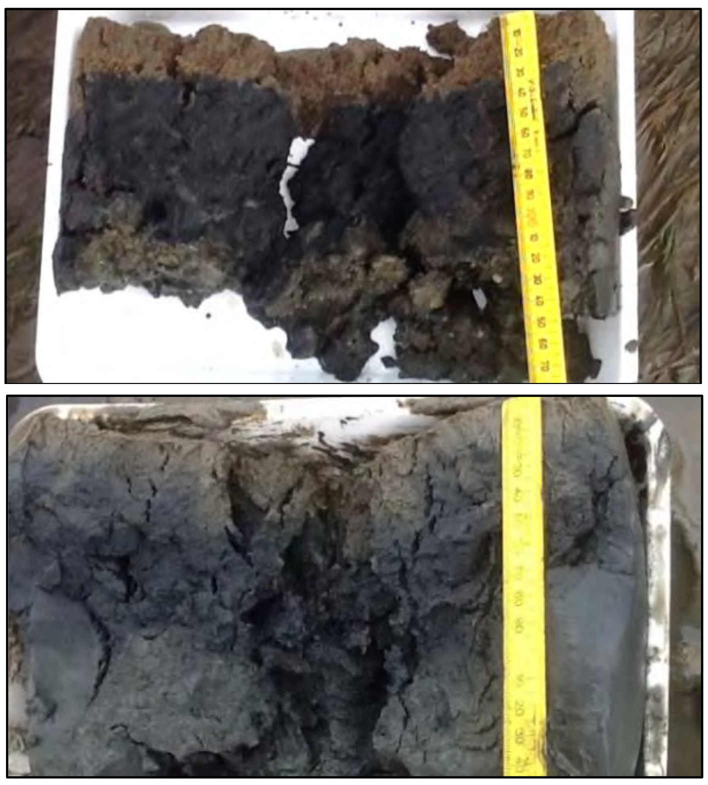


Fig. 2. Mean (±SE, 2016 n=3, 2019 n=10) aRPD depth relative to condition ratings. The aRPD depth was not recorded in December 2017.

Very Good	Good	Fair	Poor



Sediment core profiles from Site B (top, sand) and C (bottom, muddy sand) in 2019. Oxygen-depleted sediment is illustrated by the deeper grey/black colouring.

Laboratory sediment analyses revealed low levels of organic matter and nutrients, corresponding to ratings of 'very good' in 2019 (Table 2, Fig. 3). TN values were slightly elevated in 2016 at Site A and C, however reduced to less than routine laboratory method detection limits at all sites in 2019.

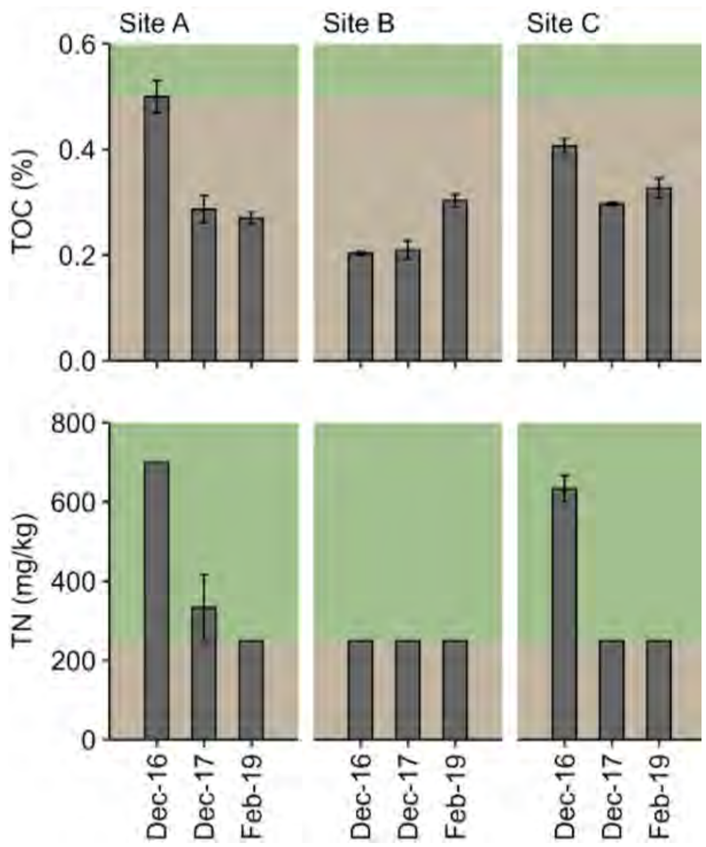


Fig. 3. Mean (±SE, n=3) sediment total organic carbon (TOC) and total nitrogen (TN) in composite samples, relative to condition ratings. TN values at Site A in 2019, Site B in all years, and Site C in 2017 and 2019, were less than routine laboratory method detection limits. Values plotted are 50% of the detection limit.

Very Good	Good	Fair	Poor

Sediment trace metal contaminants were at very low concentrations in all three surveys, and less than half of the national sediment quality Default Guideline Value (DGV; Table 2, Fig. 4). DGVs indicate "*...the concentrations below which there is a low risk of unacceptable effects occurring*" (ANZG 2018). Overall, therefore, these results suggest that there are no significant chemical contaminant inputs from the catchment that are accumulating in the estuary, and there no trends of interest in concentrations over time.

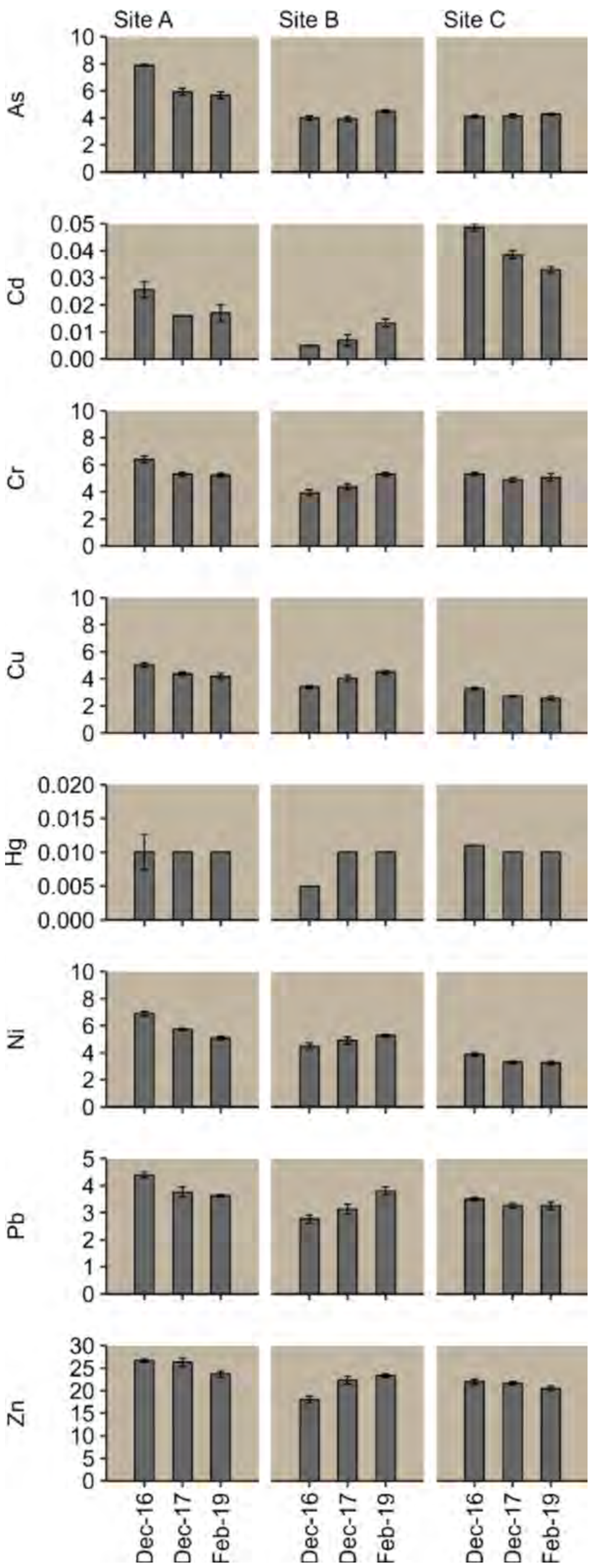


Fig. 4. Mean (±SE, n=3) trace metal concentrations in composite samples, relative to condition ratings. The grey shading corresponds to a 'very good' rating, and indicates that values were <50% of the ANZG (2018) sediment quality Default Guideline Value (DGV). Below the DGV there is a 'low risk' of unacceptable effects.

Very Good	Good	Fair	Poor

3.2 BIOTA

Surface dwelling epibiota

Epibiota were reflective of the site sediment characteristics discussed above.

The sandy lower estuary site (Site A) had three species of top shell present (*Diloma subrostratum*, *Diloma aethiops* and *Micrelenchus huttonii*) and the estuary mud whelk *Cominella glandiformis*. Epifauna were scarce at Site B with the occasional mud snail *Amphibola crenata* (~1/m^2). The elevated mud substrates at Site C within the upper estuary supported abundant mud snails (e.g., ~20/m^2 in 2017) and the stalk-eyed mud crab *Hemiplax hirtipes*.

A dense bed of seagrass was present at Site B in 2019, with seagrass visible adjacent to the site in photos from previous monitoring events.

Epifauna at Site A (top) and Site C (bottom) in 2019.

Two opportunistic (aka 'nuisance') seaweeds were recorded within the estuary: the red seaweed *Gracilaria* spp. and green 'sea lettuce' *Ulva* spp. Both species were present at Site A and B within the lower estuary, with dense blooms of *Ulva* spp. across the intertidal flats in 2013, 2016, and 2017 (Robertson et al. 2017). The biomass and cover of *Gracilaria* spp. at fine scale sites has generally been low during monitoring, however, a dense cover was observed across Site C in the upper estuary in 2013 (Robertson et al. 2017).

Looking south from Site A across the lower estuary flats covered in dense Ulva spp., 2016.

Site B with sparse cover of Ulva spp. and seagrass adjacent to the site visible in the background, 2016.

Site C with mud snails Amphibola crenata visible across the mud-elevated substrate, and nuisance seaweed Gracilaria spp. growing adjacent to the site, 2016.

Sediment-dwelling macrofauna

Macrofauna species and abundances are summarised in Appendix 5. Core sampling revealed the macrofauna to be moderately diverse in terms of the species present, with a range of sensitive and more hardy species. Interpretation of macrofauna data requires care due to provider variability between monitoring events. Key points are as follows:

- A total of 54 species or higher macrofauna taxa have been recorded from the three sites. Twelve main taxonomic groups are present, with polychaete worms by far the most abundant, and large numbers of gastropods, amphipods, and bivalves (Appendix 5).
- Mean species richness was highest in the lower estuary at Site A and reduced with distance up the estuary (average ~14 taxa per core at Site A, ~9 at Site B, ~5 at Site C across all three monitoring years). More species were identified across all sites in 2017 (Fig. 5a). This temporal fluctuation may reflect natural variability but could also have result from the use of different providers in each of the three survey years, potentially leading to variability during macrofauna sorting process or in the taxonomic identifications.
- Similarly, the greatest abundances occurred in 2017 at Site A and B, with means of 437 and 531 organisms per core, respectively (Fig. 5b; Table 1). Abundances were consistently low in 2016. Although these differences may in part be explained by natural variability (e.g., in recruitment success), they also possibly reflect sample provider differences between years. For example, very small organisms can be missed during macrofauna sample sorting, depending on whether the sorting is done by eye or under a binocular microscope, and whether a red vital stain (rose bengal) is used to make the macrofauna more visible in the sorting tray.
- Mean values of the biotic index AMBI corresponded to a condition rating of 'good' at Site A in the lower estuary. Site B had a 'good' rating in 2016, however this deteriorated to 'poor' in the two subsequent monitoring events. Macrofauna in the upper estuary at Site C consistently had a 'poor' rating (Table 2, Fig. 6). These ratings reflect that the macrofauna at Site B and C was dominated by hardy species in eco-group IV, while eco groups I-III were predominant at Site A, but their relative proportions varied

among surveys (Fig. 7). For example, mean AMBI values at Site B have increased (i.e., deteriorated) over time, which appears due mainly to increased densities of the hardy (EG-IV) tube-building amphipod *Paracorophium excavatum*. This result conceivably reflects natural processes such as physical disturbance from sand movement and migration of the main estuary channel.

- By far the most abundant species was the amphipod *P. excavatum*, noted above, which dominated the community at Site B and C in 2017 and 2019. The numbers of *P. excavatum* boomed at Site B in 2017, with ~4000 individuals observed (Appendix 5). This species is common in disturbed environments, especially in river-dominated estuaries subject to highly variable flows and salinities.

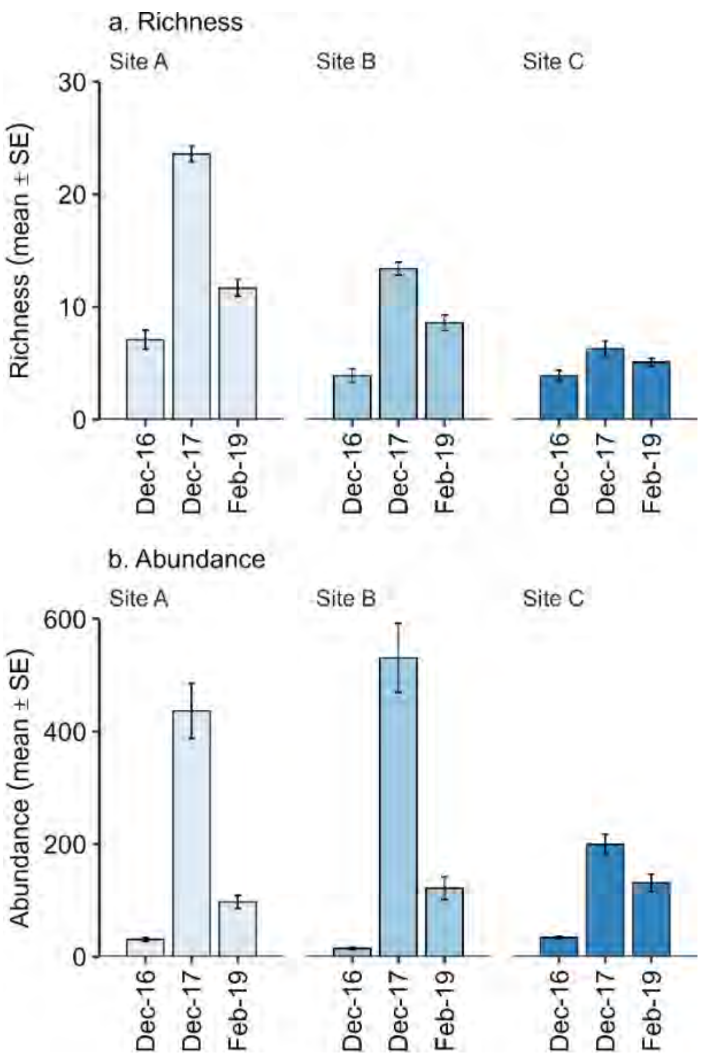


Fig. 5. Mean (±SE, n=10) macrofauna taxon richness and abundance per core.

The amphipod *Paracalliope novizealandiae* (EG-1) is common in New Zealand estuaries and was the most abundant species (>2000 individuals) at Site A in 2017. Despite the EG-I classification as a sensitive species (based on the international eco-group sensitivity for *Paracalliope* sp.) *P. novizealandiae* in New Zealand appears to tolerate sedimentation and muddy habitats to some extent. The booming numbers of this species reduced in 2019, but it was still present across all sites in low numbers.

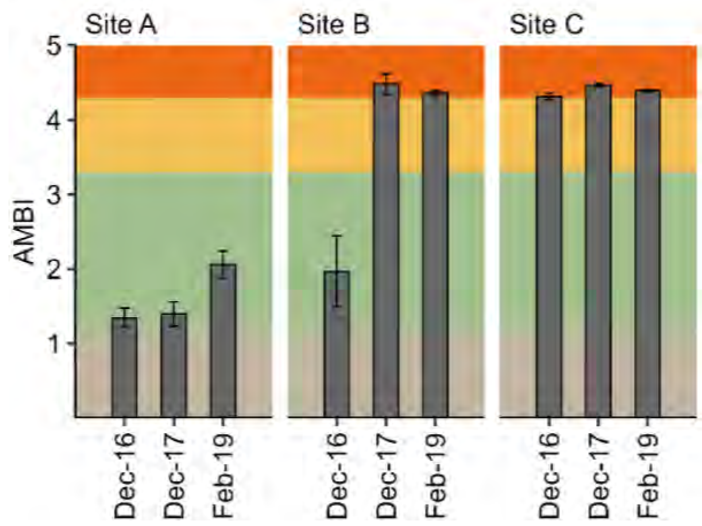


Fig. 6. Mean (±SE, n=10) AMBI scores relative to condition ratings.

Very Good	Good	Fair	Poor

The tube-building amphipod *Paracorophium excavatum* was by far the most dominant of the macrofauna at Site B and C (image from NIWA Otago estuaries collection).

The amphipod *Paracalliope novizealandiae* was the most dominant of the macrofauna at Site A.

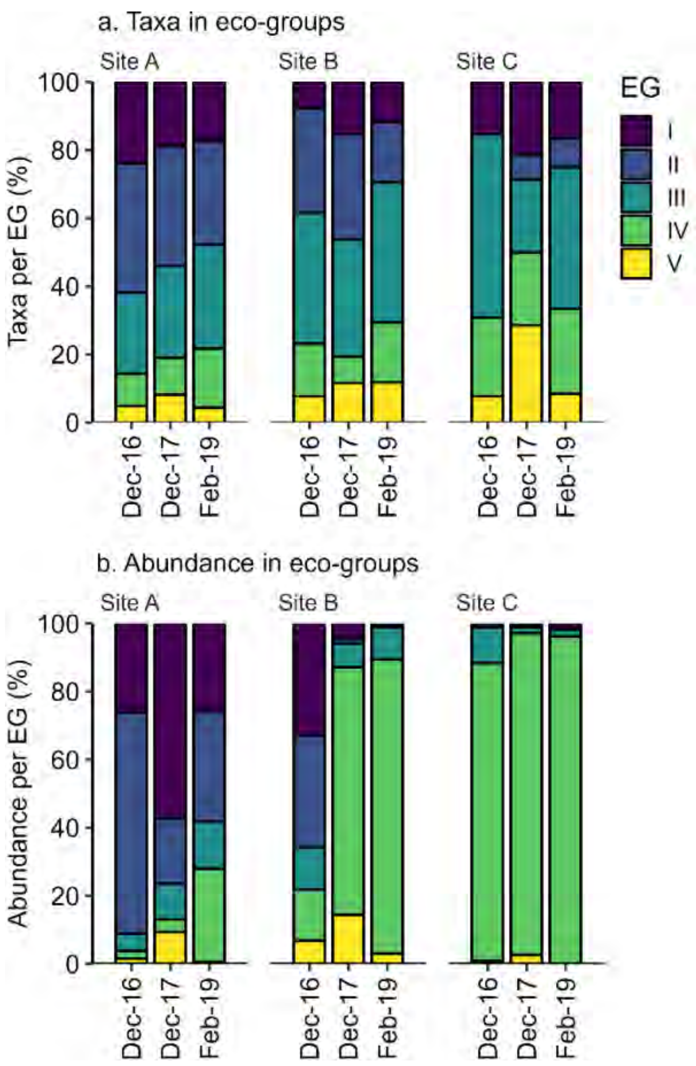


Fig. 7. Contribution to site richness and abundances of macrofauna species in eco-groups ranging from sensitive (EG-I) to resilient (EG-V). The graphs illustrate that the macrofauna was dominated by hardy (EG-IV and EG-V) organisms at Site B in 2017 and 2019 and at Site C in all years.

- Polychaete worm species were the most abundant taxa group, and many species were present that are commonly found in estuaries nationally. In particular, *Scolecolepides benhami* was ubiquitous across all sites and present in high numbers at Site C.
- In addition to the highly sensitive spionid polychaete *Aonides trifida*, two hardy polychaete species, *Boccardia acus* and *Heteromastus filiformis*, were consistently common at Site A but absent or rare at Site B and C. The spionid *Prionospio aucklandica*, considered tolerant to organic enrichment, was absent from Site B and C but also present at Site A across all monitoring events, with elevated abundances in 2017.
- The common cockle *Austrovenus stutchburyi* (EG-II) was the most abundant bivalve at Site A across all years (Appendix 5). This species is considered to be intolerant of sediment with high mud content and was absent from Site C.
- A cursory analysis of overall macrofauna community composition differences among sites and surveys was undertaken. A multivariate method was used to 'group' sites according to their similarity in macrofauna composition (Figure 8). The analysis revealed the following macrofauna composition patterns:
- Macrofauna differences between the three sites were quite pronounced, reflecting the species differences described above, as well as more subtle differences in the occurrence of sub-dominant species (Appendix 5).
- The tight grouping of Site C samples in 2017 and 2019 reflects the strong dominance in these two surveys of *P. excavatum*.
- At Site A and B, the analysis revealed differences in 2016 relative to the two other surveys, due to low numbers of juvenile Glyceridae present and the absence of *Microspio maori*, which was recorded in subsequent surveys.

A limited analysis was undertaken to determine whether macrofauna differences among sites/surveys could be 'explained' by any of the sediment quality variables. Sediment mud appears likely to be a potential explanatory variable for the difference between sites. Macrofauna composition differences were correlated with higher values of mud at Site C, and also at Sites A and B in 2016 (Spearman rank correlation coefficient ρ = 0.46 for sediment %mud; see also Figure 8). Despite 'very good' substrate oxygenation at Site A and shallow aRPD indicating 'poor' oxygenation at Site B and C (see figure 3), this parameter was unable to be further assessed due to data uncertainty in 2016 and missing data in 2017. Hence, of the variables measured, the amount of mud in the sediment is likely to have the most plausible influence on macrofaunal composition. For example, a mud content of around 20-30% or greater (i.e., as evident at Site C) is often considered as the threshold at which macrofaunal composition changes are most evident relative to sandier sediments (Robertson et al. 2015; Robertson et al. 2016; Ward et al. 2021; Bulmer et al. 2022). In general, muddy sediment is regarded as one of the key drivers of ecological health degradation in New Zealand estuaries (Cummings et al. 2003; Robertson et al. 2015; Berthelsen et al. 2018; Clark et al. 2021).

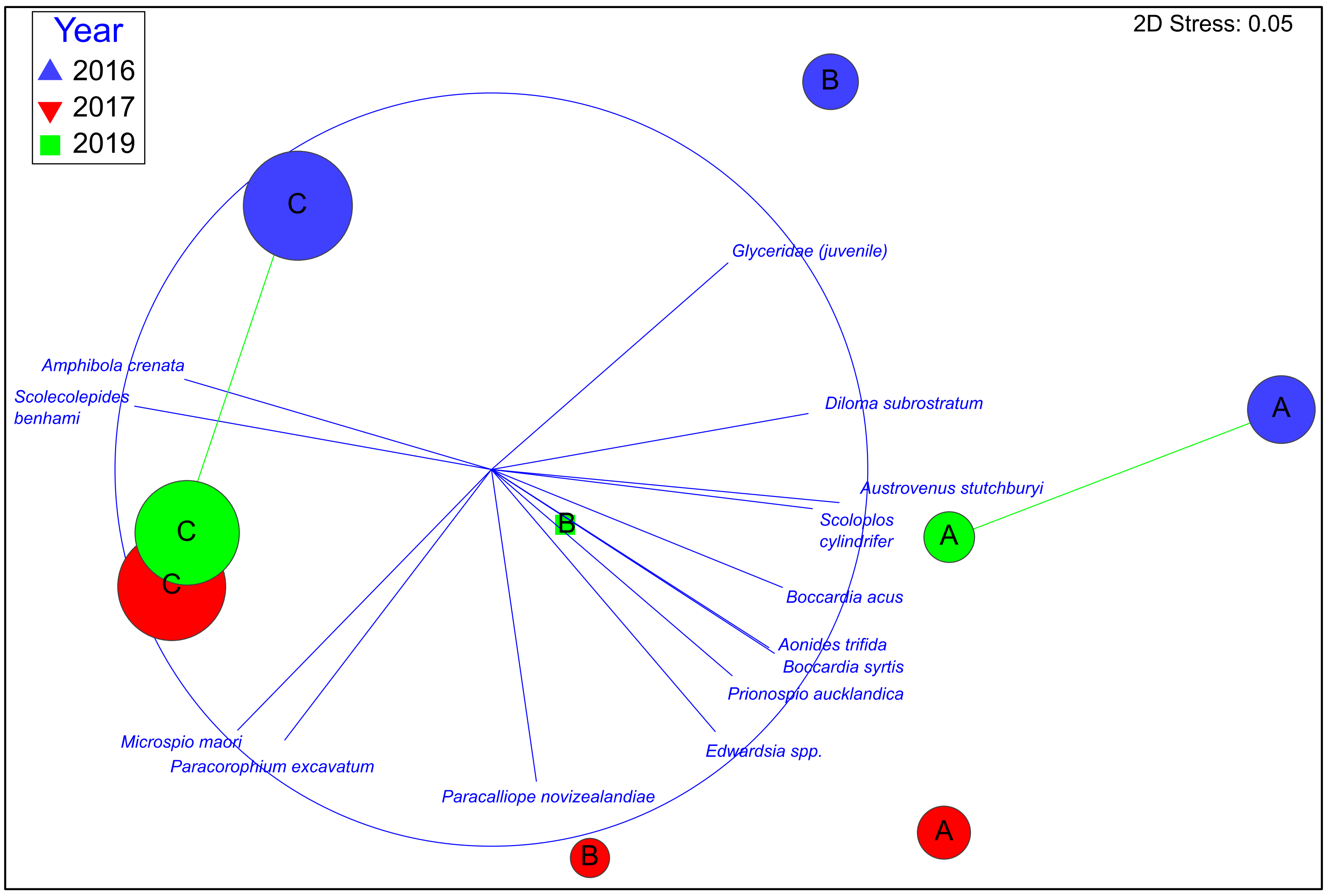


Fig. 8. Non-metric MDS ordination of macrofaunal core samples for data aggregated within each site and survey.

Sample groups closer to each other are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of 0.05 indicates that a 2-dimensional plot provides a reliable representation of differences. The green lines connect sample groups with a high similarity (60%) based on the Bray-Curtis measure. The vectors show the direction and strength of association (length of line relative to circle) of the macrofauna that were most strongly correlated with the pattern of differences. The circle size for each site is scaled relative to the mud composition of the substrate, illustrating the muddiest sediment at Site C, and muddier sediment at Sites A and B in 2016 relative to subsequent surveys at those sites.

4. MONITORING AND MANAGEMENT IMPLICATIONS

ORC undertook broad-scale habitat mapping of the Waikouaiti Estuary in 2016, which is complemented by the comprehensive baseline fine-scale monitoring described in this report. One of the reasons for compiling the present summary report was to better understand the utility of the current monitoring approach. Once data for all Otago estuaries have been collated in a similar way, ORC will be in a better position to review the programme and determine monitoring priorities. In this broader context, Waikouaiti Estuary presents some features that will need to be accounted for in the review. These include the following:

Previous sedimentation monitoring, combined with the analysis of fine-scale data in this report, suggest that sediment and nutrient loads to Waikouaiti Estuary from the catchment are exceeding the estuary's assimilative capacity.

The upper estuary has a large extent of elevated mud substrate (including at Site C) (Stevens et al. 2017), reflecting the sheltered and less well-flushed hydrodynamics of this part of the estuary. As described above, sediment mud-content at Site C was consistently elevated, yet the site has experienced annual sediment erosion (Rabel 2024). The observed erosion may be a response to a large sediment accumulation event prior to the monitoring commencing, after which erosion has consistently occurred. A longer time series of monitoring is required to ascertain potential drivers of the erosion observed.

The lower estuary, in contrast, is physically more dynamic, sand-dominated, and has a higher level of tidal flushing, with variable patterns of sediment deposition and erosion at Sites A and B. Sites A and B are well-flushed due to their position near tidal channels (Rabel 2024). Site B is located immediately adjacent to the main channel and was abandoned as a fine-scale monitoring site in 2019 due to a large scour event (assumed to be flood-related).

Macroalgae blooms of *Ulva* spp. were apparent across Sites A and B within the lower estuary in 2013, 2016, and 2017. Nuisance macroalgae was observed at Site C within the upper estuary in 2013, causing the development of 'gross eutrophic zone' conditions characterised by anoxic sediments, soft muds and high nuisance macroalgal cover (Stevens et al. 2017).

The infauna community at Site A has relatively higher diversity and more sensitive species than at Sites B and C, reflecting the sandy substrates and well flushed nature of the site. The species present at Site B were generally disturbance-tolerant in response to the dynamic hydrological conditions encountered at this site. Site C also has low diversity and a large number of hardy taxa, likely driven by the muddy substrates.

Sites A and B provide potentially useful baseline sites representative of the lower and mid-estuary, respectively. However, their position near the main channel means that they are subject to physical stresses relating to hydrological conditions and sand movement. These conditions mean that physical disturbance at the site may have an over-riding influence on macrofauna and make ecological changes due to anthropogenic drivers (e.g., catchment land use changes) difficult to detect.

Site C provides a less dynamic monitoring location with greater similarities in infauna community composition between monitoring events, increasing the likelihood of detecting a shift in community composition in response to a change in anthropogenic pressures at this site.

The above evidence suggests that sites in the lower estuary (Sites A and B) are showing symptoms of eutrophication (i.e., proliferation of nuisance macroalgae), although the bed sediments are not excessively enriched. In terms of sedimentation, the upper estuary (Site C) likely captures direct catchment pressures from ongoing muddy sediment inputs. ORC will need to consider priorities for managing these sources in the context of other regional catchment management priorities.

A question for ORCs programme review will be the merits of investigating alternative Waikouaiti fine-scale sites that may be more responsive to long term changes in direct catchment pressures such as sedimentation. For this purpose, there will be additional macrofauna core data available over the next few months from a broad scale habitat survey conducted over the most recent summer. These data can be used to inform potential site selection.

Decisions regarding future monitoring sites should form part of ORC's review of the regional estuary SOE programme. That review should consider the specific type of monitoring that is needed in the context of management goals in Waikouaiti Estuary, and the priorities for monitoring relative to other estuary systems in Otago.

5. RECOMMENDATIONS

Although there is merit in continued fine-scale monitoring in Waikouaiti Estuary, it is recommended that a decision on future fine-scale and other monitoring needs is determined as part of ORC's planned review of the regional estuary SOE programme. The results of ongoing annual sedimentation monitoring, and a NEMP broad-scale habitat mapping survey undertaken last summer, will contribute to a broader understanding of estuary state and monitoring needs.

6. 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.

Berthelsen A, Atalah J, Clark D, Goodwin E, Patterson M, Sinner J 2018. Relationships between biotic indices, multiple stressors and natural variability in New Zealand estuaries. Ecological Indicators 85: 634-643.

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 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.

Bulmer RH, Stephenson F, Lohrer AM, Lundquist CJ, Madarasz-Smith A, Pilditch CA, Thrush SF, Hewitt JE 2022. Informing the management of multiple stressors on estuarine ecosystems using an expert-based Bayesian Network model. Journal of Environmental Management 301: 113576.

Clark DE, Stephenson F, Hewitt JE, Ellis JI, Zaiko A, Berthelsen A, Bulmer RH, Pilditch CA 2021. Influence of land-derived stressors and environmental variability on compositional turnover and diversity of estuarine benthic communities. Marine Ecology Progress Series 666: 1-18.

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.

Cummings V, Thrush S, Hewitt J, Norkko A, Pickmere S 2003. Terrestrial deposits on intertidal sandflats: sediment characteristics as indicators of habitat suitability for recolonising macrofauna. Marine Ecology Progress Series 253: 39-54.

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.

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/.

Rabel H 2024. Waikouaiti Estuary: 2023/2024 Intertidal Sediment Monitoring Summary. Salt Ecology Short Report 047 prepared for Otago Regional Council, May 2024. 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. 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, Robertson BP, Stevens LM 2017. Waikouaiti Estuary: Fine Scale Monitoring 2016/17. Prepared for Otago Regional Council. 37p.

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, 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.

Stevens LM, Robertson BM 2017. Waikouaiti Estuary - Broad Scale Habitat Mapping 2016/17. Report prepared by Wriggle Coastal Management for Otago Regional Council. 36p.

Ward N, Roberts K 2021. Estuaries and Coast: Classification and Attributes for Southland. Environment Southland publication number 2020-03, Environment Southland: Invercargill. 107p. ISBN 978-0-909043-63-6.

APPENDIX 1. SUMMARY OF NEMP FINE-SCALE INDICATORS

The rationale for each indicator and sampling method is provided. The main 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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Samples sent to Hill Laboratories for analysis.
Nutrients (nitrogen and phosphorus), and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Organic matter measured as Total Organic Carbon (TOC) (note 1). Samples sent to Hill Laboratories for analysis.
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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site (note 2). Samples sent to Hill Laboratories for analysis.
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.	Ten sediment cores per site, split vertically, with average depth of aRPD (for each core) 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.	Ten sediment cores per site (130mm diameter, 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 (note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR (note 3).
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR (notes 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 used quadrat sampling in the first two surveys, but for the last survey used the 'SACFOR' approach: S = super abundant, A = abundant, C = common, F = frequent, O = occasional, R = rare . SACFOR was used instead of the quadrat sampling, which is subject to considerable within-site variation for epibiota that have clumped or patchy distributions (see Forrest et al. 2022 for further detail).

[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.

APPENDIX 2. DATA RECORDING, QA/QC AND ANALYSIS METHODS

All sediment and macrofaunal samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. Field measurements from the fine scale and sediment plate surveys were recorded electronically in templates that were custom-built using software available at www.fulcrumapp.com. Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position for that record (e.g. a sediment core). Field data were exported to Excel, together with data from the sediment and macrofaunal analyses.

The Excel sheets were imported into the software R 4.0.5 (R Core Team 2023) and merged by common sample identification codes. All summaries of univariate responses (e.g. totals, means ± 1 standard error) were produced in R, including tabulated or graphical representations of data from sediment plates, laboratory sediment quality analyses, and macrofauna. Where results for sediment quality parameters were below analytical detection limits, averaging (if undertaken) used half of the detection limit value, according to convention.

Before 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. terrestrial beetles). To facilitate comparisons with future surveys, and other Otago 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) were derived. AMBI scores reflect the proportion of taxa falling into one of five eco-groups (EG) that reflect sensitivity to pollution (in particular eutrophication), 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), with the most recent eco-group list developed in December 2020.

To reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand (e.g., Cawthron EGs used by Berthelsen et al. 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).

Multivariate representation of the macrofaunal community data used the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in site similarity as a function of macrofaunal composition and abundance were assessed using an 'unconstrained' non-metric multidimensional scaling (nMDS) ordination plot, based on pairwise Bray-Curtis similarity index scores among samples aggregated within each site and zone (see Fig. 8). The purpose of aggregation was to smooth over the 'noise' associated with a core-level analysis and enable the relationship to patterns in sediment quality variables (which were composited within zones) to be determined.

Prior to the multivariate analysis, macrofaunal abundance data were fourth-root or presence-absence transformed to down-weight the influence on the ordination pattern of the dominant species or higher taxa. The purpose of the presence-absence transformation was to explore site differences that were attributable to species occurrences irrespective of their relative abundances. The procedure PERMANOVA was used to test for compositional differences among sites, based on both types of transformed data.

Overlay vectors and bubble plots on the nMDS were used to visualise relationships between multivariate biological patterns and sediment quality data. Additionally, the Primer procedure Bio-Env was used to evaluate the suite of sediment quality variables that best explained the biological ordination pattern.

APPENDIX 3. CONDITION RATINGS FOR ASSESSING ESTUARY HEALTH

No rating criteria exist for Total Phosphorus (TP), or macrofauna variables other than AMBI. See Glossary for definition of indicators.

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			Requires development		
TOC[1]	%	<0.5	0.5 to <1	1 to <2	≥2
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.

APPENDIX 4. SEDIMENT QUALITY DATA

Values based on a composite sample within each of Zone X (reps X1-3), Y (reps Y4-6) and Z (reps Z7-10), except for aRPD in February 2019 for which the mean and range is shown for 10 replicates. The aRPD depth was not reported in December 2017. In 2016 aRPD was assessed at 3 locations per site only. DGV = Default guideline value for sediment quality (ANZG 2018); GV-High = Guideline Value High.

Site	Year	Zone	Gravel %	Sand %	Mud %	TOC %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
A	Dec-16	X	10.1	79.6	10.3	0.44	700	490	3	7.8	0.02	6.1	5	<0.01	7	4.3	27
		Y	14.5	72.6	12.9	0.52	700	430	3	7.9	0.03	6.2	4.8	0.01	6.6	4.3	26
		Z	15.9	71.7	12.4	0.54	700	540	3	8	0.027	6.9	5.3	0.01	7.1	4.6	27
	Dec-17	X	31	62.1	6.9	0.29	<250	480	-	5.8	0.016	5.2	4.5	<0.01	5.9	3.9	26
		Y	30.8	61.7	7.5	0.33	500	500	-	6.4	0.016	5.6	4.5	<0.01	5.6	4	28
		Z	28	64.4	7.5	0.24	<250	530	-	5.6	0.016	5.1	4.1	<0.01	5.7	3.4	25
	Feb-19	X	6.2	87.9	5.9	0.27	<250	550	24.0 (20 to 27)	6.1	0.013	5.5	4	<0.01	5.3	3.7	23
		Y	10.5	82.2	7.3	0.29	<250	480	28.3 (25 to 32)	5.7	0.015	5.1	4.6	<0.01	5.1	3.6	23
		Z	13.7	79.5	6.8	0.25	<250	660	31.8 (25 to 35)	5.2	0.023	5.1	4	<0.01	4.9	3.6	25
B	Dec-16	X	12	78.3	9.6	0.2	<250	760	5	3.9	<0.005	4	3.6	<0.01	4.5	2.8	18
		Y	22.6	68.3	9.1	0.21	<250	780	5	3.8	<0.005	4.3	3.4	<0.01	4.9	3	19
		Z	4.4	90.3	5.4	0.2	<250	510	5	4.3	<0.005	3.5	3.2	<0.01	4.1	2.5	17
	Dec-17	X	34.8	61.2	4	0.18	<250	590	-	4.1	<0.005	4.3	4	<0.01	4.7	3	22
		Y	24.2	71.6	4.1	0.24	<250	680	-	4.1	<0.005	4.8	4.4	<0.01	5.4	3.5	24
		Z	32	64.1	3.9	0.21	<250	610	-	3.6	0.011	4	3.7	<0.01	4.6	2.9	21
	Feb-19	X	27.4	66.6	6	0.28	<250	700	26.7 (20 to 30)	4.3	0.013	5.1	4.3	<0.01	5.4	4	23
		Y	20.4	71.4	8.2	0.31	<250	500	23.3 (20 to 27)	4.6	0.011	5.2	4.4	<0.01	5.1	3.5	24
		Z	22.3	69.2	8.5	0.32	<250	520	22.3 (18 to 30)	4.6	0.016	5.6	4.8	<0.01	5.3	3.9	23
C	Dec-16	X	0.2	69.3	30.5	0.38	600	460	0	3.9	0.05	5.1	3.1	0.01	3.7	3.4	21
		Y	0.2	69.4	30.5	0.42	600	470	0	4.2	0.046	5.4	3.4	0.01	4.1	3.6	23
		Z	0.5	67.9	31.6	0.42	700	460	0	4.2	0.05	5.5	3.3	0.01	3.8	3.5	22
	Dec-17	X	0.3	70.8	28.9	0.29	<250	530	-	4	0.036	4.7	2.6	<0.01	3.1	3.1	21
		Y	<0.1	71.3	28.7	0.3	<250	570	-	4.4	0.041	5.2	2.8	<0.01	3.4	3.3	22
		Z	0.3	66.5	33.2	0.3	<250	520	-	4	0.039	4.8	2.7	<0.01	3.4	3.4	22
	Feb-19	X	0.4	70.5	29.2	0.34	<250	520	18.3 (17 to 20)	4.4	0.032	5.3	2.7	<0.01	3.4	3.5	21
		Y	0.5	64.2	35.3	0.35	<250	530	18.0 (10 to 22)	4.2	0.035	5.4	2.7	<0.01	3.4	3.3	21
		Z	0.2	79.4	20.4	0.29	<250	500	17.5 (15 to 20)	4.2	0.032	4.5	2.3	<0.01	3	3	20
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

APPENDIX 5. MACROFAUNA CORE DATA SUMMED ACROSS TEN REPLICATES FOR EACH SURVEY AND SITE

Minor macrofauna renaming or aggregation to genus has been undertaken to standardise (to the extent feasible) across the different taxonomic provider in December 2017 vs the other two surveys.

Main group	Taxa	EG	December 2016			December 2017			February 2019		
			A	B	C	A	B	C	A	B	C
Amphipoda	*Ischyroceridae*	na		2						6	
Amphipoda	*Josephosella awa*	II								1	2
Amphipoda	*Paracalliope novizealandiae*	I	1		3	2217	205	13	24	9	15
Amphipoda	*Paracorophium excavatum*	IV			2	78	3830	1641	229	1024	1048
Amphipoda	*Paramoera chevreuxi*	II				39	10				
Anthozoa	*Edwardsia spp.*	II	3			63	17		4		
Bivalvia	*Arthritica sp. 5*	III	1	2	21	25	9	30			13
Bivalvia	*Austrovenus stutchburyi*	II	122	40		194	1		253	1	
Bivalvia	*Legrandina turneri*	na				4		1			
Bivalvia	*Macomona liliana*	II	1			7			8		
Bivalvia	*Paphies australis*	II				1	1				
Cumacea	*Colurostylis lemurum*	II				61					
Decapoda	*Austrohelice crassa*	V						1			
Decapoda	*Halicarcinus whitei*	III	2			52	17		106	57	1
Decapoda	*Hemiplax hirtipes*	III		2	7	4	2	7	6	6	8
Diptera	Diptera	IV		6						17	1
Gastropoda	*Amphibola crenata*	III			3			1			2
Gastropoda	*Cominella glandiformis*	III	1	2		9			3	1	
Gastropoda	*Diloma subrostratum*	II	1	2		2			2		
Gastropoda	*Halopyrgus pupoides*	III								19	
Gastropoda	*Micrelenchus huttonii*	na				5					
Gastropoda	*Micrelenchus tenebrosus*	I	3								
Gastropoda	*Notoacmea spp.*	II				117	40				
Gastropoda	*Nudibranchia*	na				4					
Gastropoda	*Potamopyrgus estuarinus*	IV			2			1			
Isopoda	*Exosphaeroma spp.*	V				13	613	6		16	
Mysida	Mysida	II					1	3			
Nemertea	Nemertea	III		4	1	18	66		2	2	
Oligochaeta	Oligochaeta	V	5	10	3	261	113	39	5	21	1
Polychaeta	*Aglaophamus macroura*	II		4		5	2		2	2	
Polychaeta	*Aonides trifida*	I	42			206	5		209		
Polychaeta	*Armandia maculata*	III				6					
Polychaeta	*Boccardia acus*	IV	5			14			4		
Polychaeta	*Boccardia syrtis*	II	64			312	2		25		
Polychaeta	*Capitella spp.*	V				133	43	6			
Polychaeta	*Cossura consimilis*	I				1					
Polychaeta	*Glycera spp.*	II				19					
Polychaeta	*Glyceridae (juv)*	II	4	2							
Polychaeta	*Hemipodia simplex*	II							20		
Polychaeta	*Heteromastus filiformis*	IV	2			72			27		
Polychaeta	*Levinsenia gracilis*	III					1				
Polychaeta	*Microspio maori*	I			1	2	8	4	1	1	7
Polychaeta	*Nereididae (juv)*	III	1	8	1	10	276		9	14	
Polychaeta	*Nicon aestuariensis*	III			1						2
Polychaeta	*Orbinia papillosa*	I	3			17		1			
Polychaeta	*Owenia petersenae*	II				1					
Polychaeta	*Paradoneis lyra*	III				1	1				
Polychaeta	*Perinereis vallata*	III			2	24	2		1	14	
Polychaeta	*Prionospio aucklandica*	III	10			307	1		6		
Polychaeta	*Pseudopotamilla sp.*	II	3			12					
Polychaeta	*Scolecolepides benhami*	IV		16	295	1	27	246	8	8	214
Polychaeta	*Scoloplos cylindrifer*	I	31	48		51	15		19		
Polychaeta	*Syllidae sp. 1*	II	1								
Stomatopoda	*Heterosquilla*	na					1				
	Site richness		21	14	13	39	27	15	23	18	12
	Site abundance		306	148	342	4368	5309	2000	973	1219	1314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AKATORE ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 039. Prepared by Hayden Rabel for Otago Regional Council, May 2024

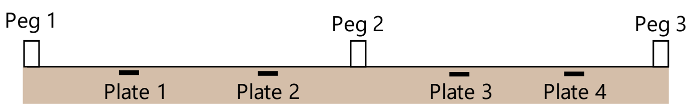
OVERVIEW

Since November 2022, Otago Regional Council has undertaken annual State of the Environment monitoring in Akatore Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 3 December 2023.

Fig. 1. Location of Akatore Estuary monitoring sites.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., O'Connell-Milne et al. 2023). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness.

Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results and their respective condition ratings for the surveys to date. The change in sediment depths over plates is plotted in Fig. 2.

Table 2. Annual sedimentation, grain size and aRPD results up to December 2023.

Site	Survey	Sed rate mm/yr	Gravel %	Sand %	Mud %	aRPD mm
A	Nov-2022	na	0.3	29.5	70.2	10
	Dec-2023	7.5	0.1	30.5	69.4	20
B	Nov-2022	na	0.5	27.7	71.7	10
	Dec-2023	5.1	0.4	32.4	67.3	20

Sedimentation rate

Sediment accretion was observed at both sites after the first full year of monitoring. The rate in Dec-2023 was ~2-3 greater than the 2mm/yr guideline value, hence corresponded to a condition rating of 'poor' (Table 2, Fig 2). A longer time series (e.g., 5 years) will be required to establish a meaningful trend. However, these early monitoring results are in accordance with a modelled estimate of sediment accretion in the estuary of 6.73mm/yr (Hicks et al. 2019).

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in O'Connell-Milne et al. (2023).

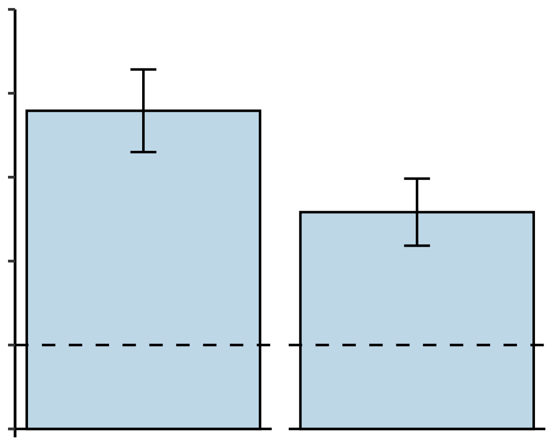


Fig. 2. Change in mean sediment depth over buried plates (±SE) in Dec-2023 relative to the Nov-2022 baseline. The dashed line shows the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

Sediment mud content across both sites and surveys has been close to 70%, hence greatly exceeding the biologically relevant threshold of 25% (Table 2). Both sites are in upper tidal reaches of Akatore Estuary where slow flushing times likely increase fine sediment retention (Roberts et al. 2022).

Despite the elevated mud-content, sediment at both sites appears to be reasonably well oxygenated. The apparent improvement in aRPD ratings from 'fair' in November 2022 to 'good' in December 2023 (Table 2) is probably an observer difference, as the sediment profile in both surveys was superficially similar. Sediment oxygenation is likely maintained by the presence of porous sandy sediments (approx. 30% at both sites), as well as organisms such as crabs and shellfish, which turn over surface sediments and transfer oxygen to underlying layers.

Surface dwelling macrofauna at Site A (left) and Site B (right) in December 2023.

Muddy but reasonably well oxygenated sandy mud at Site A (top) and Site B (bottom) in December 2023.

CONCLUSIONS

The December 2023 survey marks the first year of sedimentation results. Although a longer-time series is required to establish meaningful trends, these initial results indicate quite high muddy sediment deposition from the highly modified Akatore catchment (approx. 77% exotic forest and 12% high-producing grassland; Roberts et al. 2022).

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually.

REFERENCES

Hicks M, Semademi-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. January 2019. 190p

O'Connell-Milne S, Forrest BM, Rabel H. 2023. Fine Scale Intertidal Monitoring of Blueskin Bay, Waitati Inlet. Salt Ecology Report 110, prepared for Otago Regional Council, July 2023. 40p.

Roberts KL, Stevens LM, Forrest BM. 2022. Broad Scale Intertidal Habitat Mapping of Akatore Estuary. Salt Ecology Report 102, prepared for Otago Regional Council, August 2022. 49p.

SALT ECOLOGY

BLUESKIN BAY, WAITATI INLET: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 040. Prepared by Hayden Rabel for Otago Regional Council, May 2024

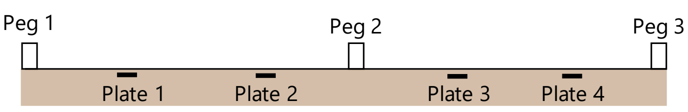
OVERVIEW

Since January 2021, Otago Regional Council has undertaken annual State of the Environment monitoring in Blueskin Bay, Waitati Inlet, to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 2 December 2023.

Fig. 1. Location of Blueskin Bay monitoring sites.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., O'Connell-Milne et al. 2023). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness.

Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Annual results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2.

Table 2. Indicator summary and condition ratings from the December 2023 survey.

Indicator	A	B
Sedimentation (mm/yr)*	-0.5	+0.7
Mud content (%)	4.9	7.6
aRPD (mm)	35	35

* Sedimentation is presented as the mean annual rate over the monitored period (n=3 yrs). Five years of data are recommended for a meaningful trend.

Sedimentation rate

Sedimentation rates have been highly variable in Blueskin Bay over the three years of monitoring (Fig 2, Table 3) and as such it will be helpful to collect more data before assessing meaningful trends. However, on average sedimentation appears to be low (< 2mm/yr upper guideline value), with Site A being rated 'very good' and Site B 'good'.

Table 1. Summary of condition ratings for sediment plate monitoring

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in O'Connell-Milne et al. (2023).

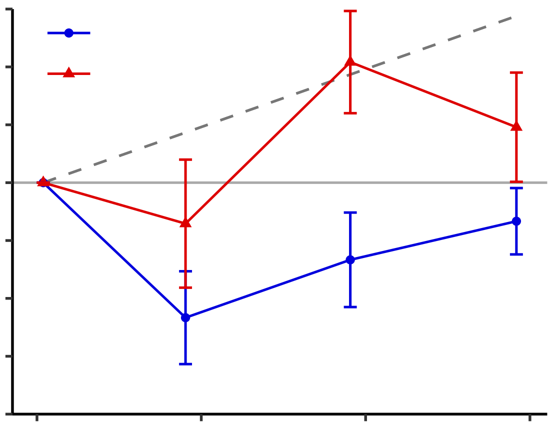


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

Sediment mud-content is typically less variable than sedimentation rates and thus the four monitoring surveys provide a reasonable baseline characterisation of the sand-dominated and low mud-content sediment at both Blueskin Bay sites (Table 3).

Table 3. Annual sedimentation, grain size and aRPD results up to December 2023.

Site	Survey	Sed rate mm/yr	Gravel %	Sand %	Mud %	aRPD mm
A	Jan-2021	na	0.6	94.5	5.0	45
	Nov-2021	-5.4	< 0.1	96.0	4.0	20
	Nov-2022	2.0	< 0.1	94.0	6.0	15
	Dec-2023	1.3	0.1	95.1	4.9	35
B	Jan-2021	na	1.1	93.2	5.7	35
	Nov-2021	-1.6	0.1	93.3	6.6	30
	Nov-2022	5.6	0.4	92.7	6.9	30
	Dec-2023	-2.2	0.3	92.2	7.6	35

< All values below lab detection limit

Firm sandy sediment at Site A (left) and Site B (right) in December 2023.

Deep sediment oxygenation (aRPD transition from brown to dark grey sediment) at Site A (left) and Site B (right) in December 2023.

Average aRPD depths at both sites generally show 'good' sediment oxygenation (Table 1, Table 3), which is commonly found with porous sand sediments. Low levels of sediment mud-content often provide a habitat for larger macrofauna species such as crabs and shellfish that turn over surface sediments and transfer oxygen to underlying layers.

CONCLUSIONS

Blueskin Bay consists of clean and well-oxygenated sandy sediments, with no significant sedimentation recorded since monitoring began. However, Blueskin Bay is considered vulnerable to likely future increases in sediment loads; for example, due to harvest of exotic plantation forest, which comprises almost a quarter of the catchment land use (O'Connell-Milne et al. 2023). For that reason, it will be useful to continue annual sedimentation monitoring in the estuary.

RECOMMENDED MONITORING

Continue annual monitoring and reporting of sedimentation rate, sediment grain size and aRPD depth.

REFERENCE

O'Connell-Milne S, Forrest BM, Rabel H. 2023. Fine Scale Intertidal Monitoring of Blueskin Bay, Waitati Inlet. Salt Ecology Report 110, prepared for Otago Regional Council, July 2023. 40p.

SALT ECOLOGY

CATLINS RIVER (POUNAWEA) ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 041. Prepared by Hayden Rabel for Otago Regional Council, May 2024

OVERVIEW

Since December 2016, Otago Regional Council has undertaken annual State of the Environment monitoring in Catlins River (Pounawea) Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at two sites (Fig. 1), with the latest survey carried out on 5 December 2023.

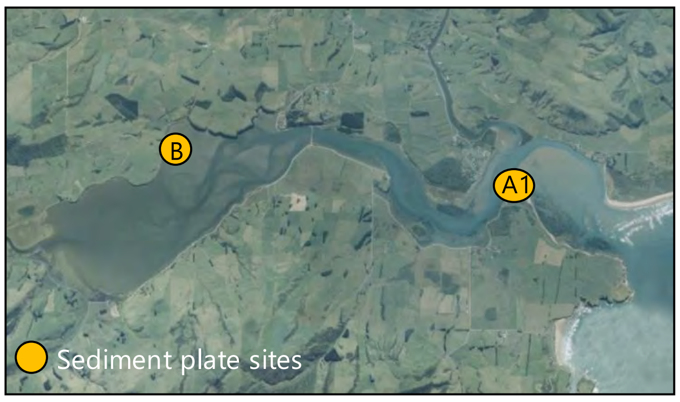
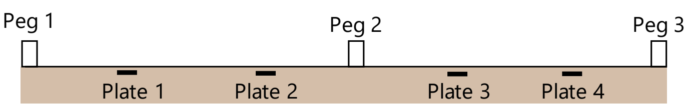


Fig. 1. Location of Catlins River Estuary monitoring sites. Site A was washed away in 2020 and replaced by Site A1 in the same general location.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., O'Connell-Milne et al. 2023). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness.

Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Annual results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2.

Table 2. Indicator summary and condition ratings from the December 2023 survey.

Indicator	A1	B
Sedimentation (mm/yr)*	+8.4	+6.2
Mud content (%)	3.5	28.1
aRPD (mm)	25	25

* Sedimentation is presented as the long-term mean annual rate over the monitored period (n=4 yrs Site A1, n=7 yrs Site B). Five years of data are recommended for a meaningful trend.

Sedimentation rate

The December 2023 survey showed another year of sedimentation rates in exceedance of the 2mm/yr national guideline (Tables 1-3, Fig 2). While accrual has been observed at Site A1, there is high variability across plates owing to the sites proximity to the main channel, the deposition of mobile sands and infauna sediment redistribution (Table 3). Sedimentation at Site B, however, likely reflects fine sediment inputs from the pasture dominated catchment (approx. 64% pastural land uses; Stevens & Robertson. 2017).

Table 1. Summary of condition ratings for sediment plate monitoring

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in O'Connell-Milne et al. (2023).

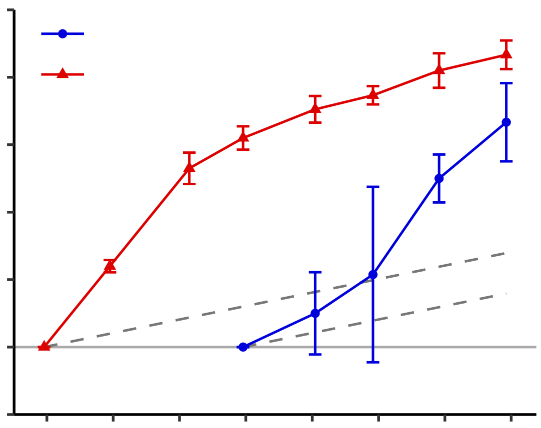


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey line shows sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

As discussed, the locations of each monitoring site influence their sediment composition. Site A1 is located on mobile sand dominated intertidal flats and has had a mud-content around 3% over the monitoring period (rated 'very good'; Table 3). Site B, in the upper estuary, is within a deposition zone and consistently exceeds the biologically relevant threshold of 25% mud-content (rated 'poor').

Sediment oxygenation has been generally rated as 'good' (aRPD >20mm; Table 3) at both sites and does not appear to be impacted by sediment accrual. In general, elevated mud-content can restrict oxygen penetration into the sediment. However, at Site B high abundances of bioturbating macrofauna (see Morrisey and Forrest 2023) draw oxygen deeper into the sediment leading to good sediment oxygenation.

Table 3. Annual sedimentation, grain size and aRPD results up to December 2023.

Site	Survey	Sed rate	Gravel	Sand	Mud	aRPD
		mm/yr	%	%	%	mm
A1	Dec-2019	na	0.1	96.9	3.1	200
	Jan-2021	4.6	< 0.1	97.7	2.3	70
	Dec-2021	6.6	0.3	96.7	3.0	20
	Nov-2022	14.3	< 0.1	96.6	3.4	21
	Dec-2023	8.2	0.1	96.5	3.5	25
B	Dec-2016	na	0.1	75.2	24.7	20
	Dec-2017	12.1	0.1	69.6	30.4	-
	Feb-2019	12.1	0.1	57.1	42.9	10
	Dec-2019	5.5	0.1	59.0	41.0	35
	Jan-2021	3.9	< 0.1	67.6	32.4	25
	Dec-2021	2.4	< 0.1	65.4	34.6	30
	Nov-2022	3.7	< 0.1	70.6	29.4	20
	Dec-2023	2.3	0.1	71.9	28.1	25

< All values below lab detection limit

December 2023 site photos: Sand-dominated sediment at Site A1 near the main channel (top), and mud-dominated sediment with surface dwelling macrofauna at Site B (bottom).

CONCLUSIONS

At Site A1 sediments are sandy, mobile and both temporally and spatially variable, consistent with the location of the site on the well-flushed lower estuary flats near the main river channel. In contrast, Site B in the upper estuary remains at risk of degraded ecosystem health due to fine sediment impacts, likely derived from pastorally dominated upstream land uses. While Fig. 2 and Table 3 show sedimentation rates and mud-content have slowly decreased, these indicators are still above thresholds of concern (i.e., rated 'poor'). The results reinforce previous recommendations (e.g., Stevens & Rovertson. 2017) to continue managing catchment inputs to the estuary.

RECOMMENDED MONITORING

Continue annual monitoring of sedimentation rate, sediment grain size and aRPD depth, and report results annually via a summary report. Consider site suitability and ongoing monitoring as part of a wider estuary programme review to be undertaken by ORC.

REFERENCES

O'Connell-Milne S, Forrest BM, Rabel H. 2023. Fine Scale Intertidal Monitoring of Blueskin Bay, Waitati Inlet. Salt Ecology Report 110, prepared for Otago Regional Council, July 2023. 40p.

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

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.

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
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Synoptic Broad Scale Ecological Assessment of Catlins (Pounawea) Estuary

Prepared by

Keryn Roberts,
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for

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August 2024

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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.

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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

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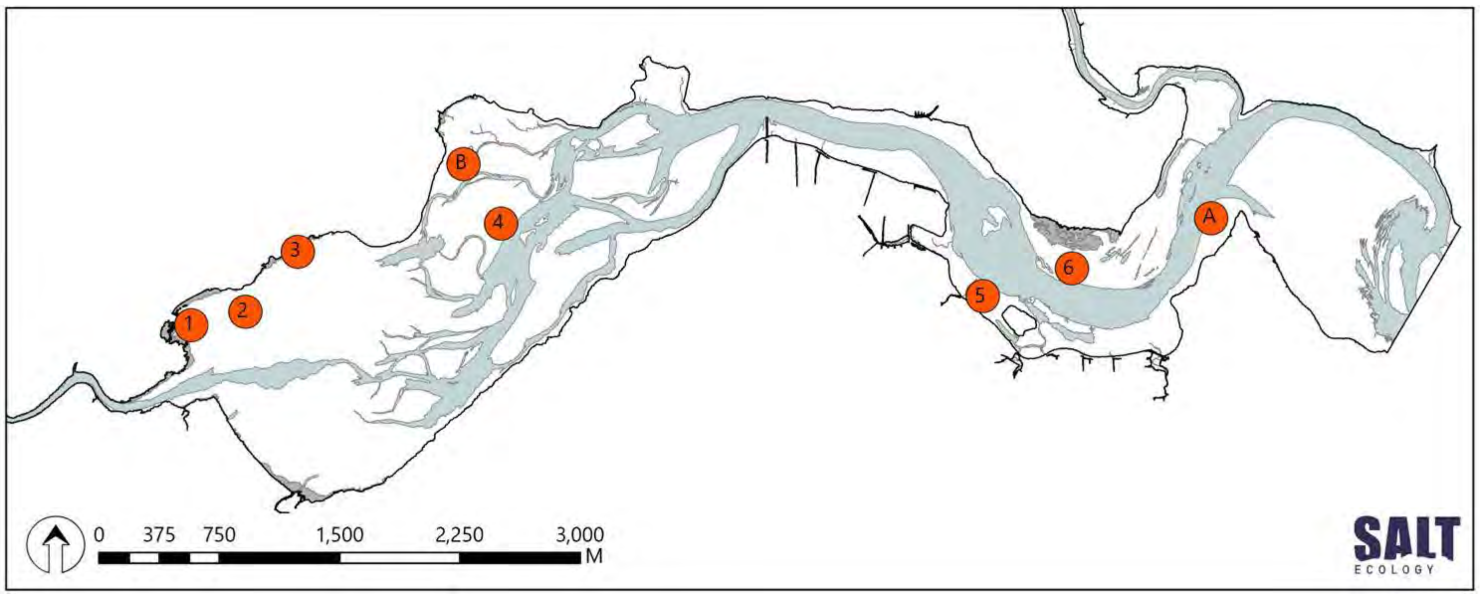


Fine Scale Indicators	Unit	Site 1	2	3	B	4	5	6	A
Mud	%	79.5	70.9	76.1	28.1	6.0	3.6	21.3	3.5
aRPD	mm	3	2	1	40	50	20	5	25
TN	mg/kg	2000	5900	7900	600	300	300	500	300
TP	mg/kg	580	920	1190	360	200	260	360	240
TOC	%	2.2	5.8	7.0	0.5	0.2	0.3	0.4	0.1
TS	%	0.5	0.8	1.3	0.09	0.07	0.05	0.1	0.03
As	mg/kg	3.7	6.2	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.

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.

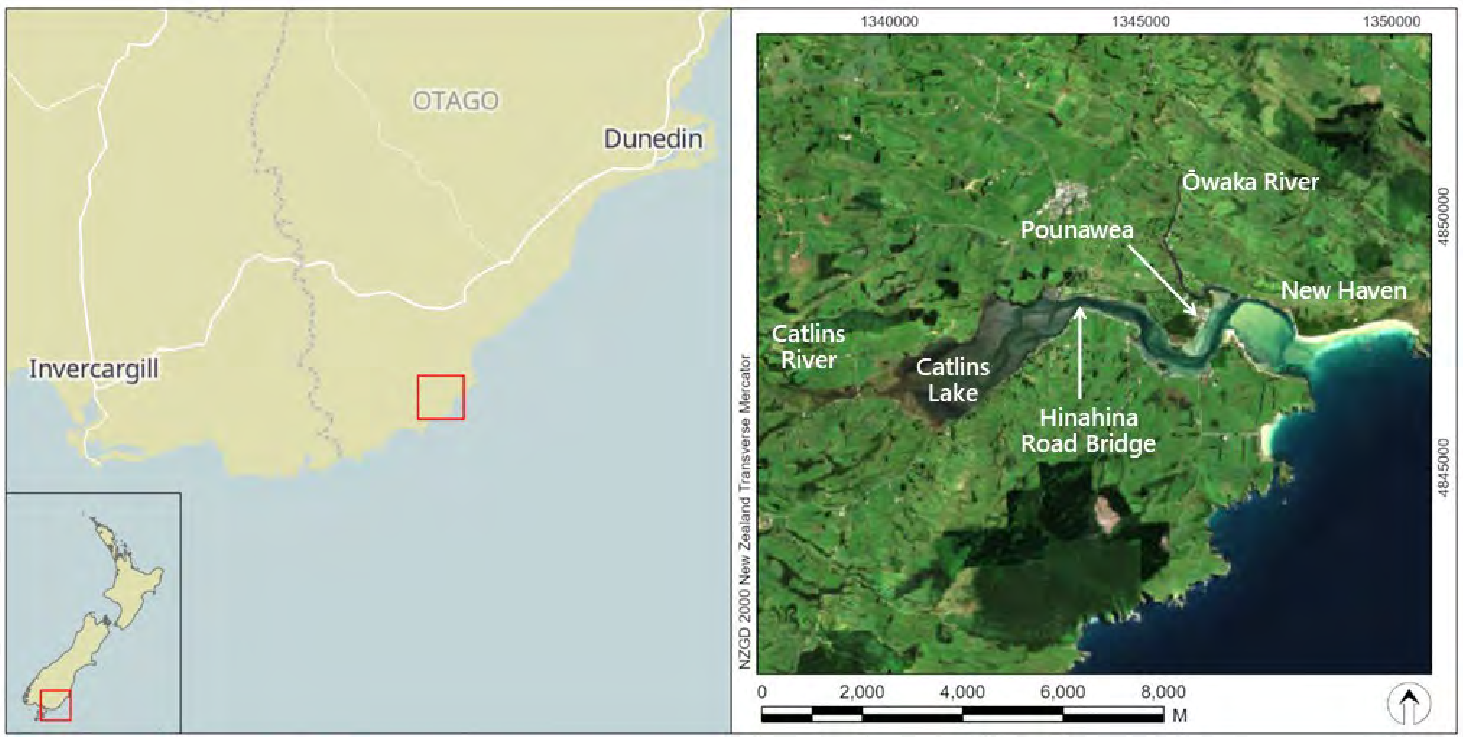


Fig. 1. Location of Catlins Estuary, Otago.

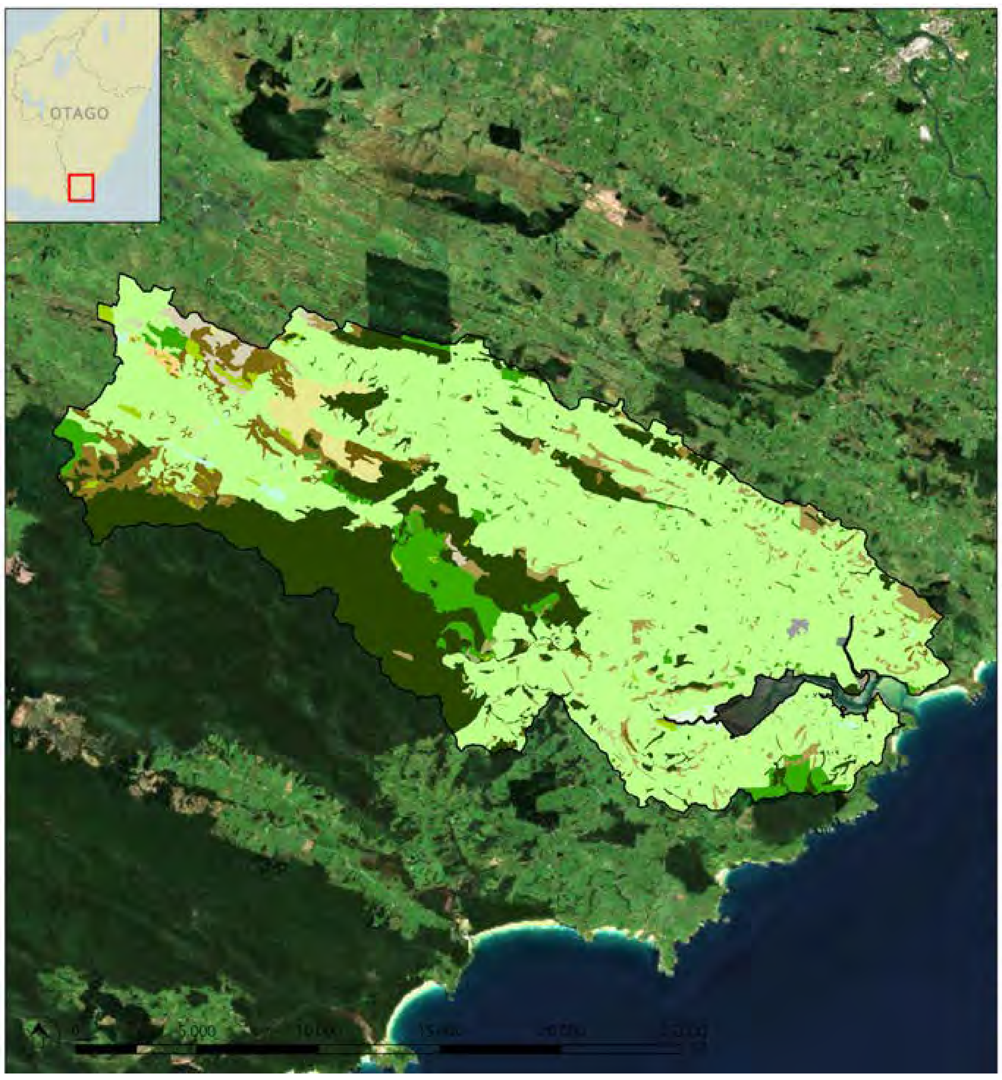
2. OVERVIEW OF CATLINS

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.

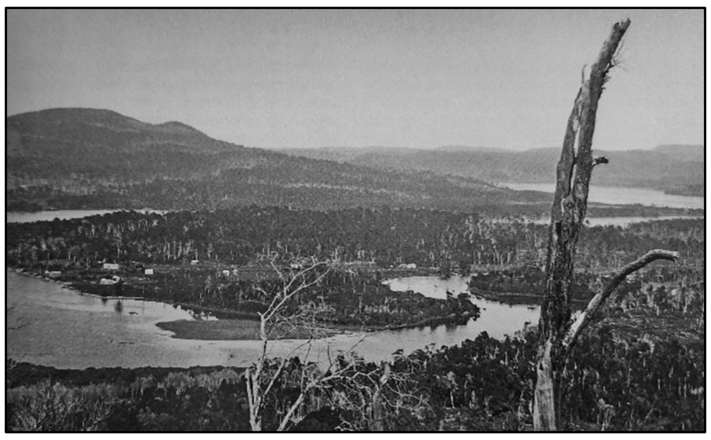


Photo taken in 1906 from Jacobs Hill looking over the town of Pounawea and Ōwaka River with Catlins Lake in the background. Dense native forest surrounds most of the estuary (source: Patrick Collection in Tyrrell 1989).

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

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).

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

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).

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

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.

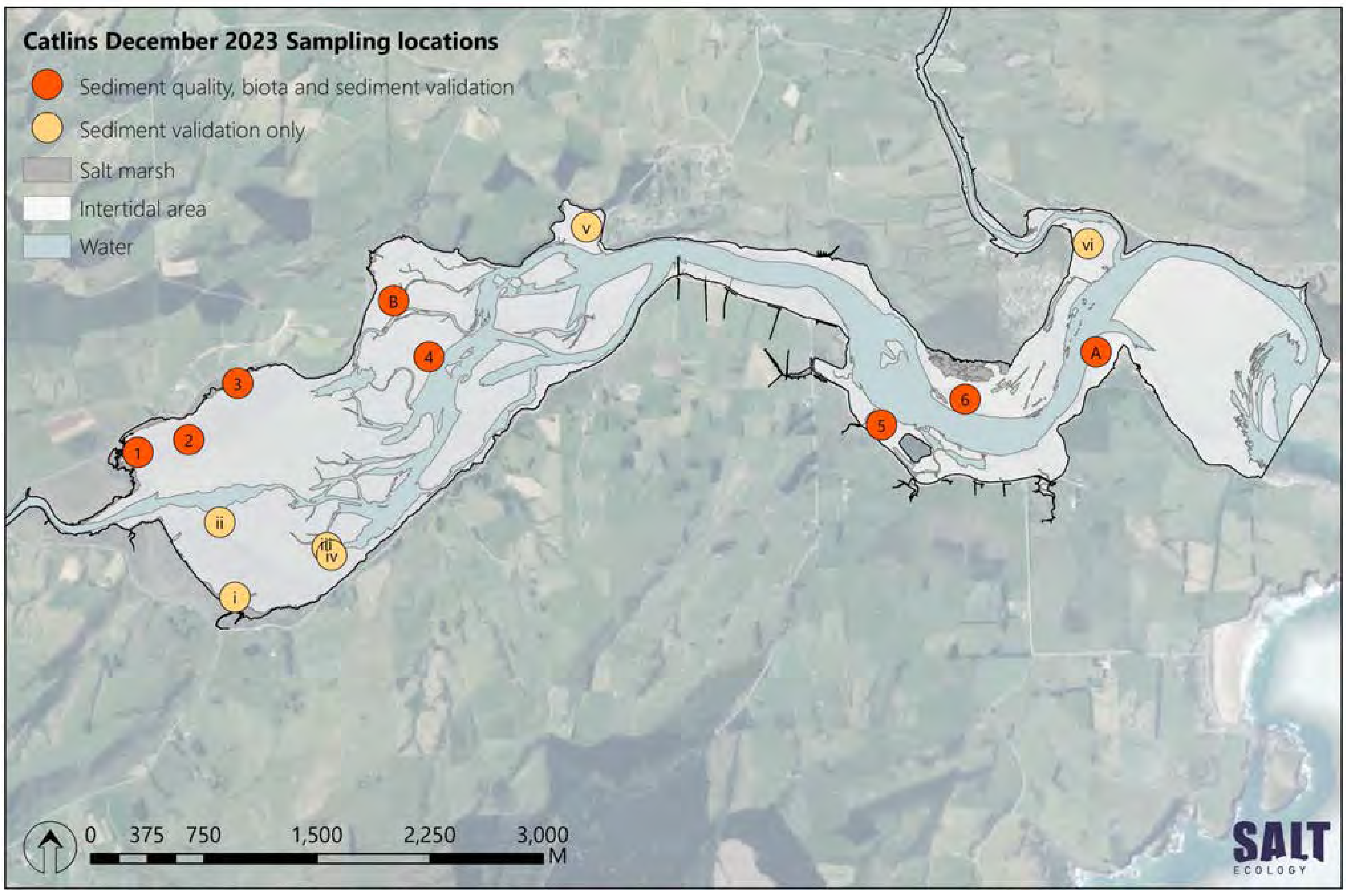


Fig. 3. Sediment quality, biota (Sites 1-6 & A-B) and sediment validation (Sites i-vi) samples, Catlins Estuary, December 2023.

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).

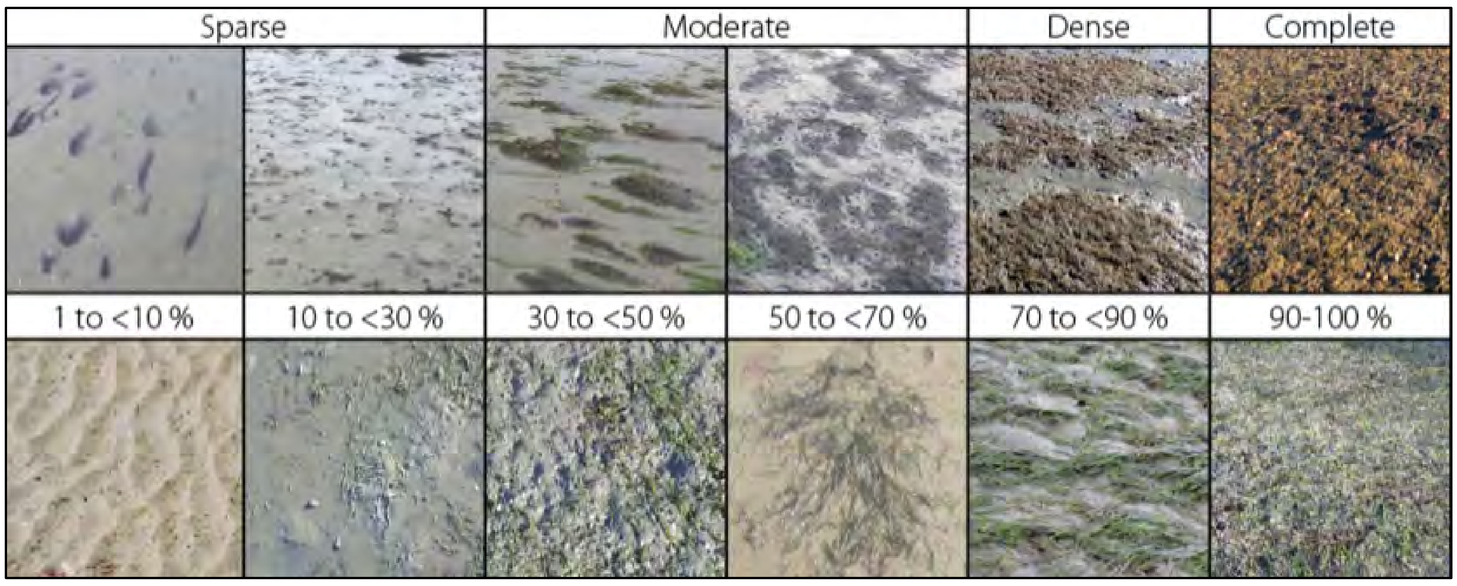


Fig. 4. Visual rating scale for % cover estimates of macroalgae and seagrass. Modified from FGDC (2012).

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.

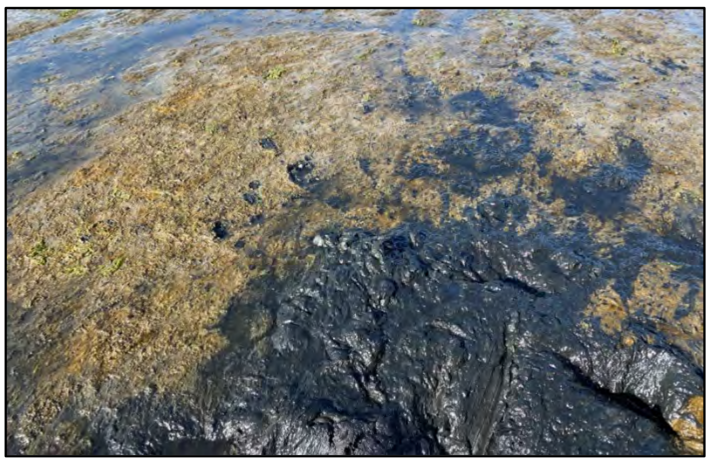
Biota: Macrofauna, which are small organisms that live within or on the sediment matrix and are retained on a 0.5mm sieve, were sampled quantitatively using sediment cores (130mm diameter, 150mm deep). The composition of the core samples in terms of macrofauna species (or higher taxa) and their abundance, 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.

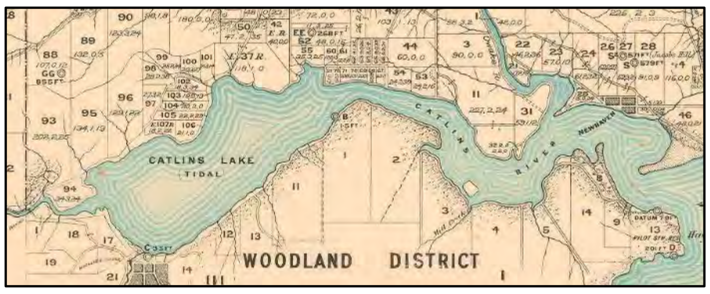
Catlins Lake, looking upstream, on the southern margin.

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.

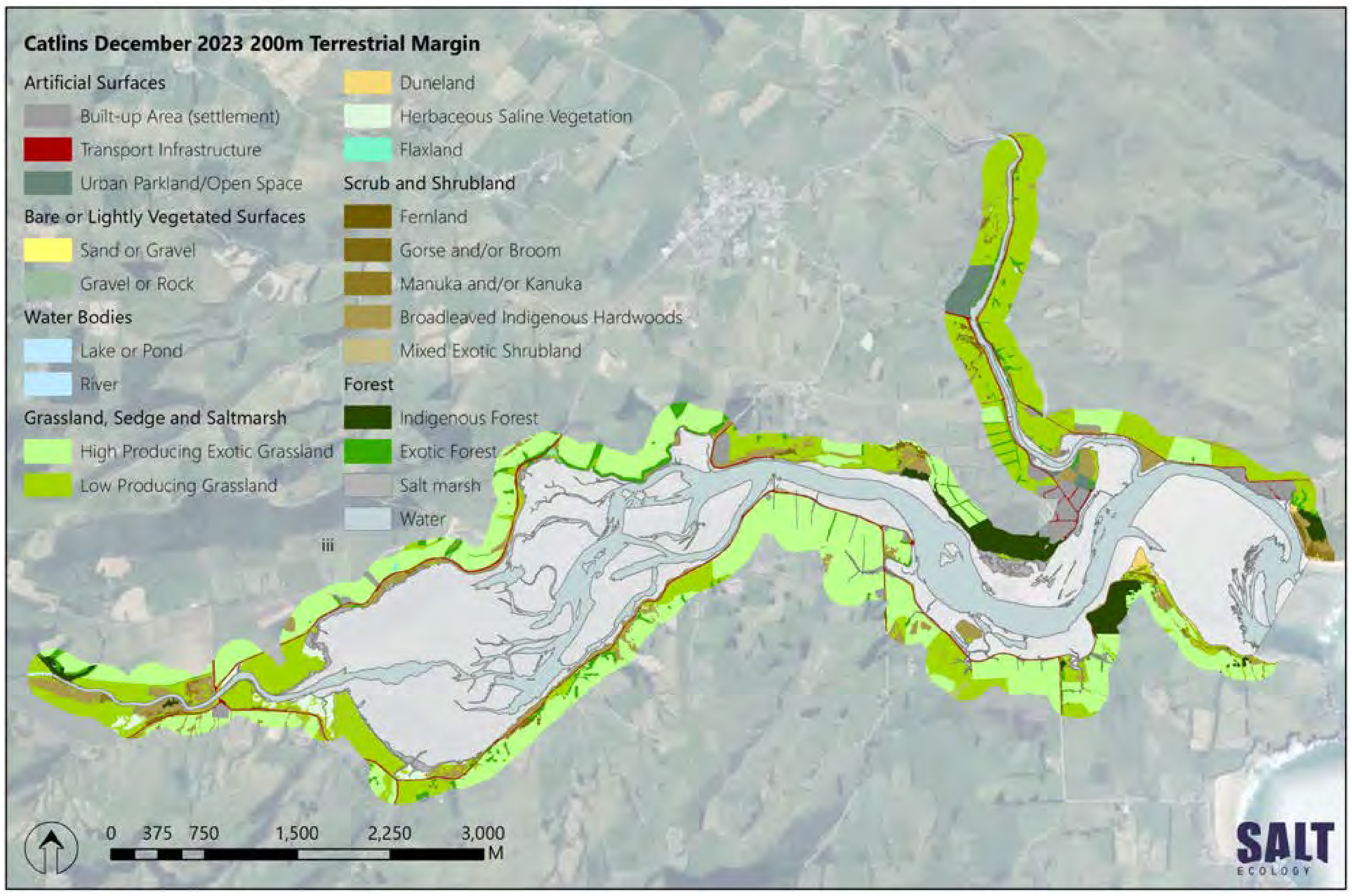


Fig. 5. Map of 200m terrestrial margin land cover, Catlins Estuary, December 2023.

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).

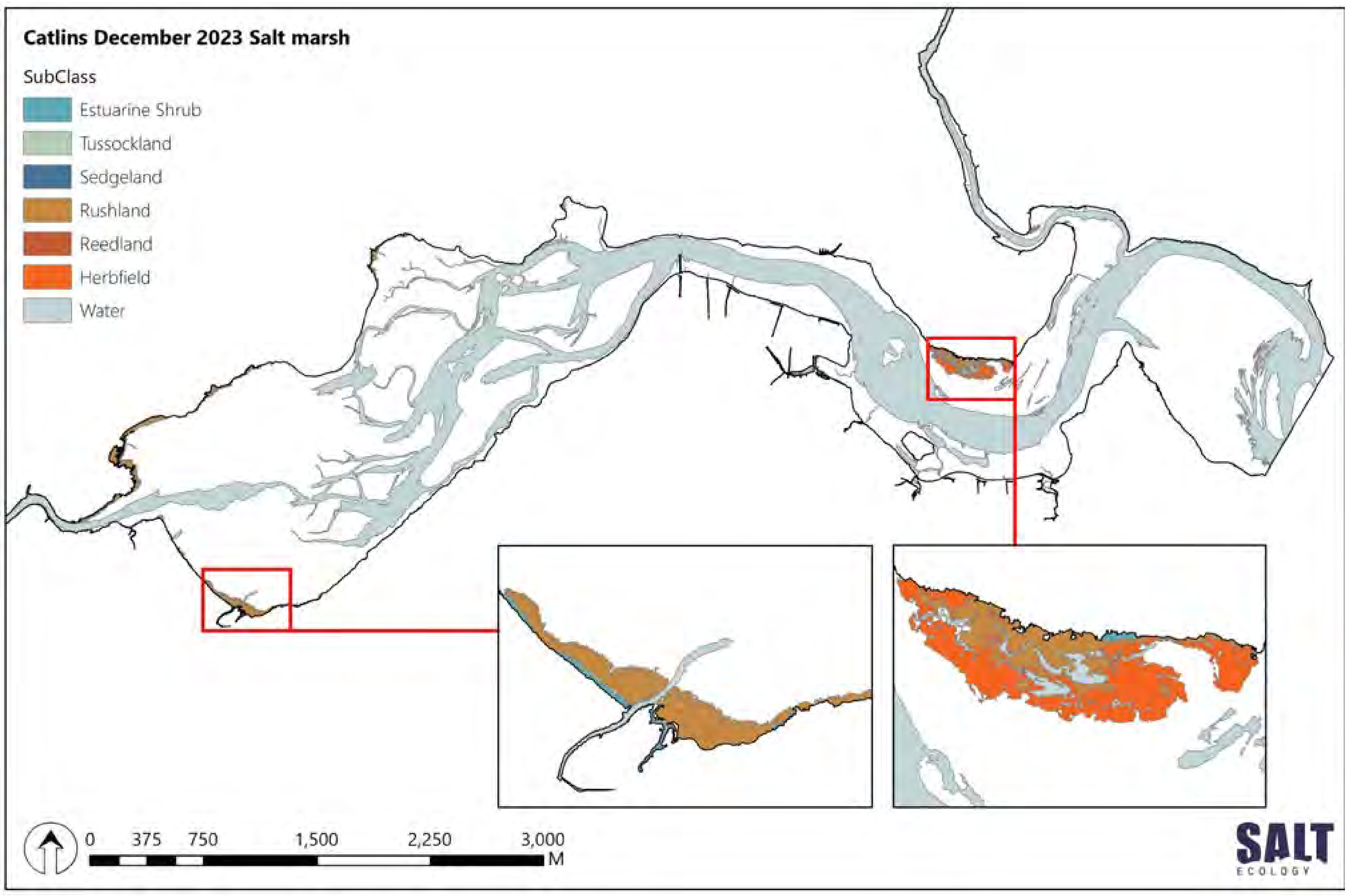


Fig. 6. Salt marsh sub-classes and their distribution, Catlins Estuary, December 2023.

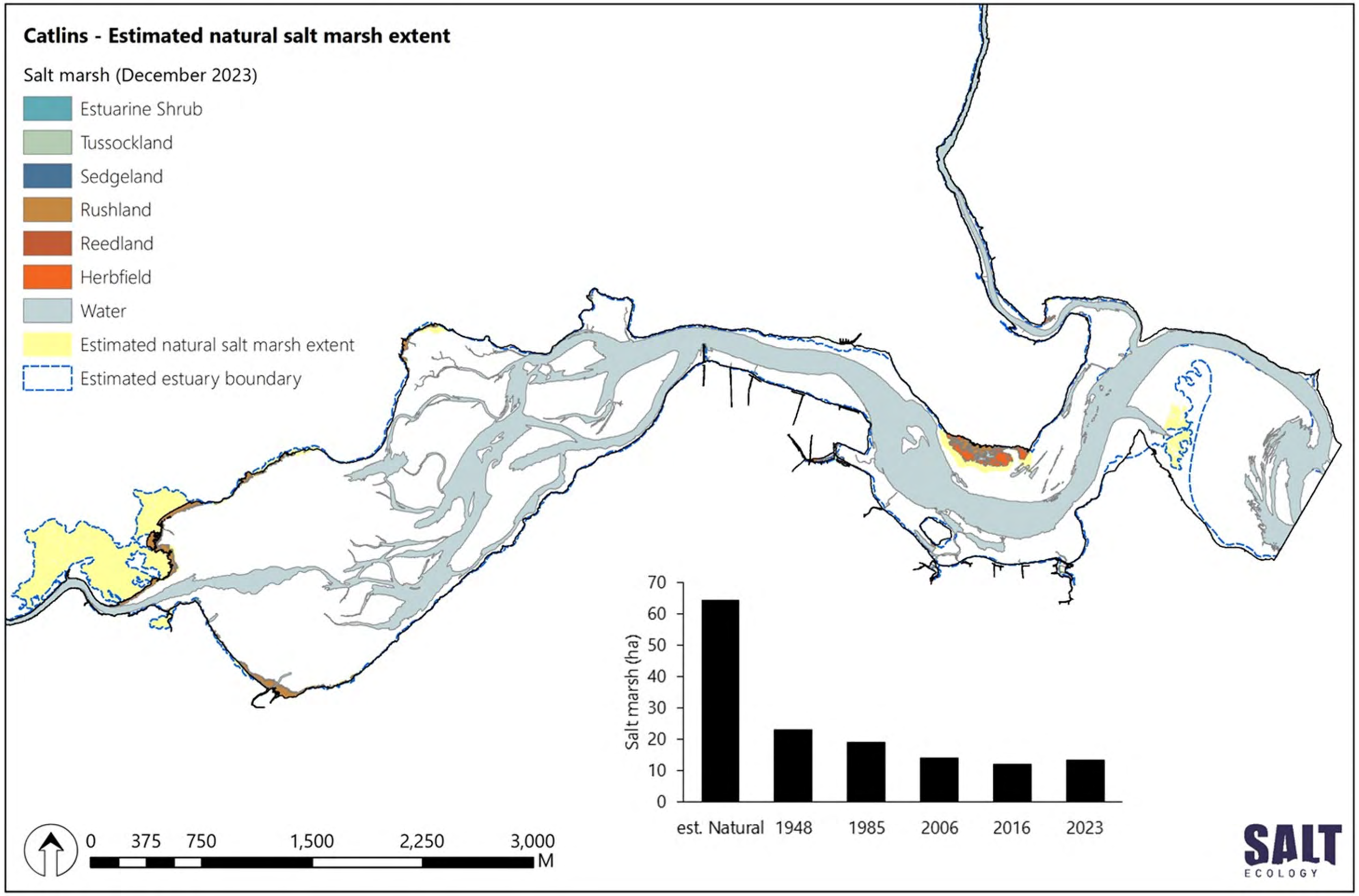


Fig. 7. The historic salt marsh extent (yellow) and historic estuary boundary (dashed line) overlaid with the current mapped salt marsh extent.

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.

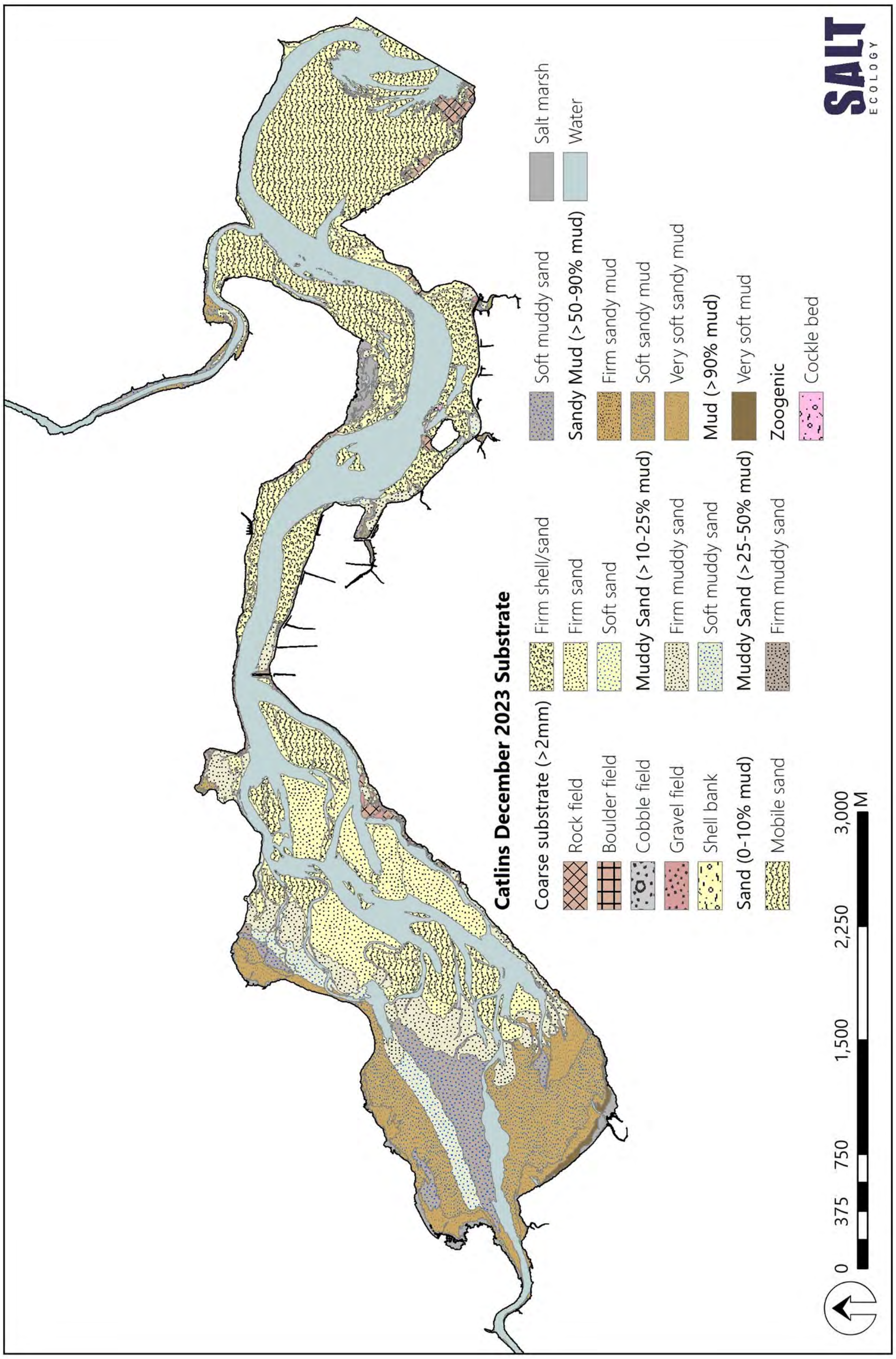


Fig. 8. Dominant intertidal substrate in the AIH (excluding salt marsh), Catlins Estuary, December 2023.

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.

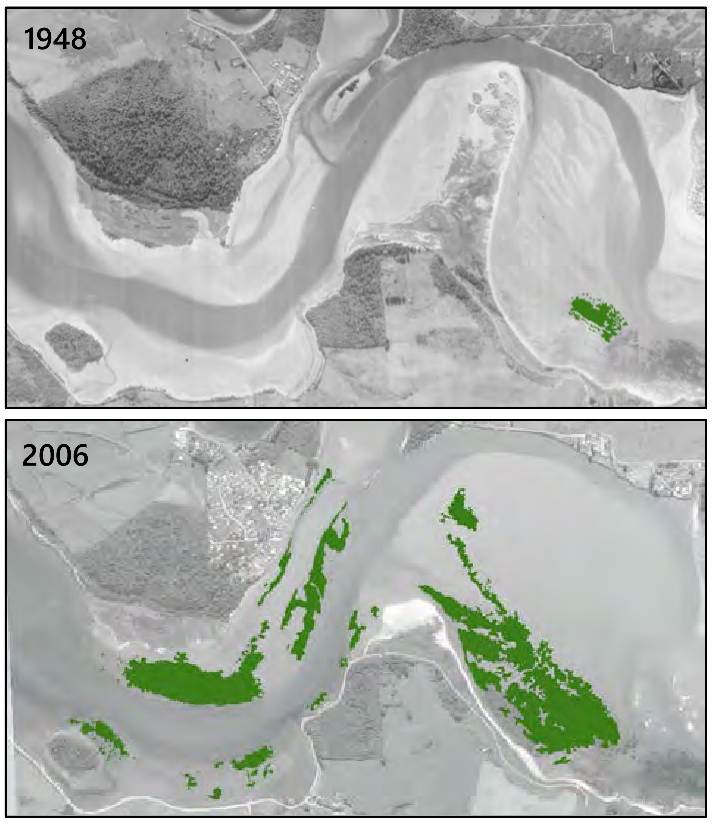
Leaf discolouration and macroalgae smothering, near Pounawea (top). Seagrass growing in mobile sands at the entrance (bottom).

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.

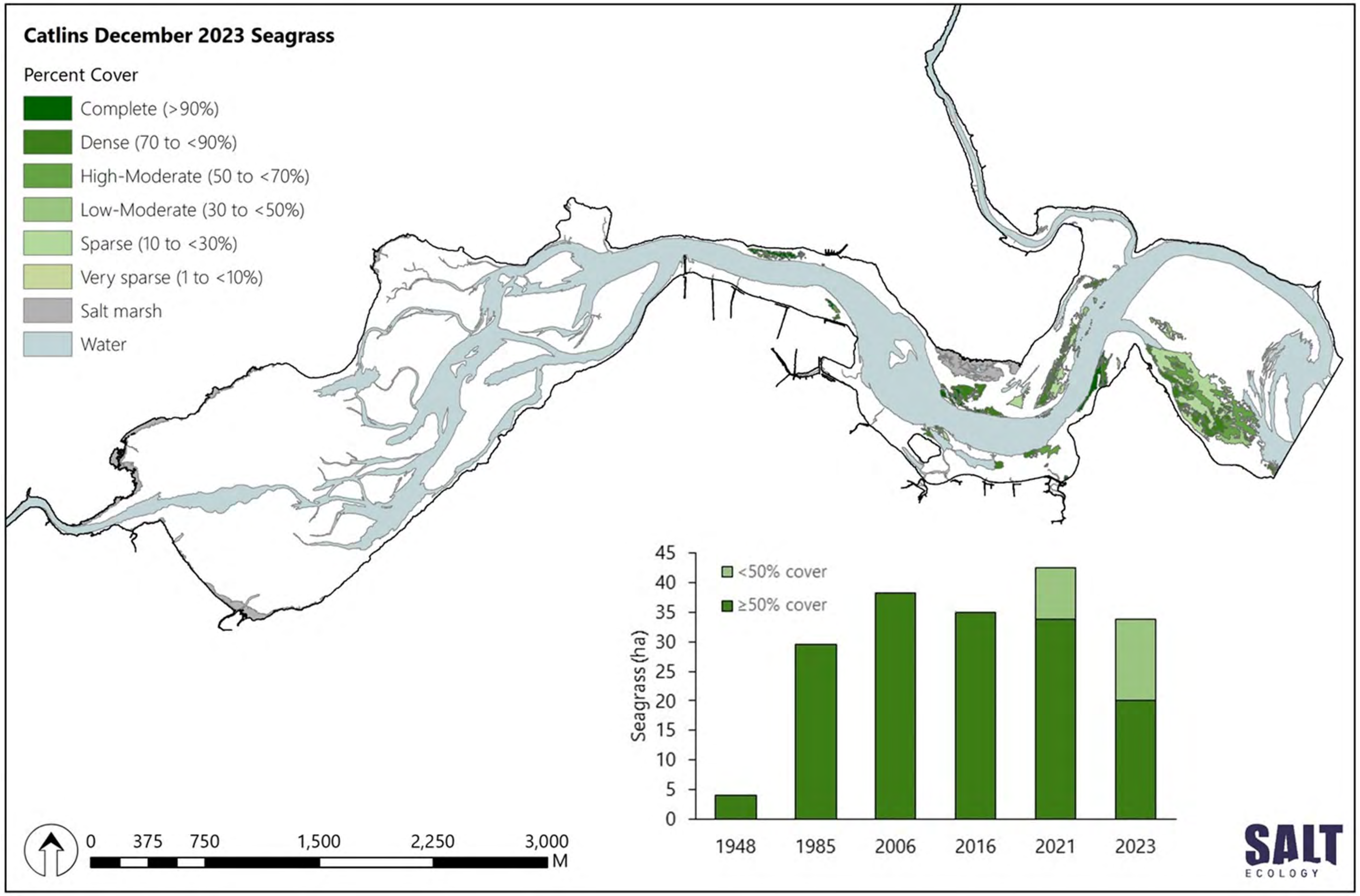


Fig. 9. Distribution and percent cover classes of seagrass, Catlins Estuary, December 2023. Inset graph represents estimated seagrass cover from historic imagery in 1948, 1985 and 2006 and ground-truthed seagrass mapped seagrass in 2016 and 2021.

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/m²)	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).

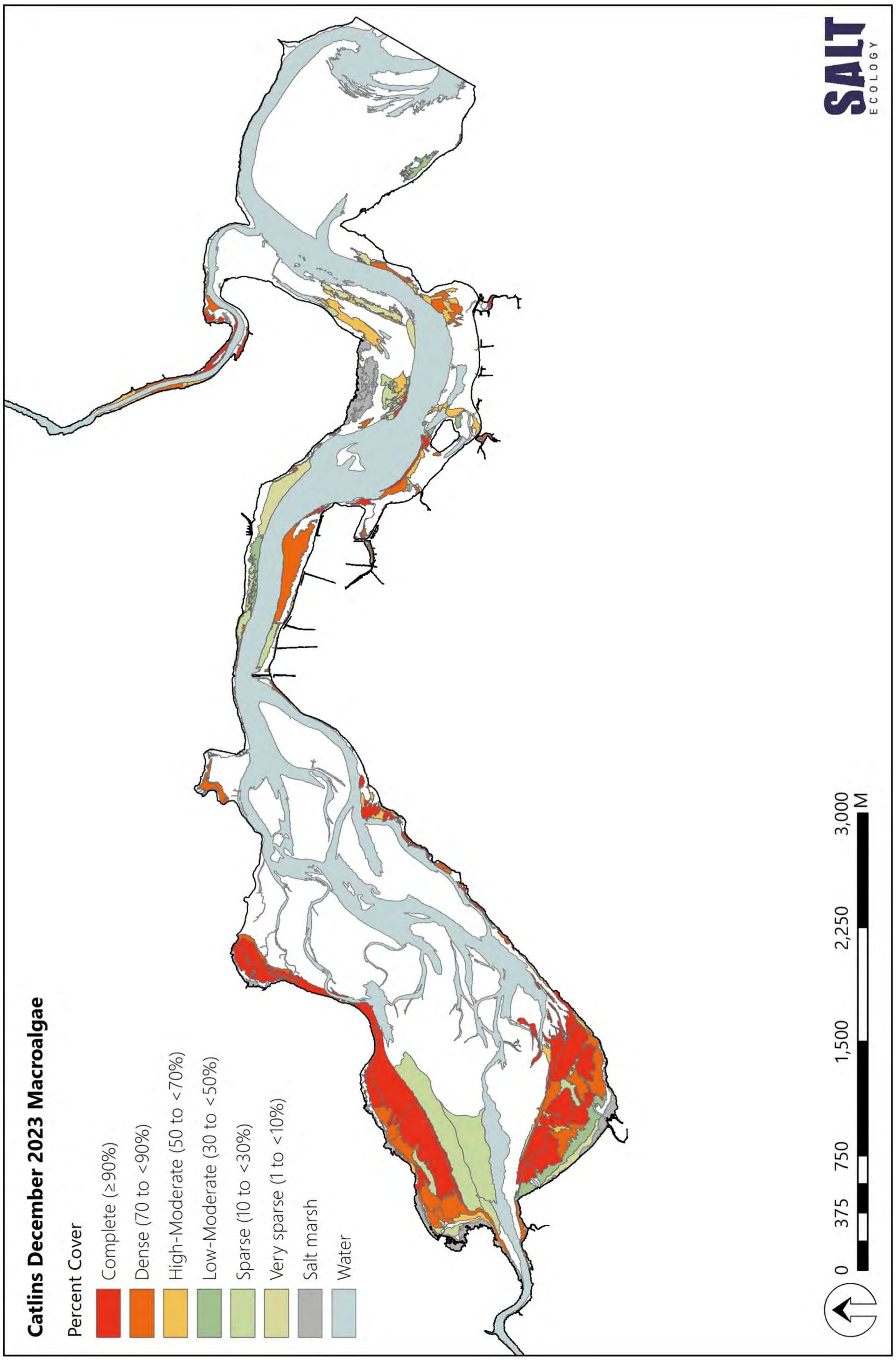


Fig. 10. Distribution and percent cover classes of macroalgae, Catlins Estuary, December 2023.

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.

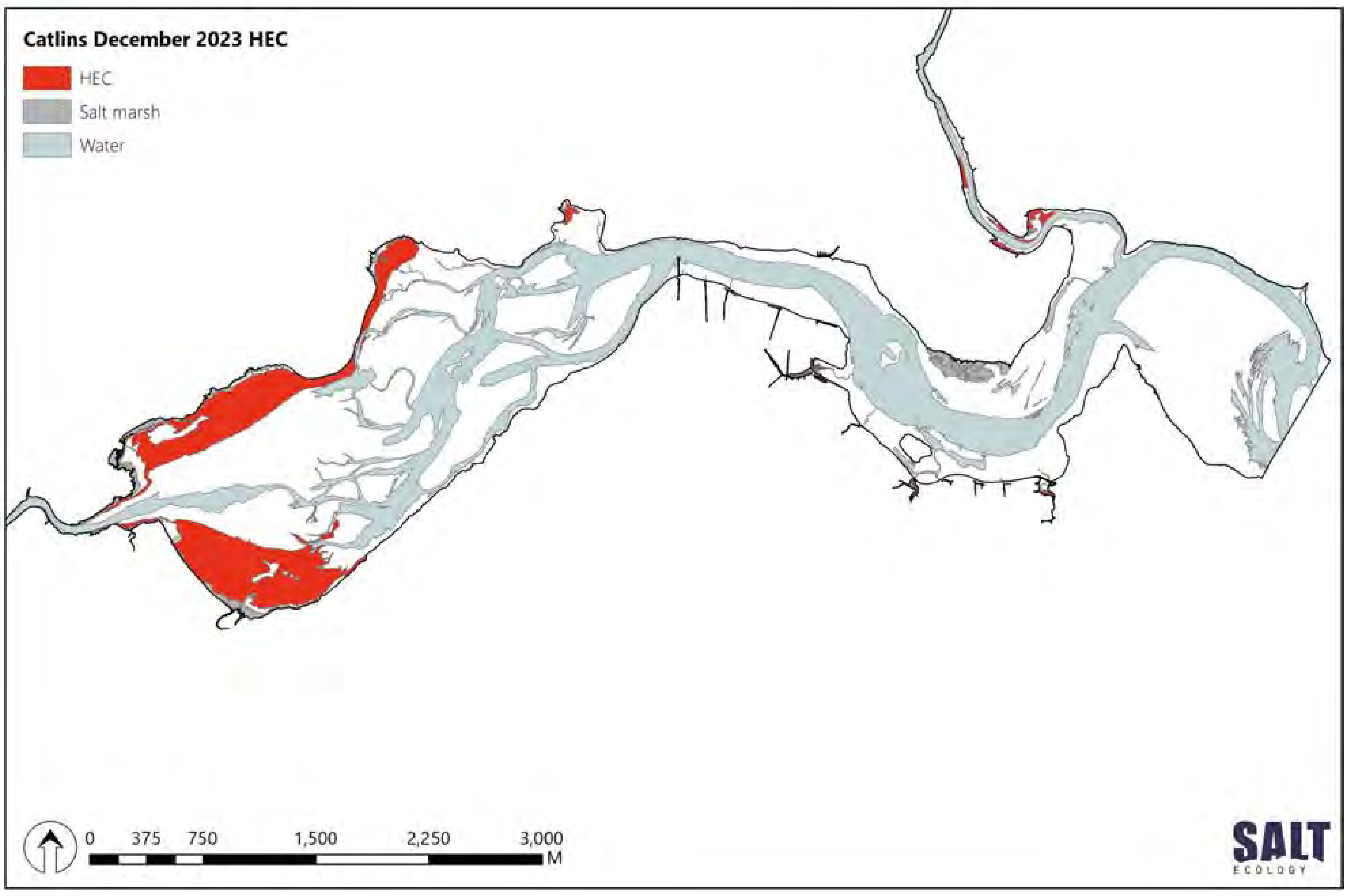


Fig. 11. Areas of High Enrichment Conditions (HEC), Catlins Estuary, December 2023.

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.

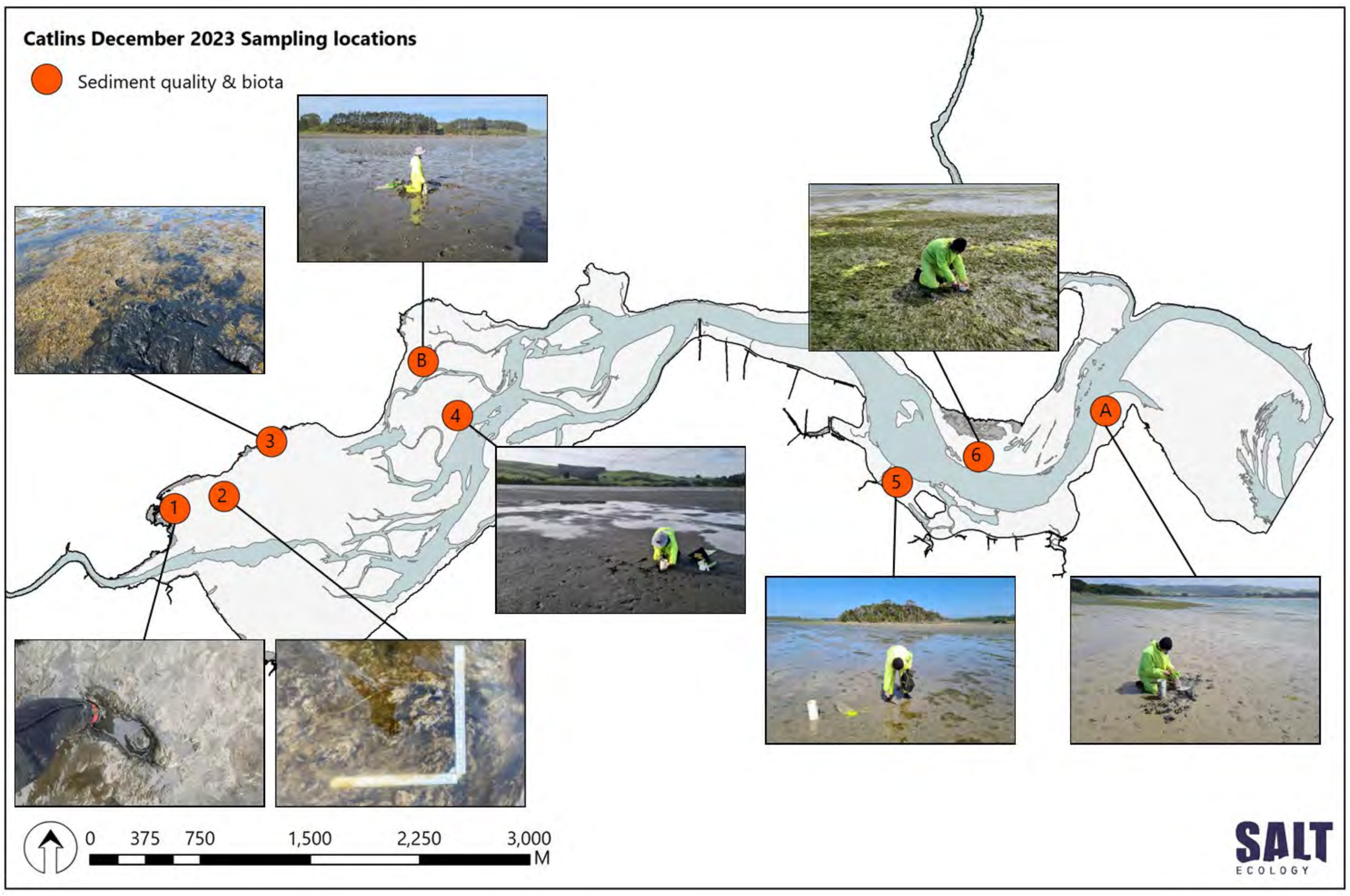


Fig. 12. Sediment quality and biota locations including site photos, Catlins Estuary, December 2023. Sites A and B are locations where intensive fine-scale monitoring has been previously undertaken (Morrisey & Forrest 2023).

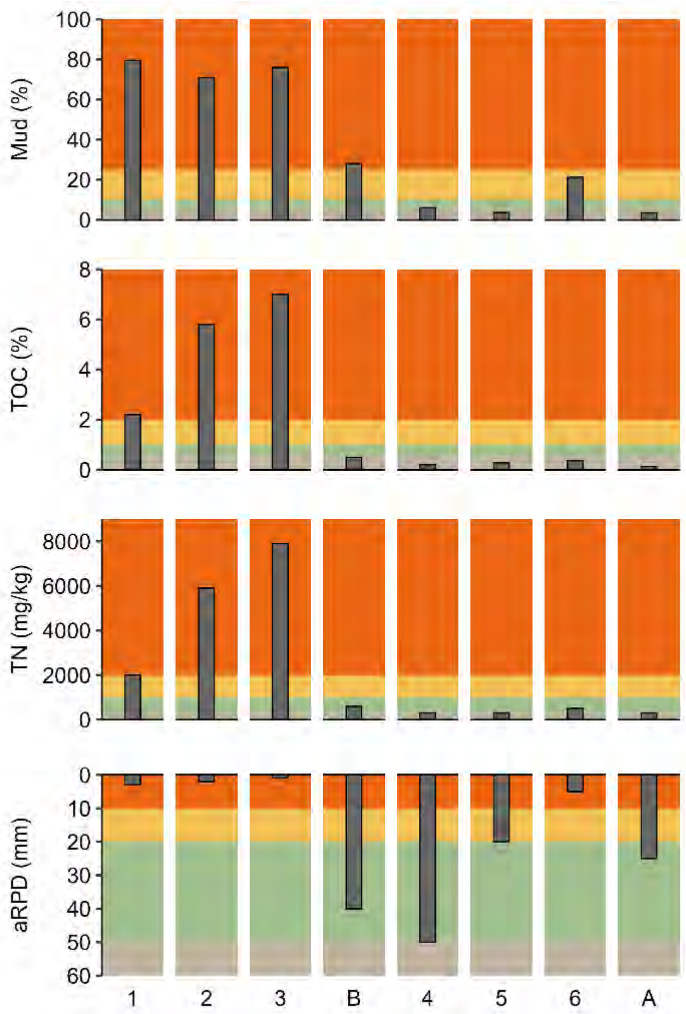


Fig. 13. Sediment %mud, total organic carbon (TOC), total nitrogen (TN) and aRPD at sediment quality and biota sites, relative to condition ratings.

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).

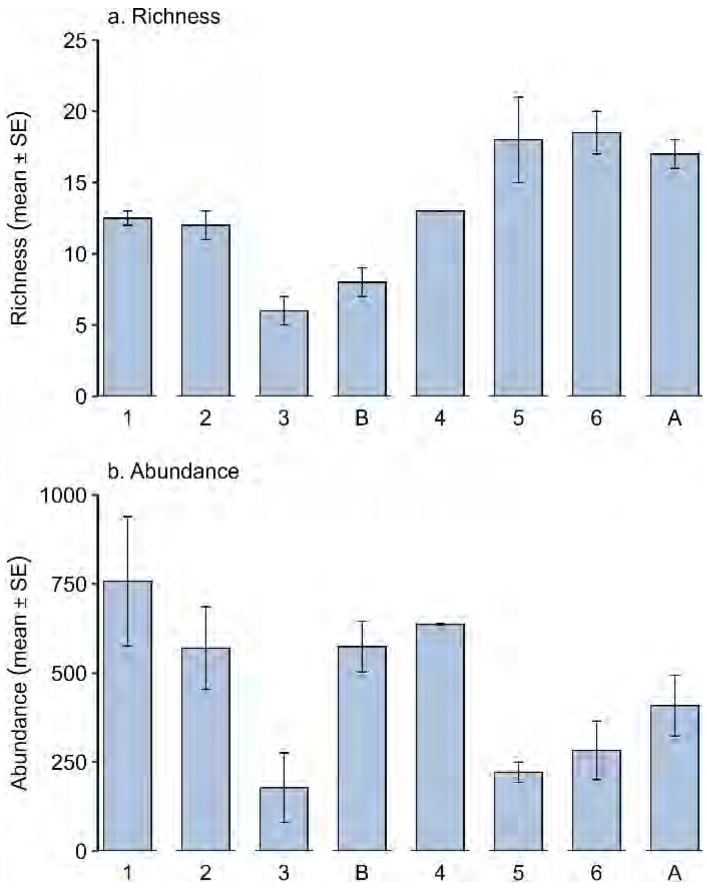


Fig. 14. Mean (±SE) taxon richness and abundance in duplicate core samples.

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.

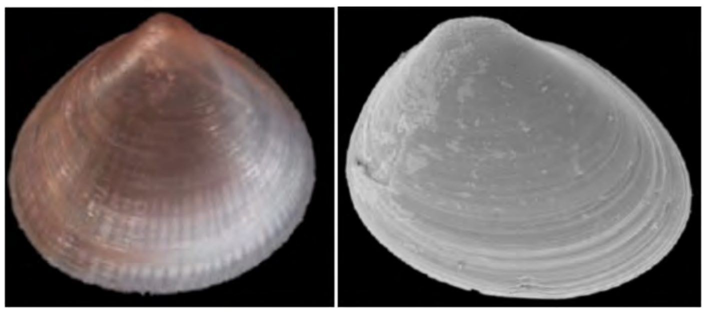
At the mid and upper estuary sites, most species were in eco-groups (EG) III-V, representing a relatively hardy suite of species, resulting in elevated AMBI scores (Fig. 15) that suggest 'Fair' to 'Poor' ecological conditions. The exception was Site 2, which was rated 'Good' and is discussed further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

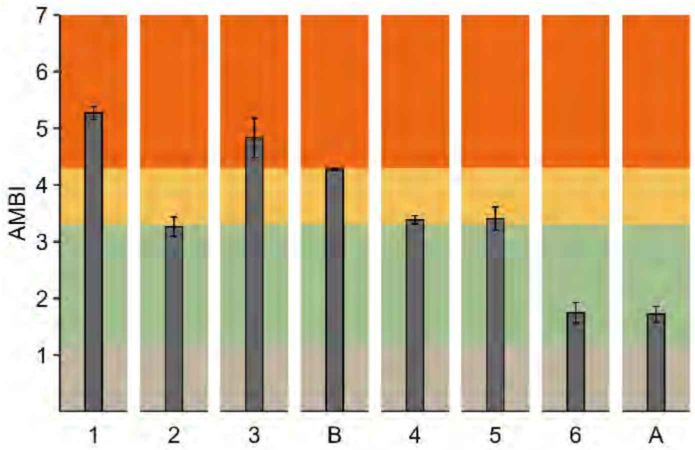


Fig. 15. Mean (±SE) macrofauna AMBI scores (in duplicate cores at Sites 1 to 6 & A to B) relative to condition ratings. Sites ordered from upper to lower estuary.

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 $\rho=0.598$ for %mud alone, $\rho=0.692$ 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.

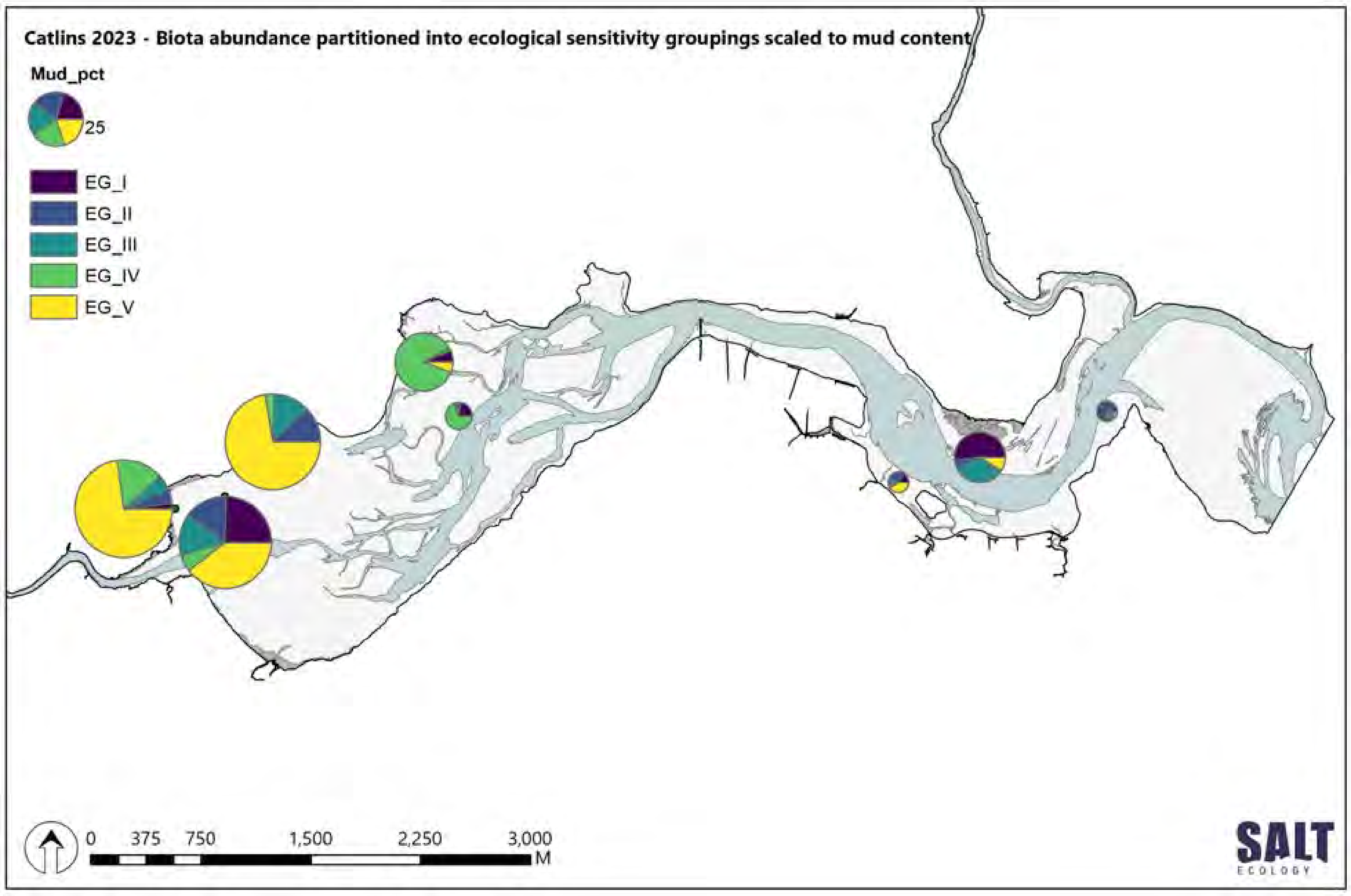


Fig. 16. Biota abundance partitioned into Ecological sensitivity Groupings (EGs), Catlins Estuary, December 2023. Circles are scaled to sediment mud content, the variable most strongly correlated with community composition. EGs range from relatively sensitive (EG-I) to relatively resilient (EG-V).

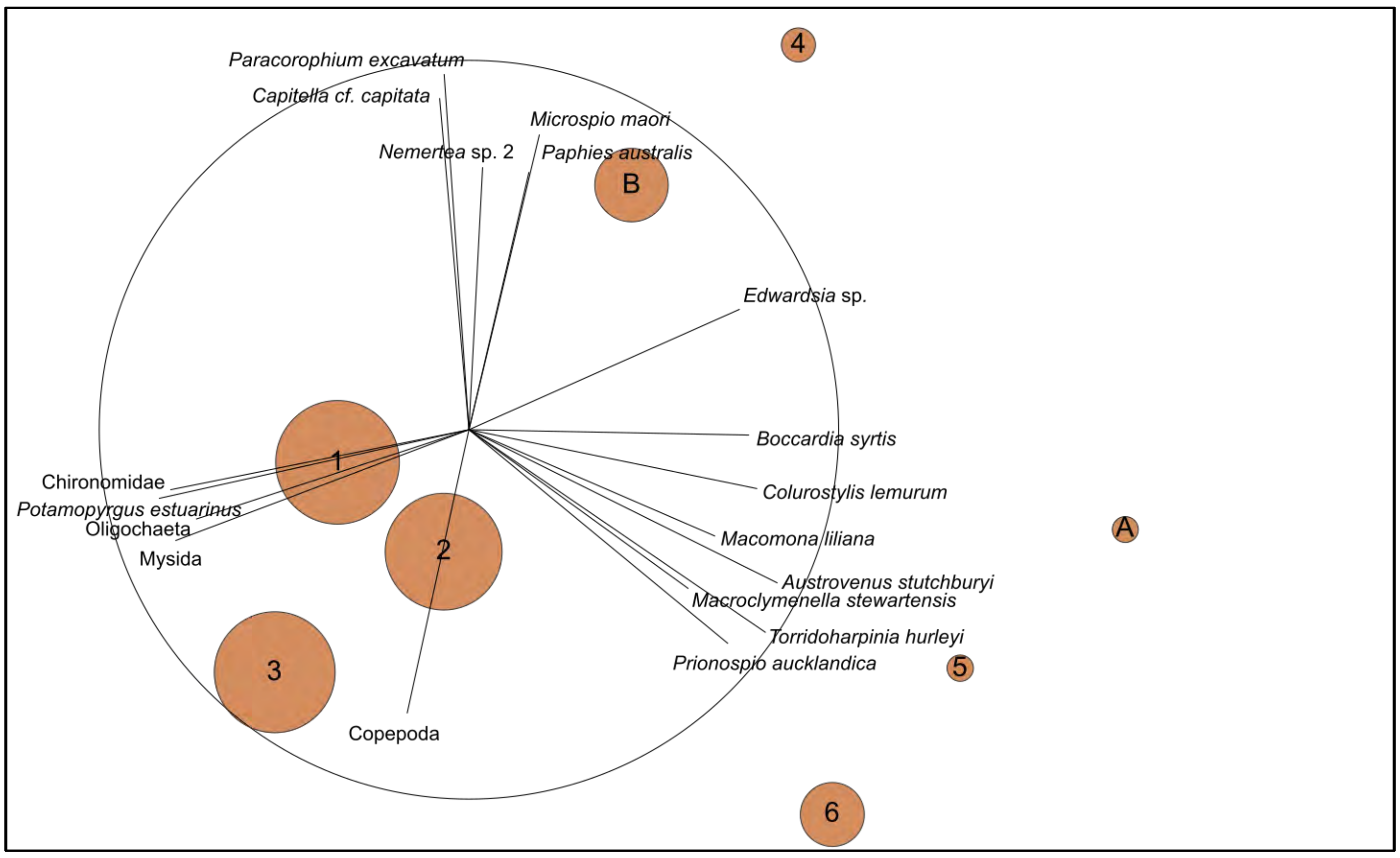


Fig. 17. Non-metric MDS ordination of macrofaunal core samples from each site.

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.

		Site							
Fine Scale Indicators	Unit	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

<u>Sediment firmness:</u> Subjectively classified as firm if you sink 0-<2cm, soft if you sink 2-5cm, or very soft if you sink >5cm.
<u>Mobile:</u> Sediment is firm but routinely moved by tidal currents or waves. Commonly characterised by having a rippled surface layer.
<u>Sand:</u> Sandy sediment that is granular when rubbed between the fingers and releases no conspicuous fines when sediment is disturbed.
<u>Shell/Sand:</u> Mixed sand and shell hash. See muddy sand sub-classes below for field guidance on estimating mud content.
<u>Muddy Sand:</u> 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. <u>Moderate mud (≥10-25%) content:</u> Muddy fines evident when sediment is disturbed. Sediments generally firm to walk on.
ii. <u>High mud (≥25-50%) content):</u> Muddy fines conspicuous when sediment is disturbed. Sediments generally soft to walk on.

<u>Sandy Mud (≥50-90% mud content):</u> 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.
<u>Mud (≥90% mud content):</u> 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:

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

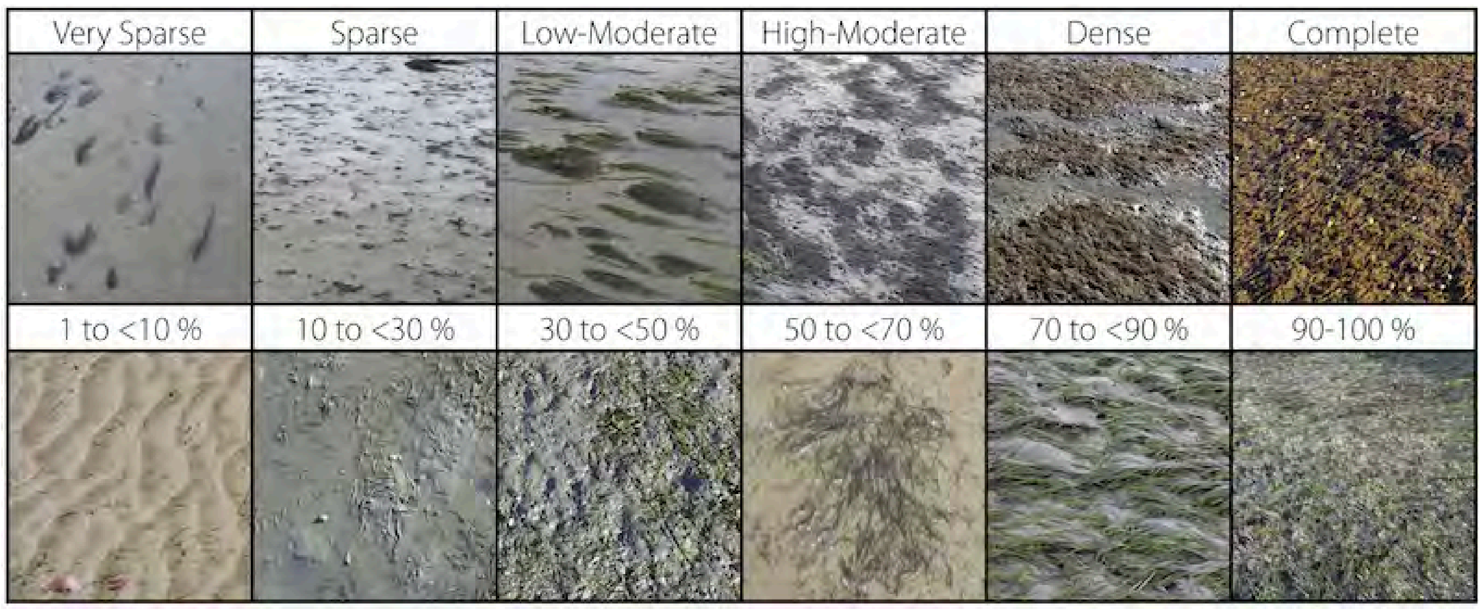


Fig. A1. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

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.

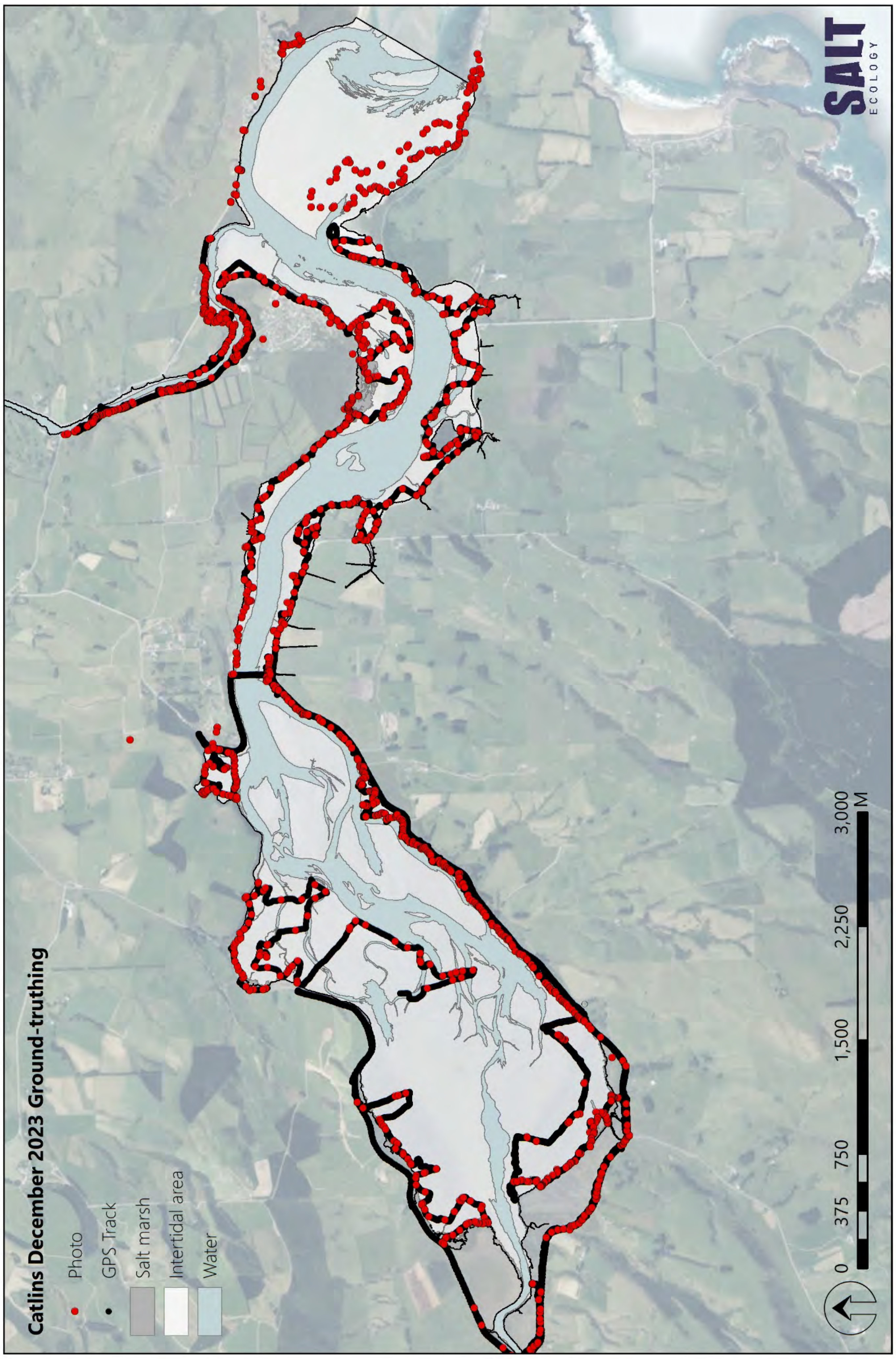
Stevens LM, Robertson BM 2014. Havelock Estuary 2014: Broad scale habitat mapping. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

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
	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
Coarse substrate (>2mm)	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
	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
Sand (0-10% mud)	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

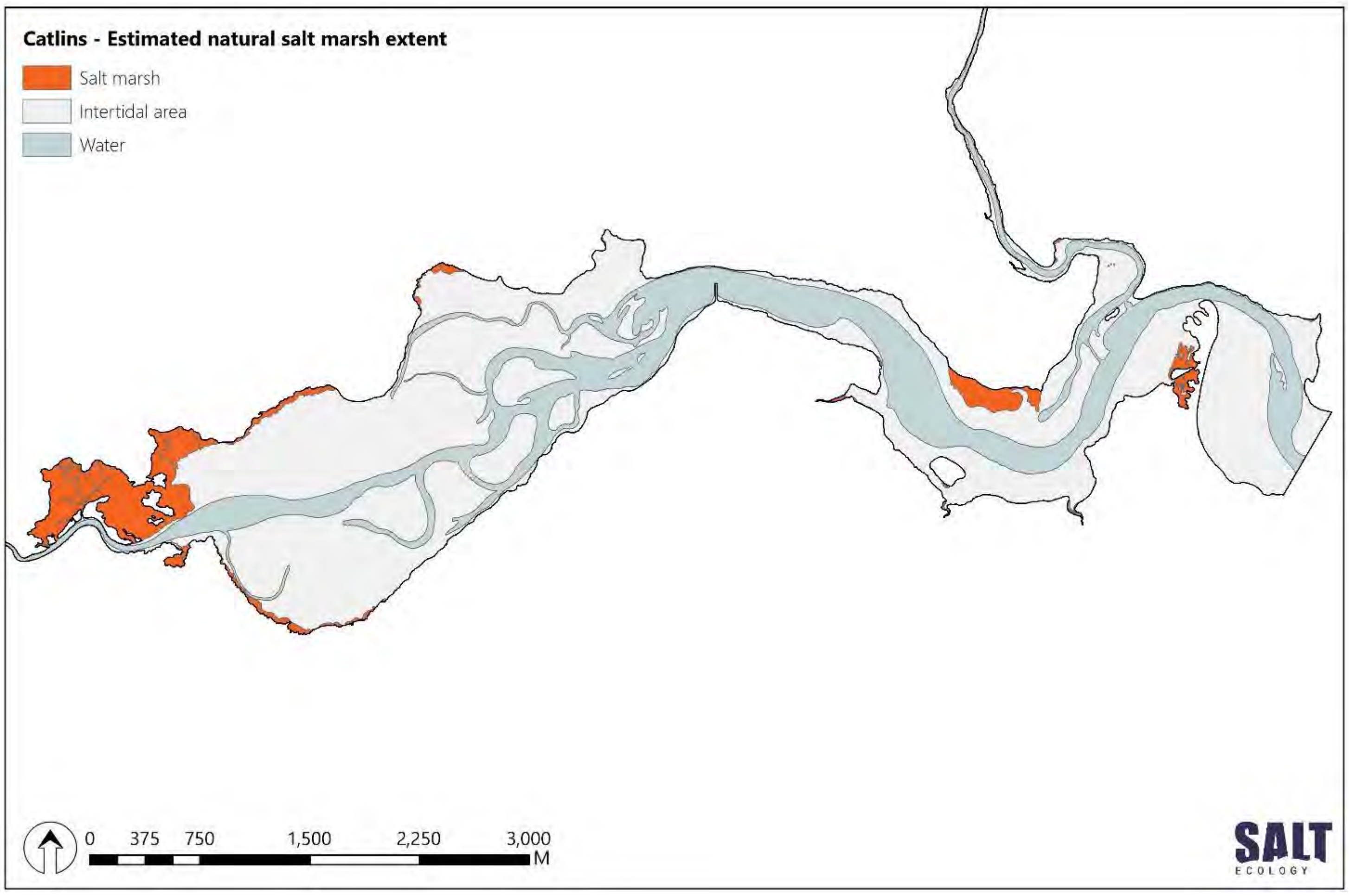
To estimate historic seagrass extent, we assessed current mapped layers and historic aerial imagery captured in 1948, 1985 (source: retrolens.co.nz), and 2006 (data.linz.govt.nz). Where required, imagery was merged and georectified to digitise the seagrass area and inform historic extent. Historic seagrass 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).

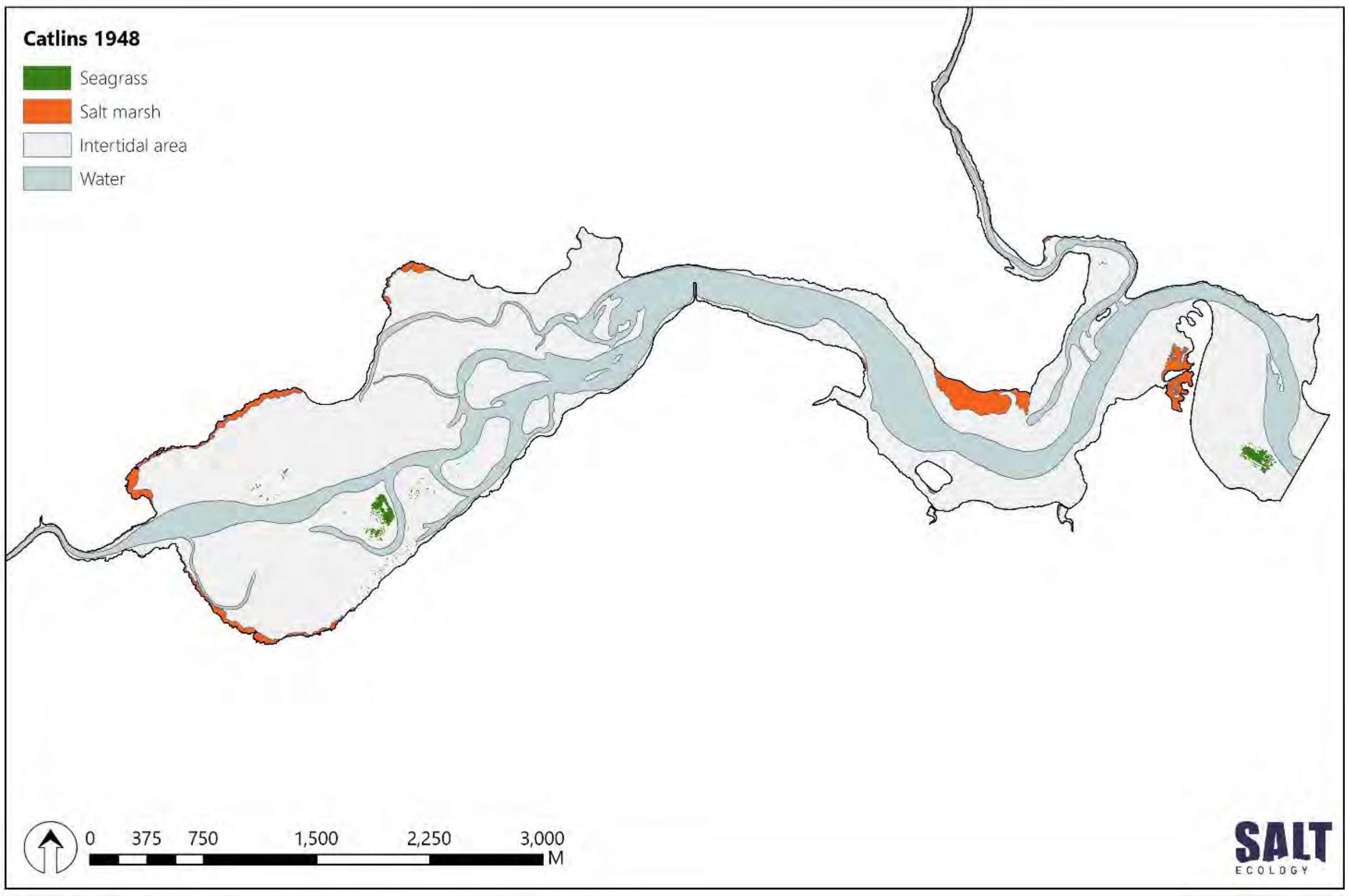
Year	Estuary (ha)	Intertidal (ha)	Subtidal (ha)	AIH* (ha)	Seagrass (ha) (>1-100% cover)	Seagrass (ha) (≥50% cover)	% AIH (≥50% cover)
1948	798.7	561.4	237.4	538.3	4.0	4.0	0.7
1985	816.7	581.9	234.8	562.8	29.6	29.6	5.3
2006	825.3	613.0	212.2	599.2	38.3	38.3	6.4
2016	829.1	636.4	192.6	624.3	35.0	35.0	5.6
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

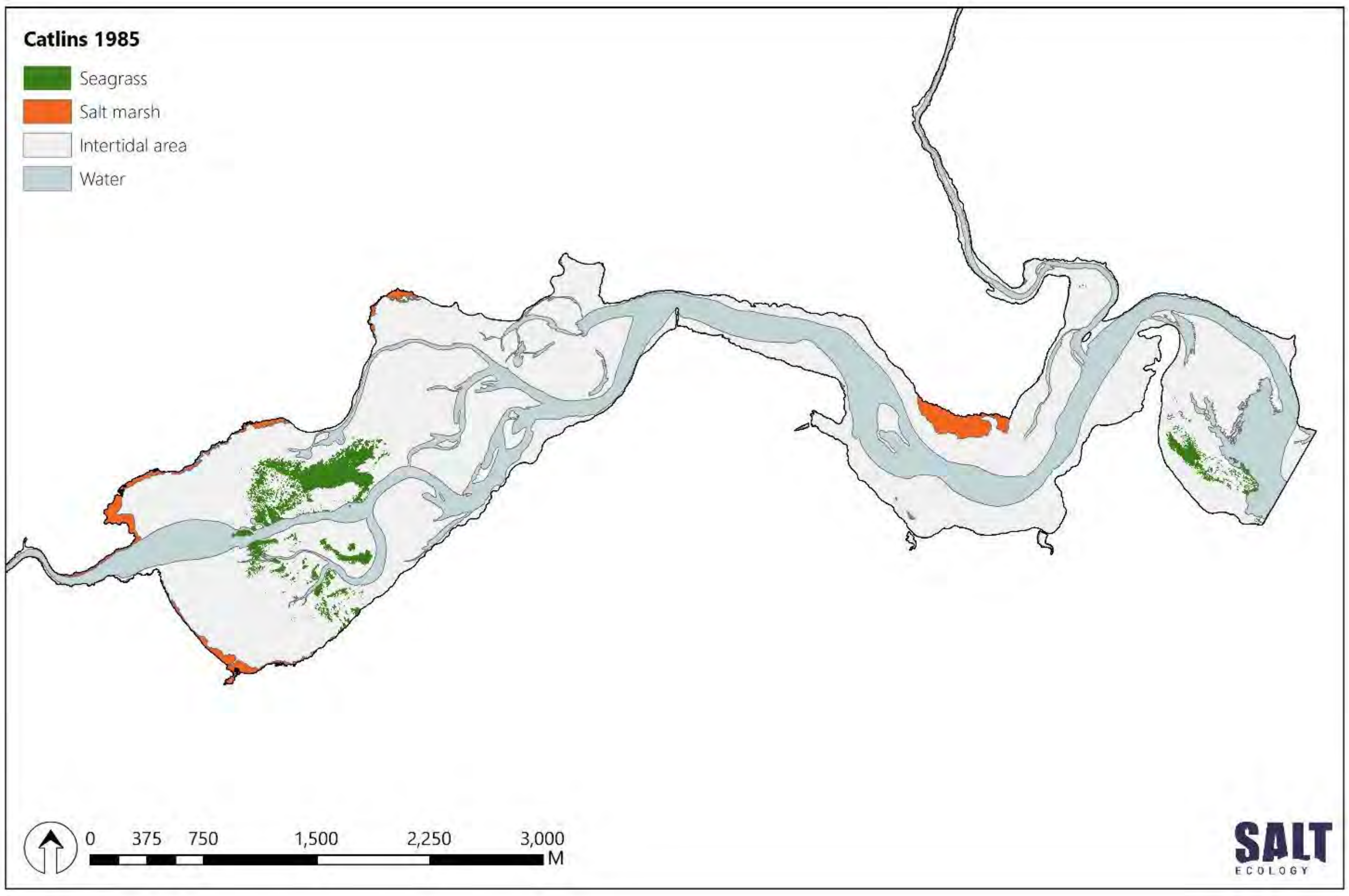
Estimated natural salt marsh extent. *Note natural seagrass extent could not be determined.*



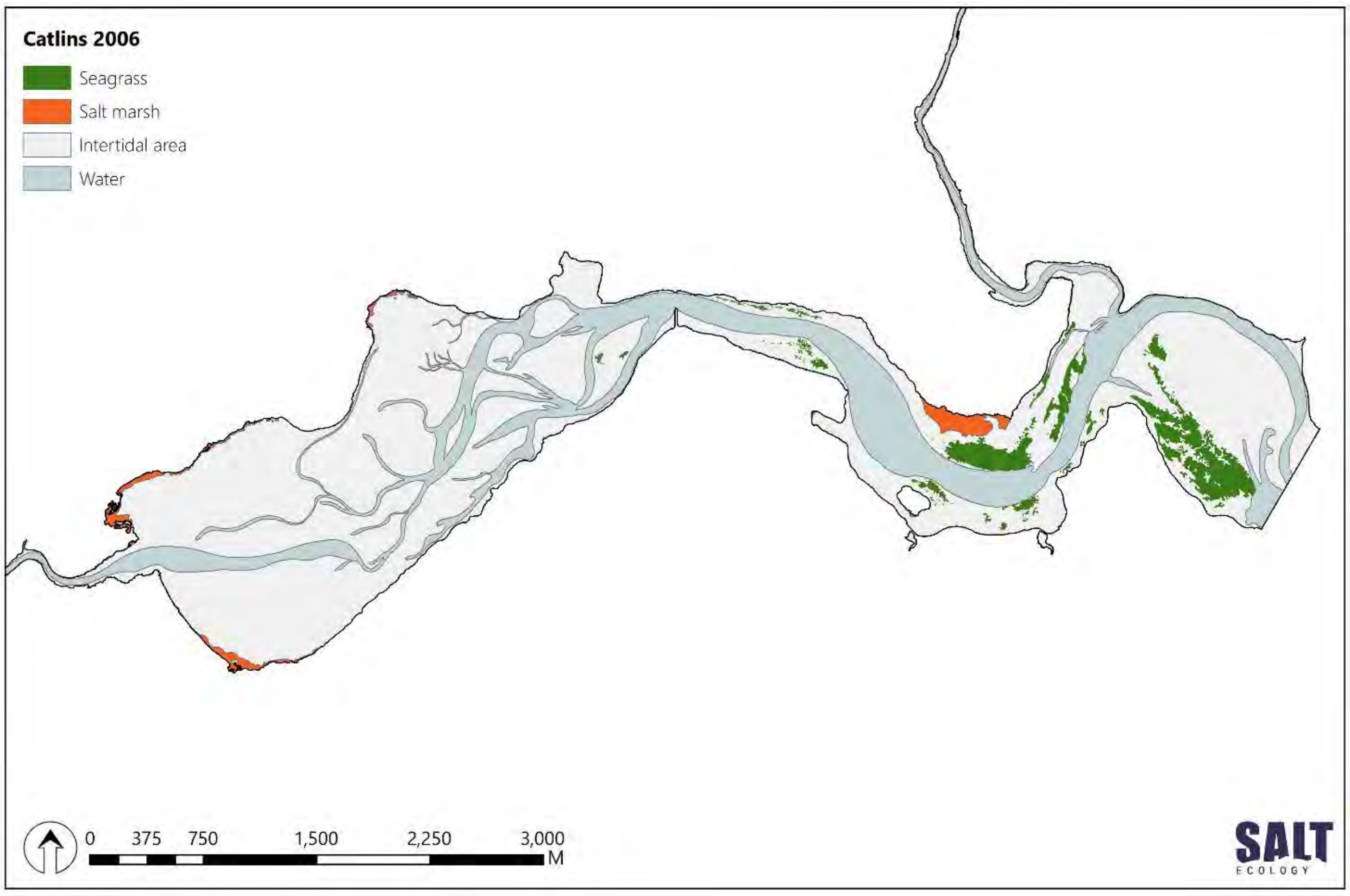
Salt marsh and seagrass extent in 1948.



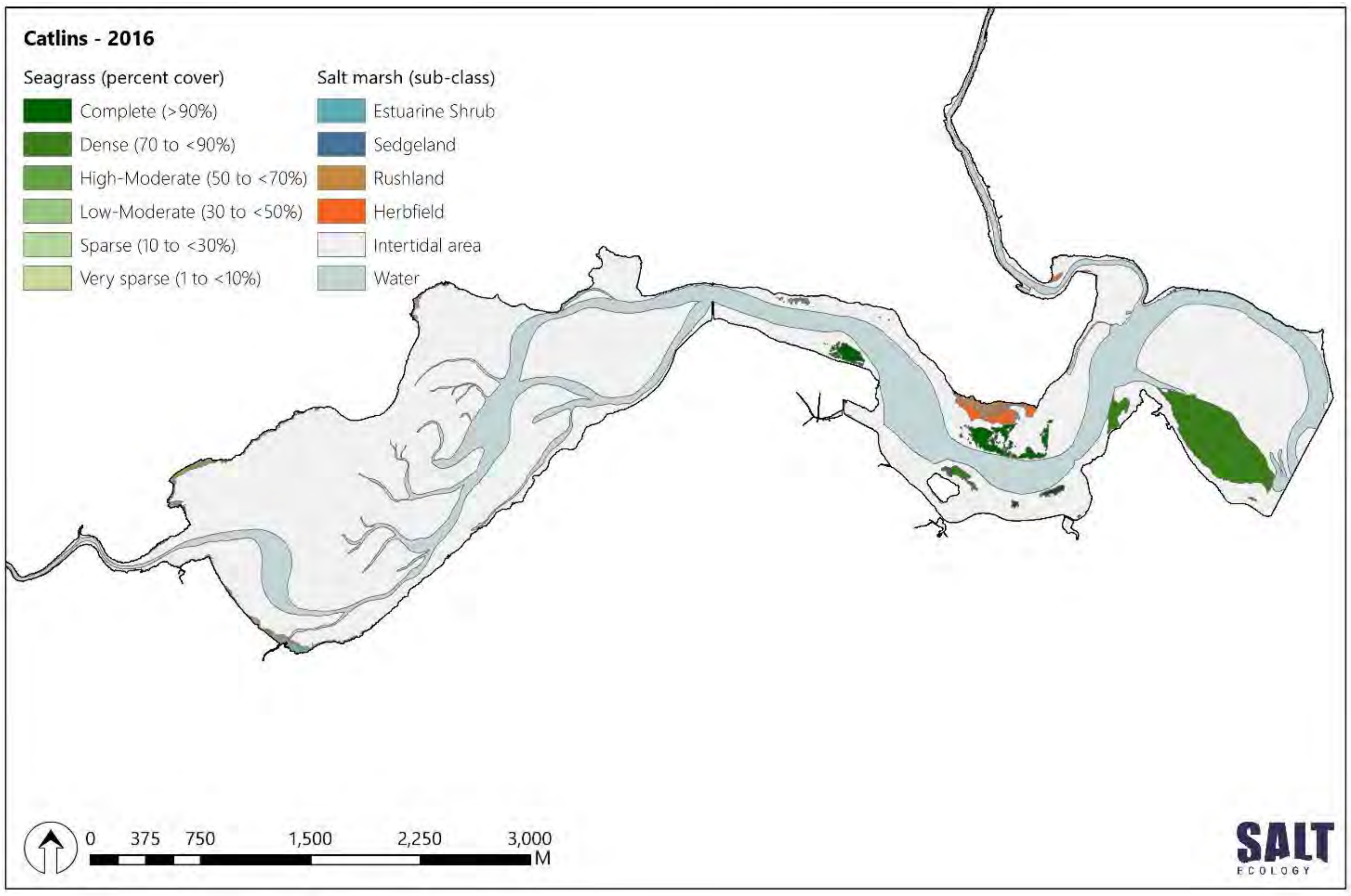
Salt marsh and seagrass extent in 1985.



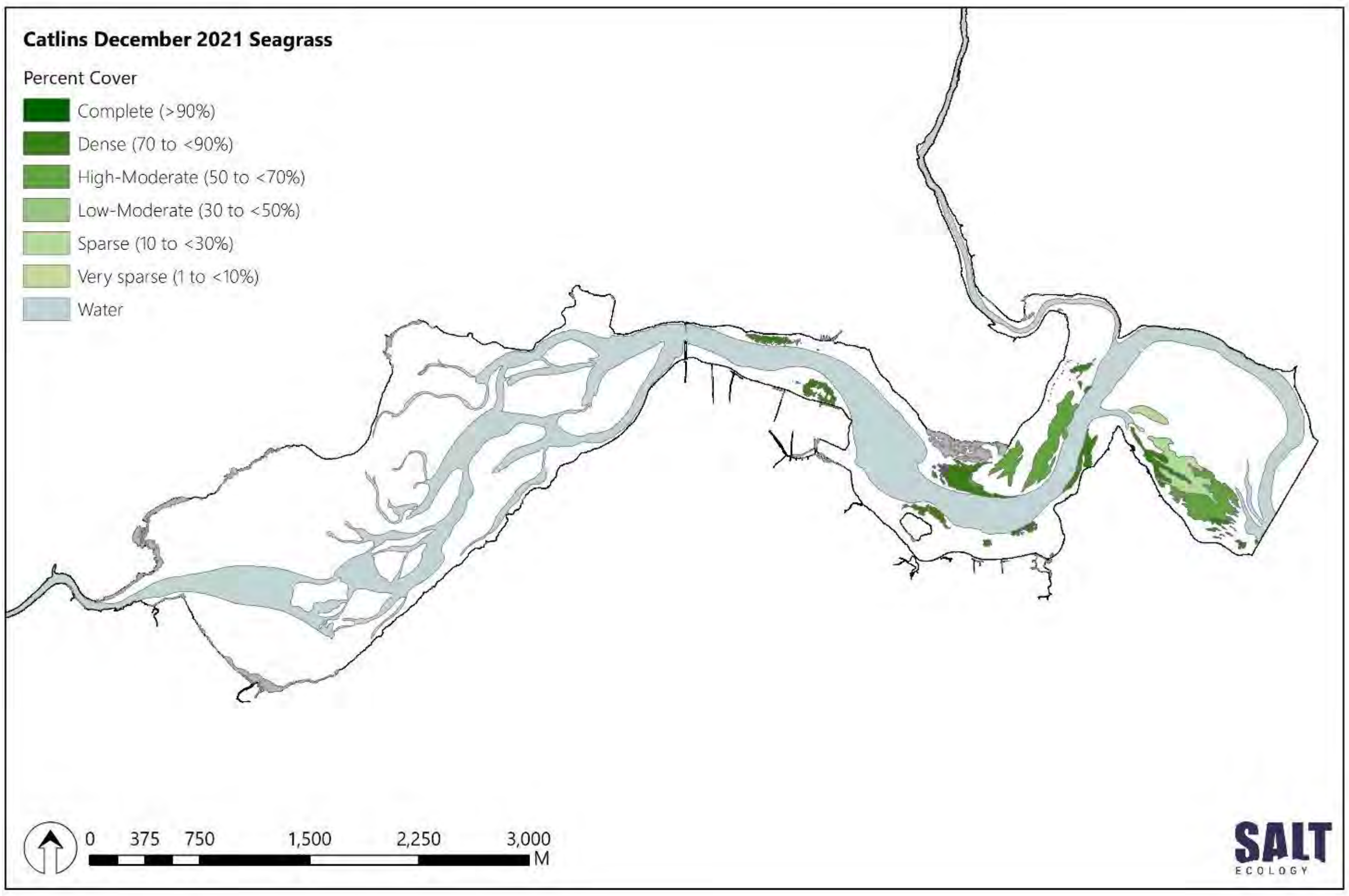
Salt marsh and seagrass extent in 2006.



Salt marsh and seagrass extent in 2016.



Seagrass extent in 2021 (salt marsh not mapped)



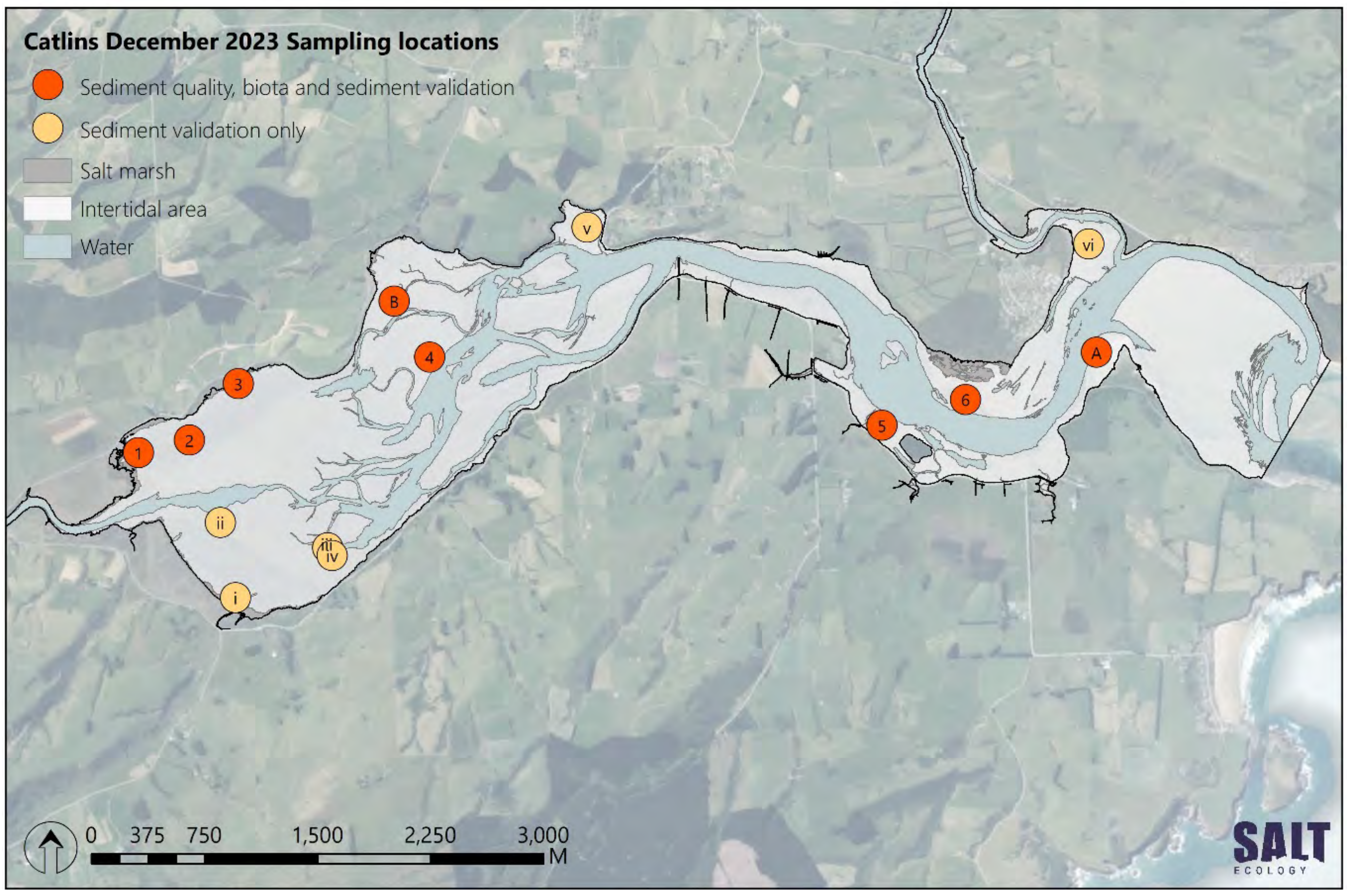
APPENDIX 6. SEDIMENT VALIDATION

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

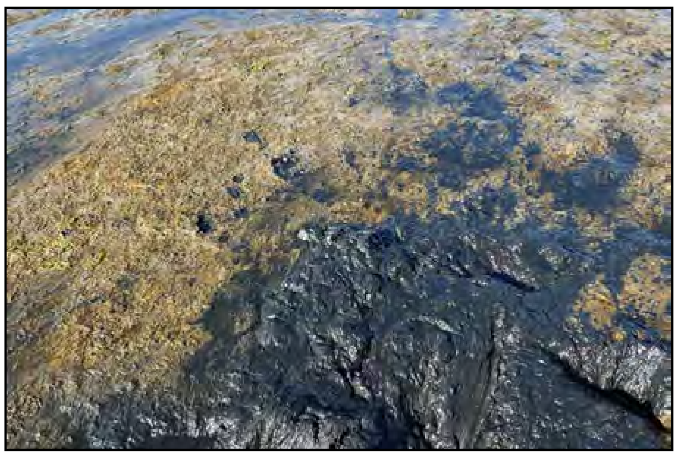
Site 1 - aRPD

Site 2

Site 2 - aRPD

Site 3

Site 3 - aRPD



Site 4

Site 4 - aRPD

Site B

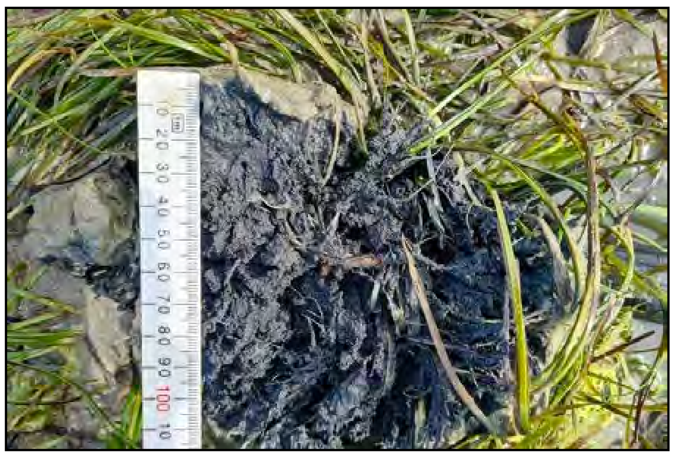
Site B - aRPD

Site 5

Site 5 - aRPD

Site 6

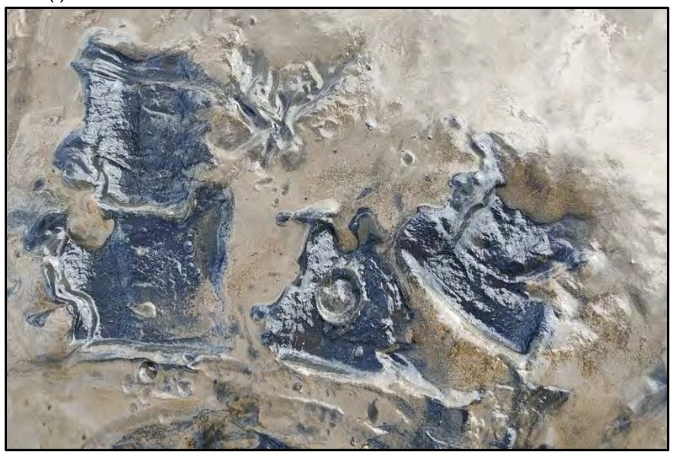
Site 6 - aRPD



Site A

Site A - aRPD

Site (i)



Site (ii)

Site (iii)

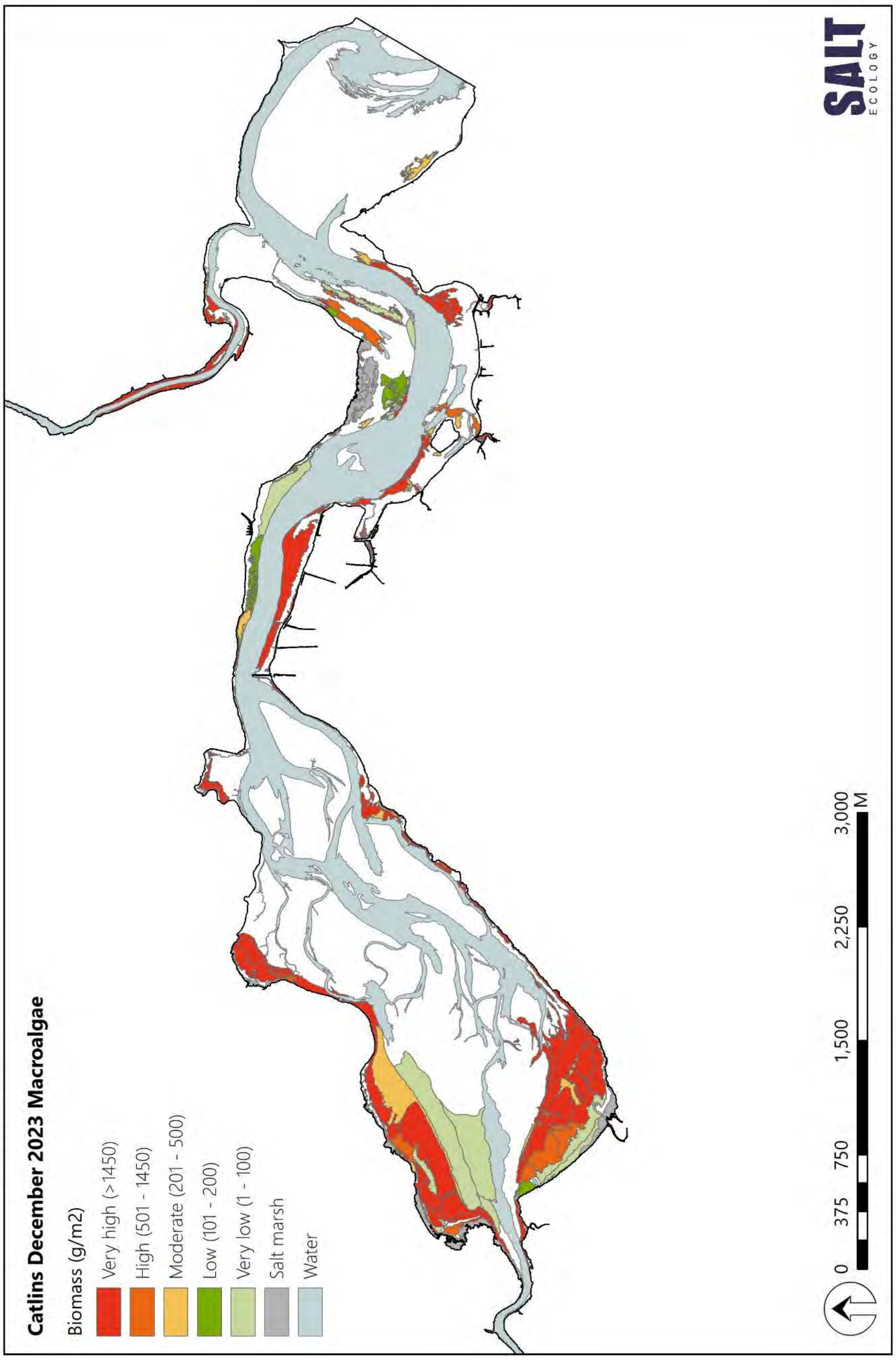
Site (iv)

Site (v)

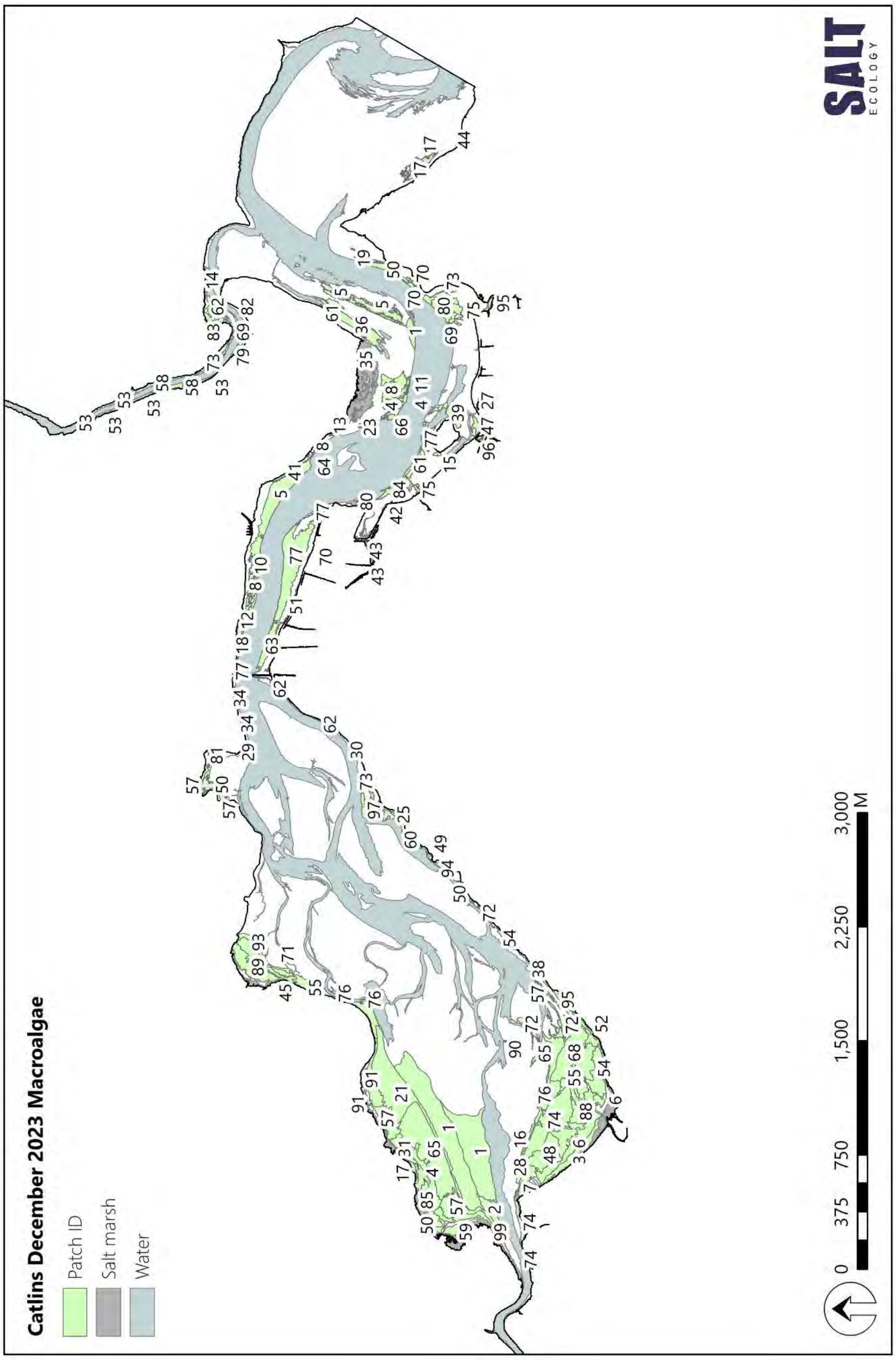
Site (vi)

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	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Catlins/Pounawea Estuary Intertidal Fine-Scale Monitoring Data Summary

Prepared for

Otago Regional Council

February 2024

Salt Ecology
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SALT ECOLOGY

For the People
Mō ngā tāngata

Catlins/Pounawea Estuary Intertidal Fine-Scale Monitoring Data Summary

Prepared by

Don Morrisey
and Barrie Forrest

for

Otago Regional Council
February 2024

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For the environment
Mō te taiao

GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of Environment (Monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total phosphorus
Zn	Zinc

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FIGURES

TABLES

1. INTRODUCTION

Between December 2016 and February 2019, Otago Regional Council (ORC) undertook three ecological and sediment quality surveys in Catlins/Pounawea (hereafter Catlins) Estuary. A report was produced on the first survey (Robertson et al. 2017) but data from the two subsequent surveys were archived. This report provides a high-level summary of the data for all three surveys, to support a planned review of ORC's estuary State of the Environment (SOE) monitoring programme.

2. METHODS

The survey methods are described in Robertson et al. (2017) and were based on the 'fine-scale' approach in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). Monitoring was conducted at two sites (Fig. 1). Different providers have undertaken the surveys, namely Wriggle Coastal Management (December 2016), Ryder Associates (December 2017) and Salt Ecology (February 2019). Monitoring indicators and methods are described in Appendix 1, and were as follows:

- Sediment quality indicators: Included sediment mud content, oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients and organic content, and selected trace contaminants. Sediment aRPD was measured in the field. For the other variables, three samples (each composited from 3-4 sub-samples of the surface 20mm of sediment) were collected and sent to Hill Laboratories for analysis.
- Biotic indicators: Included surface-dwelling snails and macroalgae, and benthic macrofauna. Macrofauna sampling was undertaken using cores (130mm diameter, 150mm deep, ~2L volume,

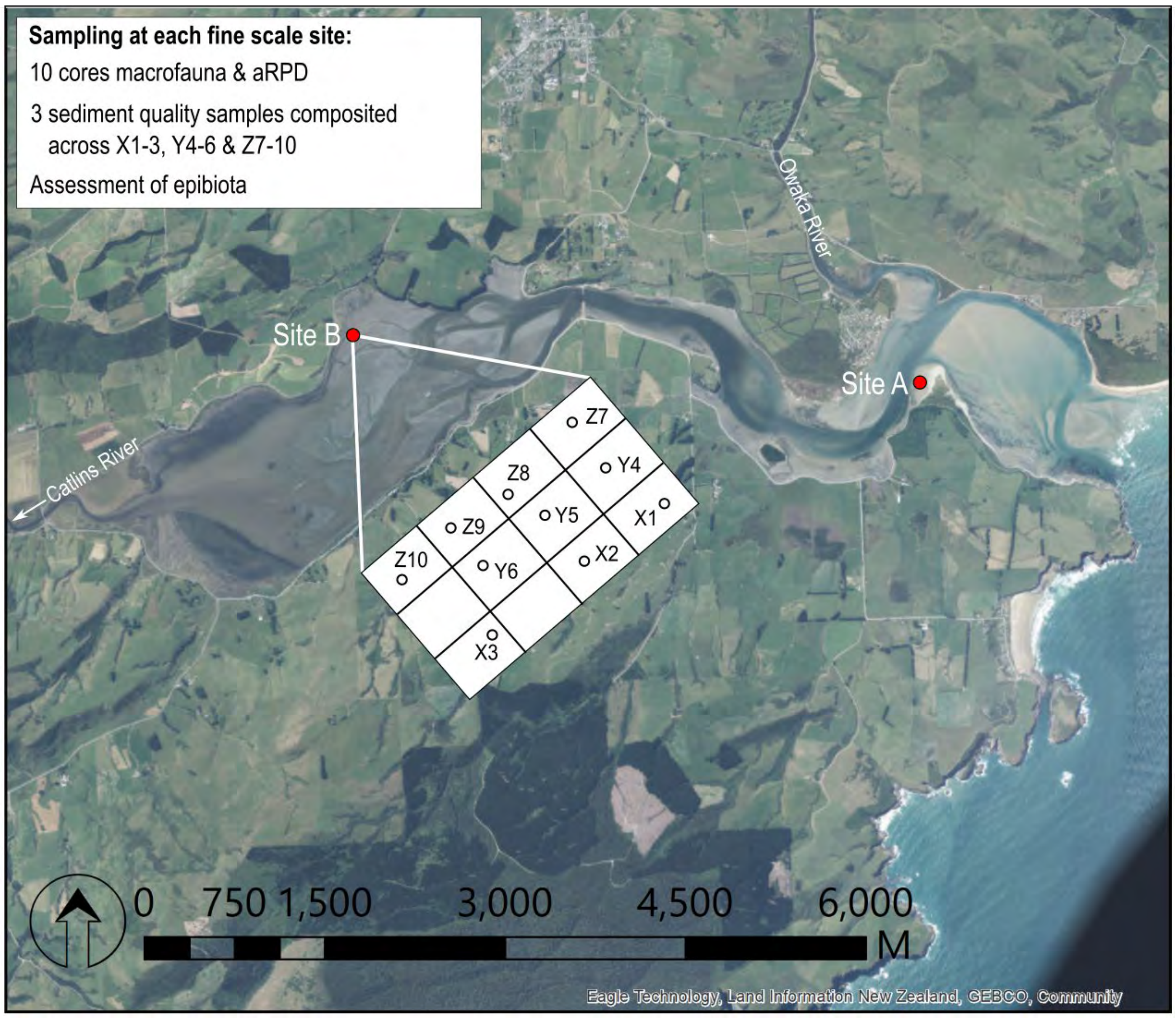


Fig. 1. Location of the two fine-scale monitoring sites in Catlins Estuary. The schematic depicts the sediment sample and macrofauna core collection. Information on site GPS positions and other location information is provided in Robertson et al. (2017).

sieved to 0.5mm). Macrofauna species taxonomy and counts were made by Ryder Associates in December 2017, and by Coastal Marine Ecology Consultants for the other two surveys. For reporting purposes, macrofauna naming differences among surveys have been standardised to the extent feasible.

The data analysis methods are described in recent ORC reports (e.g., Forrest et al. 2022a). Macrofauna assessment included calculation of scores for the international biotic health index 'AMBI'. To assess estuary health, results for most indicators are evaluated against 'condition ratings' described in Appendix 2.

3. KEY FINDINGS

An overall summary of results, with condition ratings applied where available, is provided in Table 1.

3.1 SEDIMENT QUALITY

Sediment quality data are collated in Appendix 3. Sediments consisted of sand at Site A and muddy sand at Site B (Fig. 2, see photos opposite). There was an increase in the amount of mud in the sediment at Site B in consecutive years, from 24.7% in 2016 to 42.9% in 2019. This corresponds to a change in status from 'fair' to 'poor' (Table 1). Site A is on the edge of the channel in the lower estuary, and is likely strongly influenced by the physical effects of water movement (e.g., tide, wind and flood-related water movement), leading to habitat instability. The muddier sediments at Site B appear more stable, which reflects the more sheltered location of this site in the upper estuary.

These site characteristics are reflected in data from annual sedimentation monitoring between 2016 and 2022 (Forrest 2023). That monitoring shows a steady sediment accrual at Site B (average rate of 5.8mm/yr). By contrast, Site A experienced periods of sand erosion prior to 2020, with accrual measured thereafter (Forrest 2023). This pattern at Site A is likely to reflect movement of sand by water currents rather than input of fine sediment from the catchment, while the latter is a likely explanation for the steady build-up of muddy sediment at Site B.

Data from December 2019 to November 2022 (i.e., subsequent to the fine scale surveys) show that the percentage of mud in sediments at Site B has decreased since the February 2019 peak in Fig. 2 (from 42.9% to 29.4%). These changes may reflect specific events in the catchment, such as periods of intense rainfall that have led to variable inputs of muddy sediment. In addition, beds of macroalgae (mainly *Gracilaria* spp., which has previously been called *Agarophyton* spp.) are present in the upper estuary margins, including in the area adjacent to Site B (Stevens & Roberts 2022), and may enhance the deposition and accumulation of fine sediment.

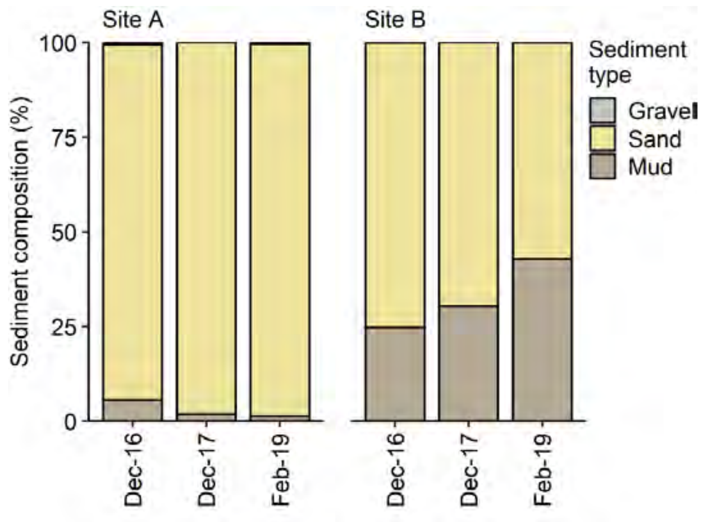
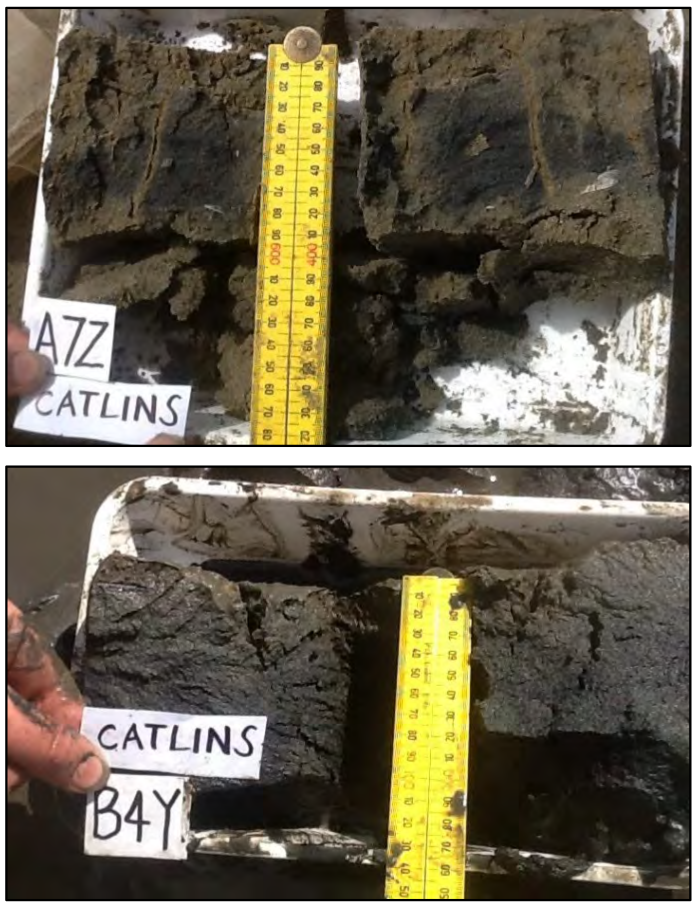


Fig. 2. Sediment particle grain size analysis showing percentage composition of mud (<63μm), sand (<2mm to ≥63μm) and gravel (≥2mm) from composite samples (n=3) at fine-scale sites.



Sediment core profiles from Site A (top, sand) and B (bottom, muddy sand) in 2019. Faunal burrows are visible at Site A and oxygen-depleted sediment is the deeper grey/black colouring.

Table 1. Summary of mean values of key indicators at fine-scale monitoring sites in Catlins Estuary. Values are rated against condition scores of ecological health, where available (Appendix 2). No rating criteria exist for Total Phosphorus (TP), macrofauna richness (Rich) or macrofauna abundance (Abun). See Glossary for definition of indicators.

Site	Year	Mud	aRPD	TN	TP	TOC	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Rich	Abun	AMBI
		%	mm	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	na	na	na
A	Dec-16	5.5	30	<500	217	<0.05	5.3	0.013	6.0	2.3	1.3	<0.01	4.1	11.1	5	17	1.3
	Dec-17	1.9	-	<1300	440	<0.13	6.1	0.013	5.7	2.3	1.2	<0.02	3.5	12.4	9	176	2.3
	Feb-19	1.3	45	<500	211	<0.13	5.4	0.009*	5.7	1.9	1.1	<0.02	3.0	11.1	9	149	2.7
B	Dec-16	24.7	20	367*	263	0.27	2.9	0.019	8.6	4.5	2.2	0.01*	5.7	24.3	8	274	4.4
	Dec-17	30.4	-	<500	387	0.36	3.6	0.018	9.3	4.9	2.5	<0.02	6.0	30.0	6	280	4.5
	Feb-19	42.9	20	<500	337	0.35	3.3	0.016	8.8	4.2	2.4	0.02	5.2	27.0	8	386	4.4

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

Very Good	Good	Fair	Poor

Sediment oxygenation assessed by the aRPD method, was rated 'fair' to 'good' in both surveys where it was recorded (Table 1, Fig. 3). The core photos on the previous page illustrate the change in aRPD transition between brown surface sediment and deeper oxygen-depleted sediment. There were no signs of excessive sediment enrichment, such as an intense black colour throughout the depth profile or a strong sulphide ('rotten egg') odour when the sediment was disturbed.

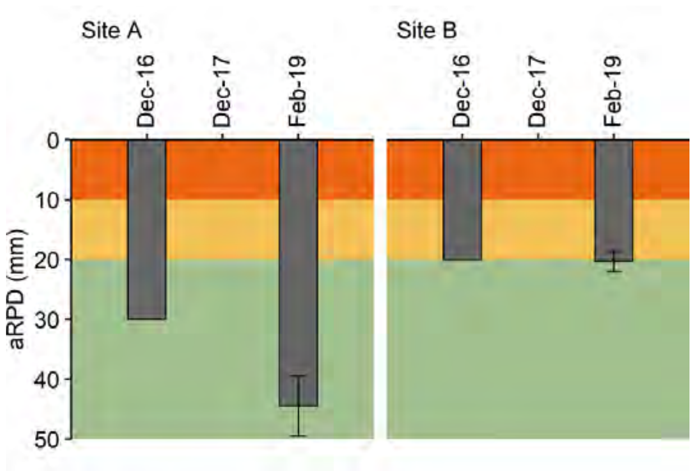


Fig. 3. Mean (±SE, n=3-10) aRPD depth relative to condition ratings. The aRPD depth was not recorded in December 2017.

Very Good	Good	Fair	Poor

Intertidal flats at Site A looking towards lower estuary.

Site B in upper estuary.

Laboratory sediment analyses revealed low levels of organic matter and nutrients, corresponding to ratings of 'very good' (Table 1, Fig. 4). TOC values at Site A, and TN values at both sites, were often less than routine laboratory method detection limits.

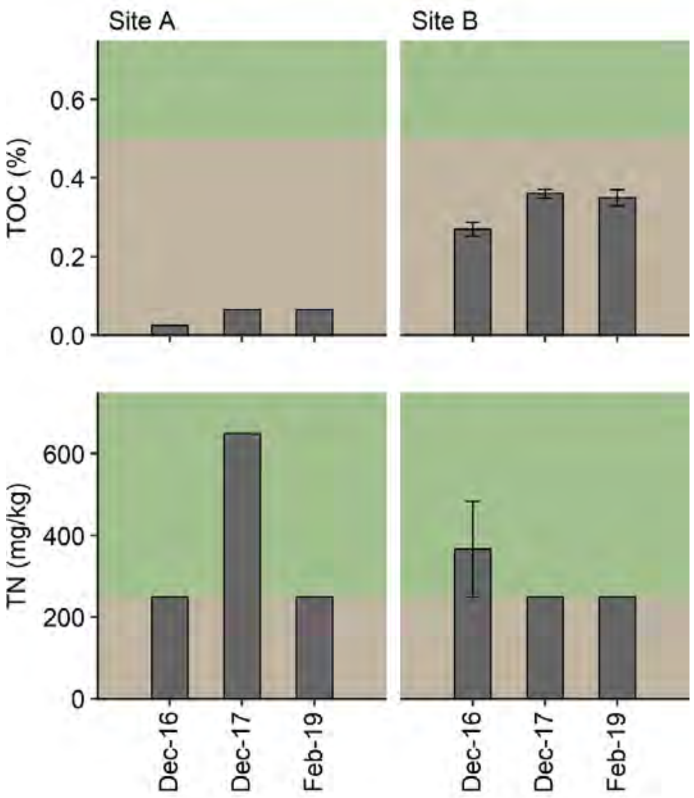


Fig. 4. Mean (±SE, n=3) sediment total organic carbon (TOC) and total nitrogen (TN) in composite samples, relative to condition ratings. TOC and TN values at Site A in all years, and TN values at Site B in December 2017 and 2019, were less than routine laboratory method detection limits. Values plotted are 50% of the detection limit.

Very Good	Good	Fair	Poor

Sediment trace metal contaminants were at very low concentrations in all three surveys, and less than half of the national sediment quality Default Guideline Value (DGV; Table 1, Fig. 5). DGVs indicate "*...the concentrations below which there is a low risk of unacceptable effects occurring*" (ANZG 2018). Overall, therefore, these results suggest that there are no significant chemical contaminant inputs from the catchment that are accumulating in the estuary, and no trends in concentrations over time.

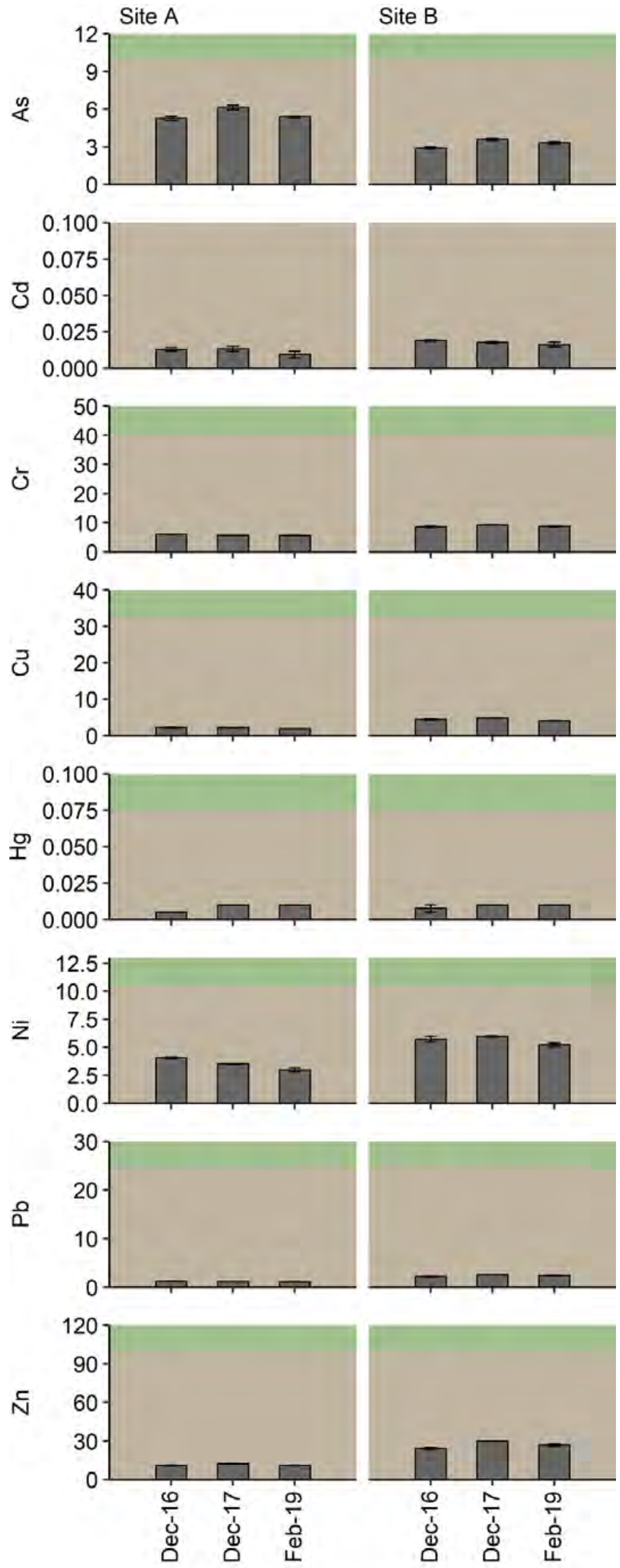


Fig. 5. Mean (±SE, n=3) trace metal concentrations in composite samples, relative to condition ratings. The boundary between 'very good' and 'good' represents 50% of the ANZG (2018) sediment quality Default Guideline Value (DGV). Below the DGV there is a 'low risk' of unacceptable effects.

Very Good	Good	Fair	Poor

3.2 BIOTA

Surface dwelling epibiota

Epibiota were sparse at both sites, except for mud snails (*Amphibola crenata*), which were relatively common at Site B (e.g., 10-20/m^2 in 2019). Mudflat top shells (*Diloma subrostratum*) and whelks (*Cominella glandiformis*) were also present at Site B in 2019, but described as 'rare' (<0.1/m^2). The seaweeds *Gracilaria* spp. and *Ulva* spp. ('sea lettuce') have also been described from both sites, but are not consistently present and, when recorded, have been at a low prevalence (<1% cover).

Sediment-dwelling macrofauna

Macrofauna species and abundances are summarised in Appendix 4. Core sampling revealed the macrofauna to be moderately impoverished in terms of the range of species present, and dominated by hardy species. Key points are as follows:

- A total of 34 species or higher macrofauna taxa have been recorded from the two sites. Eleven main taxonomic groups are present, but shrimp-like amphipods, bivalves and polychaete worms are by far the most abundant (Appendix 4).
- Mean species richness at both sites was low (range ~5-9 taxa per core at Site A, ~6-8 at Site B). At Site A, more species were present in 2017 and 2019 than in 2016 (Fig. 6, top). Fewer species were present at Site B in 2017 than in 2016 or 2019, which had similar numbers.
- Similarly, the greatest abundances occurred in 2017 and 2019 at Site A, with means of 176 and 149 organisms per core, respectively (Fig. 6, bottom). Abundances were similar in 2016 and 2017 but increased in 2019 at Site B. This temporal fluctuation likely reflects natural variability. While it is possible that the use of different providers in each of the three survey years resulted in variability, the observed consistency between consecutive surveys (2017 and 2019 at Site A, 2016 and 2017 at Site B) suggests that the abundance increases over time are unlikely to be an artefact.
- Mean values of the biotic index AMBI corresponded to a condition rating of 'good' at Site A and 'poor' at Site B (Table 1, Fig. 7). These ratings reflect that the macrofauna at Site B was consistently dominated by hardy species in eco-group IV while eco groups I-III were predominant at Site A, but their relative proportions varied among surveys (Fig. 8). For example, mean AMBI values at Site A have increased (i.e., deteriorated) over time, which appears due mainly to increased densities of the hardy (EG-IV) tube-building amphipod *Paracorophium excavatum*. This result conceivably reflects natural processes such as physical disturbance from sand movement and migration of the main estuary channel.

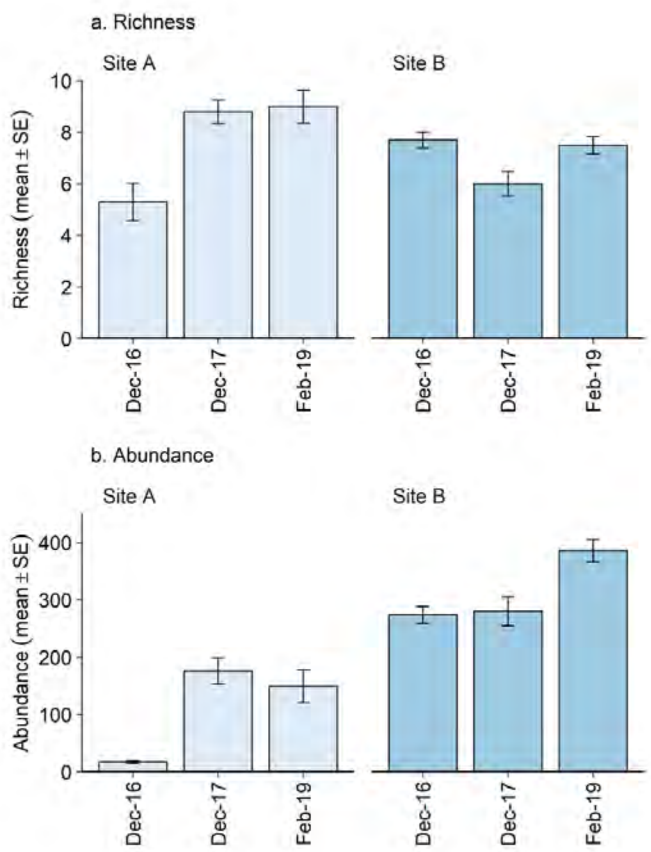


Fig. 6. Mean (±SE, n=10) macrofauna taxon richness and abundance per core.

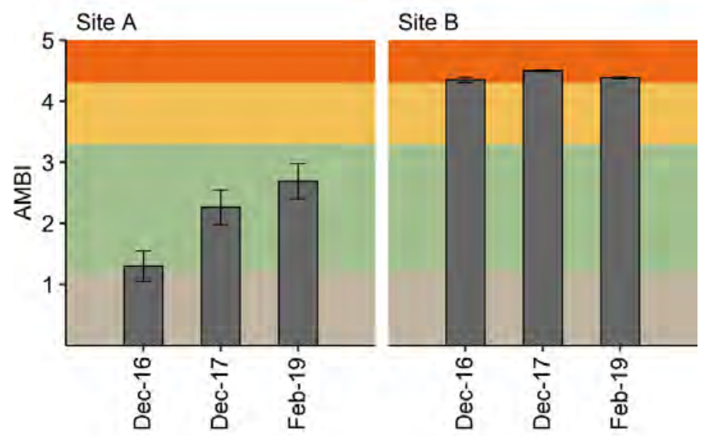
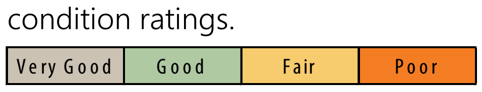


Fig. 7. Mean (±SE, n=10) AMBI scores relative to condition ratings.



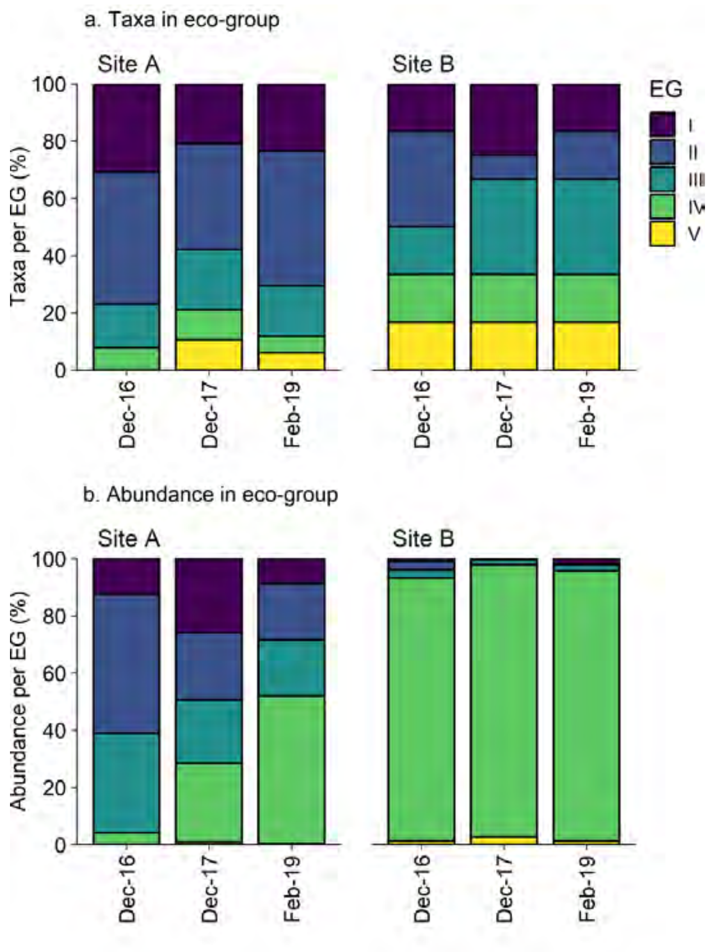
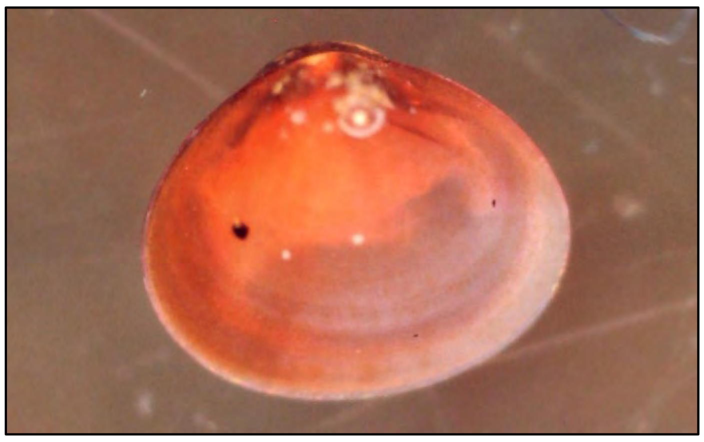


Fig. 8. Contribution to site richness and abundances of macrofauna species in eco-groups ranging from sensitive (EG-I) to resilient (EG-V). The graphs illustrate that the macrofauna was dominated by hardy (EG-IV) organisms at Site B in all years, and at Site A in 2019.

- The small bivalve *Legrandina turneri* was the most abundant species at Site A in 2017 and 2019 but was present in much smaller numbers in 2016 (Appendix 4, photo opposite). This species has a southern New Zealand distribution, and is considered to be intolerant of mud and organic material (Robertson et al. 2017). Note that this species does not have an AMBI eco-group designation, hence these high abundances are not reflected in the AMBI data in Figs 7 and 8.
- In addition to *Legrandina turneri*, two amphipod species, *Torridoharpinia hurleyi* and *Waitangi* sp. 1, were consistently common at Site A but absent from Site B.
- By far the most abundant of the hardy species at Site B was the amphipod *Paracorophium excavatum* noted above (Appendix 4, photo opposite). This species is common in disturbed environments, especially in river-dominated estuaries subject to highly variable flows and salinities. Also present at Site B were oligochaete and polychaete worm species that are commonly found in estuaries nationally, in particular *Scolecolepides benhami*. The small and nationally-common estuarine bivalve *Arthritica* sp. 5 was also common at Site B.
- Cockles were recorded in both sites in most surveys but were not abundant (1-2 individuals per core). The few cockles present were smaller at Site A (4-15mm shell length) than Site B (mainly 26-34mm shell length).



The small bivalve *Legrandina turneri* was the most dominant of the macrofauna at Site A. This is a little-known species whose distribution appears to be restricted to southern New Zealand.

The tube-building amphipod *Paracorophium excavatum* was by far the most dominant of the macrofauna at Site B. This species is common in physically disturbed environments, especially in river-dominated estuaries where water flows and salinities are highly variable (image from NIWA Otago estuaries collection).

A cursory analysis of macrofauna community composition differences among sites and surveys was undertaken. A multivariate method was used to 'group' sites according to their similarity in macrofauna composition (Fig. 9). The analysis revealed the following macrofauna composition patterns:

- Macrofauna differences between the two sites were quite pronounced, reflecting the species differences described above, as well as more subtle differences in the occurrence of sub-dominant species (Appendix 6).
- The tight grouping of Site B samples in all years reflects the strong dominance in all three surveys of the amphipod *Paracorophium excavatum*, and to a lesser degree oligochaete worms and the polychaete worm *Scolecolepides benhami*.
- At Site A, the analysis revealed differences in 2016 relative to the two other surveys, which reflect the relatively species-poor nature and low abundance of macrofauna in that year (see Fig. 6).

A limited analysis was undertaken to determine whether macrofauna differences among sites/surveys could be 'explained' by any of the sediment quality variables. Sediment mud appears likely to be a potential explanatory variable for the difference between sites. Macrofauna composition differences were correlated with higher values of mud at Site B (and at Site A in 2016), and with a higher TOC and shallower aRPD (Spearman rank correlation coefficient ρ = 0.713 for sediment %mud; see also Fig. 9). However, absolute TOC values were low and aRPD values reasonably high (corresponding to 'fair' and 'good' condition ratings; see Table 1). In this respect, of the variables measured, the amount of mud in the sediment is likely to have the most plausible influence on macrofaunal composition. For example, a mud content of around 25% or greater (i.e., as evident at Site B) is often considered as the level at which macrofaunal composition changes can occur relatively to sandier sediments (Robertson et al. 2015; Ward & Roberts 2021). In general, muddy sediment is regarded as one of the key drivers of ecological health degradation in New Zealand estuaries (Cummings et al. 2003; Robertson et al. 2015; Berthelsen et al. 2018; Clark et al. 2021).

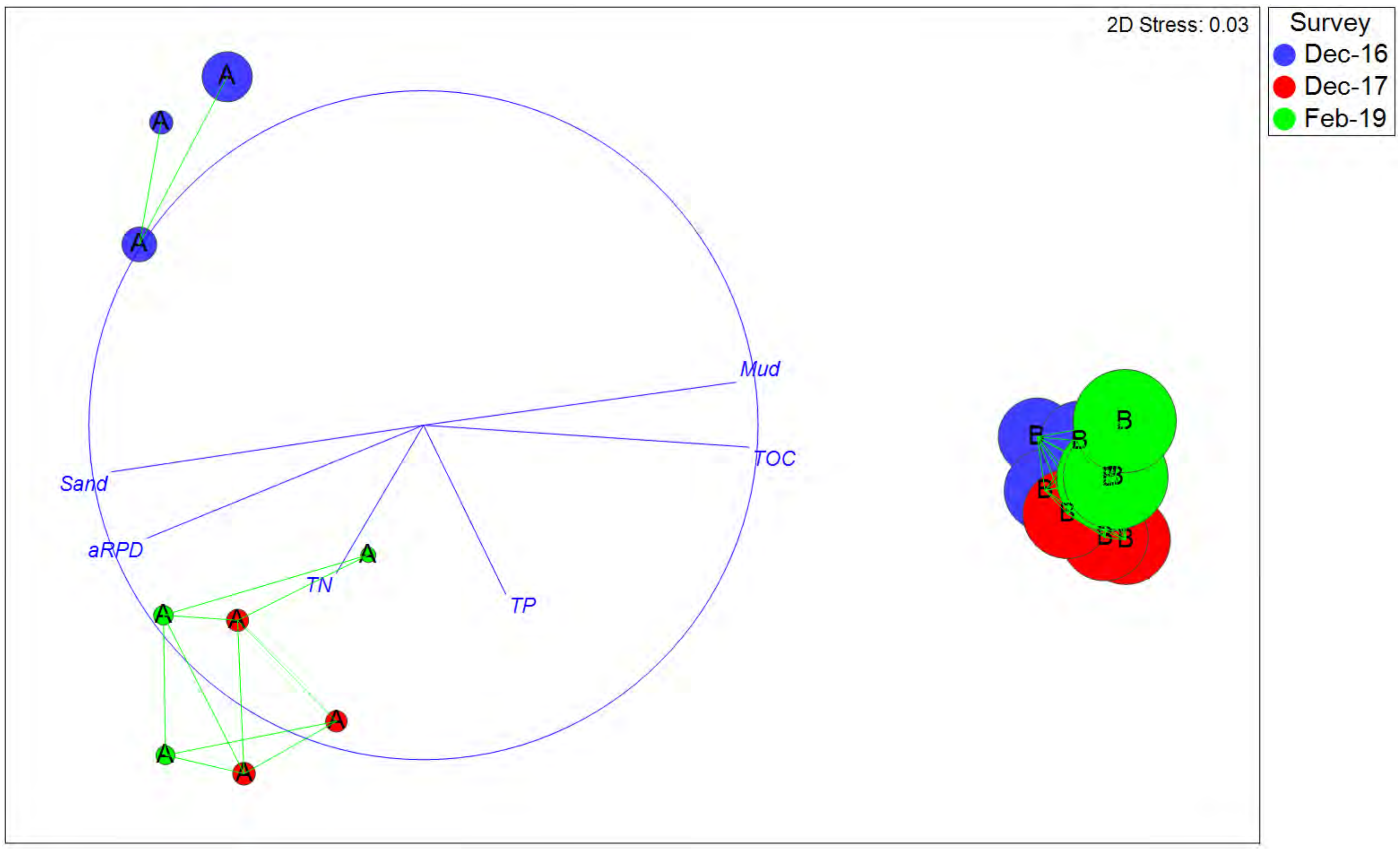


Fig. 9. Non-metric MDS ordination of macrofaunal core samples for data aggregated within each site-zone and survey.

Sample groups closer to each other are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of 0.03 indicates that a 2-dimensional plot provides a reliable representation of differences. The green lines connect sample groups with a high similarity (65%) based on the Bray-Curtis measure. The vectors show the direction and strength of association (length of line relative to circle) of the measured environmental variables that were most strongly correlated with the pattern of differences. Bubble sizes are scaled to sediment mud content, which was highly correlated with TOC.

4. MONITORING AND MANAGEMENT IMPLICATIONS

ORC began broad-scale habitat monitoring of the Catlins Estuary in 2008 with repeat surveys in 2012, 2017, 2022 and 2024. To complement broad-scale monitoring comprehensive baseline fine-scale monitoring was undertaken in 2016, 2017 and 2019. One of the reasons for compiling the present summary report was to better understand the utility of the current monitoring approach. Once data for all Otago estuaries have been collated in a similar way, ORC will be in a better position to review the programme and determine monitoring priorities. In this broader context, Catlins Estuary presents some features that will need to be accounted for in the review. These include the following:

- The upper estuary (including Site B) appears susceptible to catchment influences, with land uses being predominantly pasture for sheep and beef farming (61% of catchment area; Robertson et al. 2017). ORC will need to consider priorities for managing these sources in the context of other regional catchment management priorities.
- Monitoring of macroalgal cover and biomass in the estuary (Stevens & Roberts 2022) has shown a marked degradation in ecological quality in the upper estuary margins, due to nuisance growths of *Gracilaria* spp. Between 2016 and late 2021, the area of the estuary affected by nuisance macroalgae had increased from 54ha to 127ha, and the biomass had tripled. Some areas show widespread degradation of sediment quality (shallow aRPD, high mud content and high organic content). Site B is immediately adjacent to one of these areas, hence provides a potentially useful baseline site against which to quantify the effects of any future expansion of the *Gracilaria* beds. That said, note that the macrofaunal species present at Site B are generally tolerant of mud and organic enrichment, and may be reasonably resilient to future changes.
- Previous sedimentation and macroalgal monitoring, combined with the analysis of fine scale data in this report, suggest that sediment and nutrient loads to Catlins Estuary from the catchment are exceeding the estuary's assimilative capacity. At present these problems are mainly confined to the upper estuary (and also the Ōwaka Arm; see Fig 1), reflecting their more sheltered and less well-flushed hydrodynamic environments.
- The lower estuary, in contrast, is physically more dynamic, with a higher level of tidal flushing and variable patterns of sediment deposition and erosion at Site A (Forrest 2023). Nevertheless, macroalgal beds are also present just upstream of Site A and could expand in the future (Stevens & Roberts 2022). While Site A provides a potentially useful baseline site for quantifying the effects of such an expansion, the positioning of the site near the channel means that it is subject to physical stresses relating to hydrological conditions and sand movement. These conditions mean that physical disturbance at the site may have an over-riding influence on macrofauna, and make future ecological changes difficult to detect.

In terms of future monitoring, the above discussion suggests that neither site is ideal in terms of being sensitive to a change in direct catchment pressures (e.g., ongoing muddy sediment inputs). That said, if future changes include proliferation of nuisance algae, this type of habitat has its own characteristics that set it apart ecologically from 'barren' sand/mud habitats (Forrest et al. 2022b). As such, continued fine-scale monitoring, particularly at Site B, provides a means of characterising this type of ecological effect.

A question for ORCs programme review will be the merits of investigating alternative Catlins fine scale sites that may be more sensitive to long term changes in direct catchment pressures such as sedimentation. For this purpose, there will be additional macrofauna core data available over the next few months from a broad scale habitat survey conducted over the current summer. These data can be used to inform potential site selection. There are also limited data available from four mid-lower estuary sites that were sampled historically (Stewart & Bywater 2009; Stewart 2012), although these appear no more species-rich than Sites A and B described in the present report. Decisions regarding future monitoring sites should form part of ORC's review of the regional estuary SOE programme. That review should consider the specific type of monitoring that is needed in the context of management goals in Catlins Estuary, and the priorities for monitoring relative to other estuary systems in Otago.

5. RECOMMENDATIONS

Although there is merit in continued fine scale monitoring in Catlins Estuary, it is recommended that the scheduled monitoring in the present (2023/24) summer be deferred, with a decision on future fine-scale and other monitoring needs for Catlins Estuary determined as part of ORC's planned review of the regional estuary SOE programme. The results of ongoing annual sedimentation monitoring, and a NEMP broad-scale habitat mapping survey undertaken in the current summer, will contribute to a broader understanding of estuary state and monitoring needs.

6. 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.

Berthelsen A, Atalah J, Clark D, Goodwin E, Patterson M, Sinner J 2018. Relationships between biotic indices, multiple stressors and natural variability in New Zealand estuaries. Ecological Indicators 85: 634-643.

Clark DE, Stephenson F, Hewitt JE, Ellis JI, Zaiko A, Berthelsen A, Bulmer RH, Pilditch CA 2021. Influence of land-derived stressors and environmental variability on compositional turnover and diversity of estuarine benthic communities. Marine Ecology Progress Series 666: 1-18.

Cummings V, Thrush S, Hewitt J, Norkko A, Pickmere S 2003. Terrestrial deposits on intertidal sandflats: sediment characteristics as indicators of habitat suitability for recolonising macrofauna. Marine Ecology Progress Series 253: 39-54.

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.

Forrest BM 2023. Catlins Estuary: 2022/2023 Intertidal Sediment Monitoring Summary. Salt Ecology Short Report 025, prepared for Otago Regional Council, March 2023. 2p.

Forrest BM, Roberts KL, Stevens LM 2022a. Fine scale intertidal monitoring of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 093, prepared for Otago Regional Council, June 2022. 29p.

Forrest BM, Roberts KL, Stevens LM, Rabel H 2022b. Fine Scale Intertidal Monitoring of New River Estuary: Synthesis of Survey Data 2001-2022. Salt Ecology Report 100, prepared for Environment Southland, September 2022. 47p.

Robertson B, Gillespie P, Asher R, et al. 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, Robertson BP, Stevens LM 2017. Catlins Estuary: Fine Scale Monitoring 2016/17. Prepared for Otago Regional Council. 32p.

Robertson BM, Stevens L, Robertson B, et al. 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, 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.

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.

Stewart B 2012. Habitat Mapping of the Owaka Estuary. Otago Regional Council State of the Environment Report, prepared by Ryder Consulting, November 2012. 37p.

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

Ward N, Roberts K 2021. Estuaries and Coast: Classification and Attributes for Southland. Environment Southland publication number 2020-03, Environment Southland: Invercargill. 107p. ISBN 978-0-909043-63-6.

APPENDIX 1. SUMMARY OF NEMP FINE-SCALE INDICATORS

The rationale for each indicator and sampling method is provided. The main 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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Samples sent to Hill Laboratories for analysis.
Nutrients (nitrogen and phosphorus), and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Organic matter measured as Total Organic Carbon (TOC) (note 1). Samples sent to Hill Laboratories for analysis.
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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site (note 2). Samples sent to Hill Laboratories for analysis.
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.	Ten sediment cores per site, split vertically, with average depth of aRPD (for each core) 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.	Ten sediment cores per site (130mm diameter, 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 (note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR (note 3).
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR (notes 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 used quadrat sampling in the first two surveys, but for the last survey used the 'SACFOR' approach: S = super abundant, A = abundant, C = common, F = frequent, O = occasional, R = rare . SACFOR was used instead of the quadrat sampling, which is subject to considerable within-site variation for epibiota that have clumped or patchy distributions (see Forrest et al. 2022 for further detail).

[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.

APPENDIX 2. CONDITION RATINGS FOR ASSESSING ESTUARY HEALTH

No rating criteria exist for Total Phosphorus (TP), or macrofauna variables other than AMBI. See Glossary for definition of indicators.

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		Requires development			
TOC[1]	%	<0.5	0.5 to <1	1 to <2	≥2
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.

APPENDIX 3. SEDIMENT QUALITY DATA

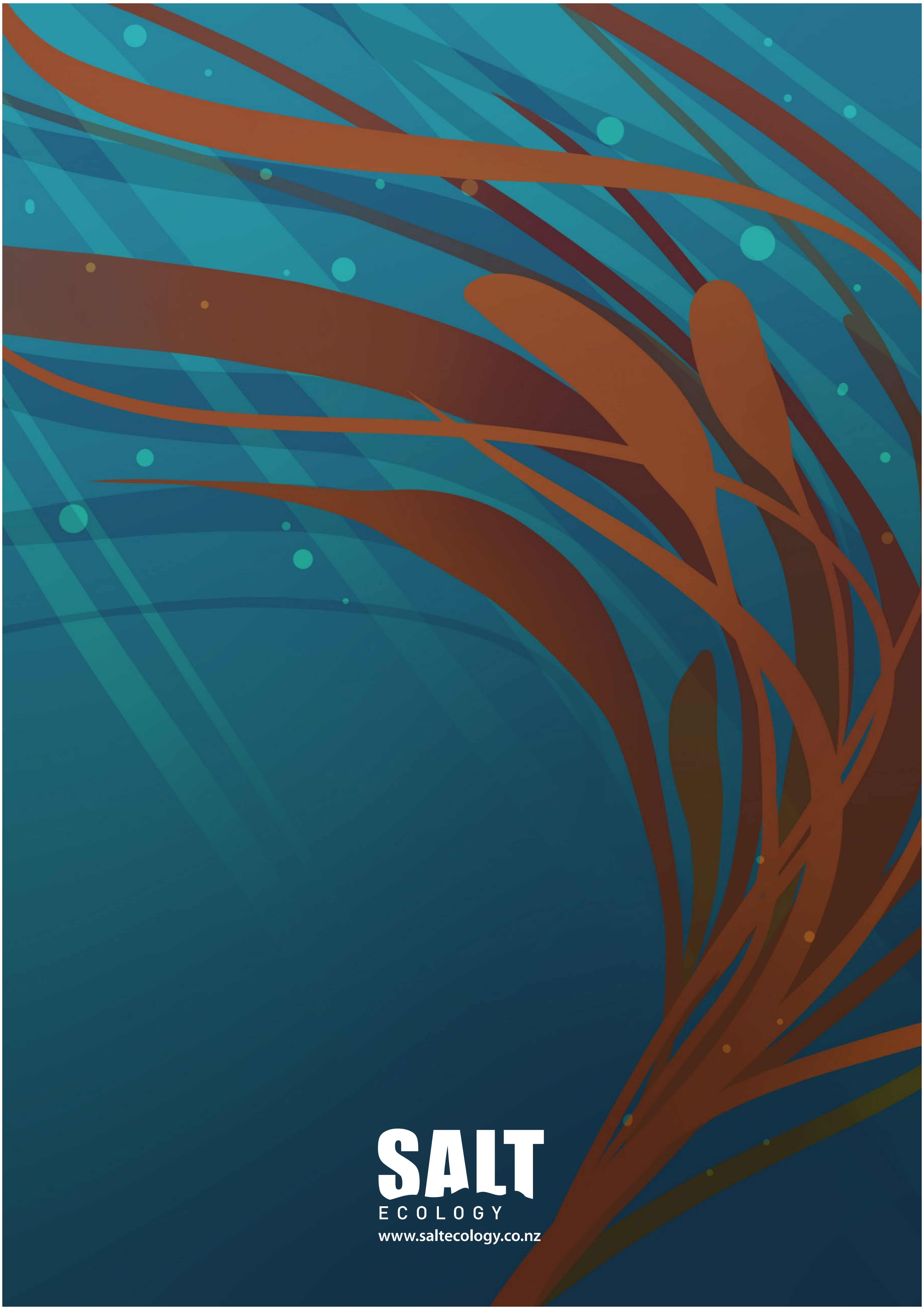
Values based on a composite sample within each of Zone X (reps X1-3), Y (reps Y4-6) and Z (reps Z7-10), except for aRPD in February 2019 for which the mean and range is shown for 10 replicates. The aRPD depth was not reported in December 2017. DGV = Default guideline value for sediment quality (ANZG 2018); GV-High = Guideline Value High.

Site	Survey	Zone	Gravel	Sand	Mud	TOC	TN	TP	aRPD	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
			%	%	%	%	mg/kg	mg/kg	mm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
A	Dec-16	X	0.6	97.3	2.1	<0.05	<500	220	30	5.1	0.015	6.1	2.2	<0.01	4.2	1.3	12
		Y	0.6	89.6	9.8	<0.05	<500	210	30	5.1	0.013	5.9	2.1	<0.01	3.9	1.2	10
		Z	0.4	94.8	4.7	<0.05	<500	220	30	5.6	0.011	6	2.5	<0.01	4.1	1.3	11
	Dec-17	X	<0.1	98.1	1.9	<0.13	<1300	240	-	6.4	0.011	5.7	2.2	<0.02	3.5	1.2	12
		Y	<0.1	98	2	<0.13	<1300	540	-	5.8	0.012	5.7	2.3	<0.02	3.5	1.2	12
		Z	<0.1	98.2	1.8	<0.13	<1300	540	-	6.2	0.017	5.8	2.3	<0.02	3.6	1.2	13
	Feb-19	X	0.9	98.2	0.9	<0.13	<500	193	41.7 (30 to 60)	5.5	0.01	5.5	1.8	<0.02	2.7	1.1	11
		Y	<0.1	98.5	1.5	<0.13	<500	220	48.3 (40 to 65)	5.4	0.013	5.8	1.9	<0.02	3.3	1.2	11
		Z	<0.1	98.6	1.4	<0.13	<500	220	43.8 (25 to 70)	5.3	<0.010	5.7	1.9	<0.02	3	1.1	11
B	Dec-16	X	<0.1	76.5	23.5	0.24	600	270	20	2.9	0.019	8.5	4.3	<0.01	5.5	2.1	23
		Y	<0.1	73.8	26	0.27	<500	260	20	2.8	0.018	8.2	4.2	0.01	5.5	2.1	24
		Z	<0.1	75.3	24.7	0.3	<500	260	20	3.1	0.02	9.2	4.9	<0.01	6.2	2.3	26
	Dec-17	X	<0.1	69.3	30.7	0.36	<500	390	-	3.5	0.017	9.5	4.9	<0.02	5.9	2.5	30
		Y	<0.1	70.5	29.5	0.34	<500	380	-	3.5	0.017	9.3	4.9	<0.02	6.1	2.5	30
		Z	<0.1	69.1	30.9	0.38	<500	390	-	3.8	0.019	9.1	4.8	<0.02	5.9	2.5	30
	Feb-19	X	<0.1	55.6	44.4	0.38	<500	350	19.0 (10 to 25)	3.5	0.018	9	4.3	<0.02	5.5	2.5	28
		Y	<0.1	57.3	42.7	0.36	<500	340	21.7 (15 to 30)	3.4	0.018	8.9	4.3	<0.02	5.3	2.4	28
		Z	<0.1	58.4	41.5	0.31	<500	320	20.3 (20 to 21)	3.1	0.013	8.5	3.9	<0.02	4.9	2.3	25
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

APPENDIX 4. MACROFAUNA CORE DATA SUMMED ACROSS TEN REPLICATES FOR EACH SURVEY AND SITE

Minor macrofauna renaming or aggregation to genus has been undertaken to standardise (to the extent feasible) across the different provider in December 2017 vs the other two surveys.

Main group	Taxa	EG	Dec-16 A	Dec-17 A	Feb-19 A	Dec-16 B	Dec-17 B	Feb-19 B
Amphipoda	Paracalliope novizealandiae	I		3		10	2	28
Amphipoda	Paracorophium excavatum	IV	3	65	176	2455	2570	3597
Amphipoda	Torridoharpinia hurleyi	I	3	54	15		2	
Amphipoda	Waitangi sp. 1	II	17	20	8			
Anthozoa	Anthopleura hermaphroditica	III					1	
Anthozoa	Edwardsia sp. 1	II		12	11			
Bivalvia	Arthritica sp. 5	III		9		76	50	77
Bivalvia	Austrovenus stutchburyi	II	1	1	1	2		2
Bivalvia	Hiatula sp. 1	I	1					
Bivalvia	Legrandina turneri	na	97	1521	1151		2	
Bivalvia	Paphies australis	II		1	3			
Bivalvia	Paphies subtriangulata	na			1			
Copepoda	Copepoda	II				8		
Cumacea	Colurostylis lemurum	II	7	16	8	17		
Decapoda	Hemiplax hirtipes	III				2	2	1
Isopoda	Eurylana arcuata	na		1				
Isopoda	Pseudaega punctata	na			1			
Mysida	Mysida	II	1			57	3	6
Oligochaeta	Oligochaeta	V		1		21	63	24
Polychaeta	Aonides trifida	I		2				
Polychaeta	Boccardia syrtis	II	7	5	20			
Polychaeta	Capitella spp.	V		1	1	14	10	25
Polychaeta	Macroclymenella stewartensis	II	2	1	15			
Polychaeta	Microspio maori	I	4	3	3	16	2	49
Polychaeta	Nereididae (juv)	III	24		24			1
Polychaeta	Nicon aestuariensis	III					1	3
Polychaeta	Orbinia papillosa	I	1		10			
Polychaeta	Paradoneis lyra	III		8				
Polychaeta	Perinereis vallata	III	1	28	33			
Polychaeta	Phyllodocidae sp. 1	II			1			
Polychaeta	Prionospio aucklandica	III		8	10			
Polychaeta	Scolecolepides benhami	IV		1		59	94	47
Polychaeta	Thoracophelia otagoensis	I			2			
Stomatopoda	Heterosquilla	na	3	1				
	Site richness		15	22	20	12	13	12
	Site abundance		172	1762	1494	2737	2802	3860



Environmental Science and Policy Committee - 4 December 2024

KAIKORAI ESTUARY: 2023/2024 INTERTIDAL SEDIMENT MONITORING SUMMARY

Salt Ecology Short Report 042. Prepared by Hayden Rabel for Otago Regional Council, May 2024

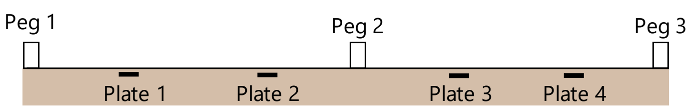
OVERVIEW

Since December 2017, Otago Regional Council has undertaken near-annual State of the Environment monitoring in Kaikorai Estuary to assess trends in the deposition rate, mud content, and oxygenation of intertidal sediments. Sediment monitoring is undertaken at three sites (Fig. 1), with the latest survey carried out on 3 December 2023.

Fig. 1. Location of Kaikorai Estuary monitoring sites. In Feb-2019, Site D replaced nearby Site C, which was subject to river erosion.

METHODS

Sedimentation is measured using the 'sediment plate' method (e.g., Forrest et al. 2020). The approach involves measuring sediment depth from the sediment surface to the top of each of four buried concrete pavers. Measurements are averaged across each plate and used to calculate a mean annual sedimentation rate for each site.



A composite sample of the surface 20mm of sediment is collected adjacent to the plates and analysed for particle grain size (wet sieve, RJ Hill laboratories), enabling assessment of sediment muddiness.

Sediment oxygenation is visually assessed in the field by measuring the depth at which sediments show a change in colour to grey/black, commonly referred to as the apparent Redox Potential Discontinuity (aRPD). Results for all indicators are compared to condition ratings of ecological state shown in Table 1.

RESULTS

Table 2 shows a summary of results for the latest survey and their respective condition ratings. Results for all surveys are provided in Table 3, and cumulative changes in sediment depth over plates are shown in Fig 2. Note that the estuary was not surveyed in 2022 (see footnote to Table 3).

Table 2. Indicator summary and condition ratings from the December 2023 survey.

Indicator	A	B	D
Sedimentation (mm/yr)*	+2.8	+4.8	+2.4
Mud content (%)	11.6	85.0	28.0
aRPD (mm)	11	5	8

* Sedimentation is presented as the long-term mean annual rate over the monitored period (n=6 yrs Sites A & B, n=5 yrs Site D).

Sedimentation rate

Sedimentation has been highly variable in Kaikorai Estuary since monitoring began (Fig 2, Table 3), however longer-term trends indicate there is generally more sediment accrual than erosion. The long-term average sedimentation rates at all sites were rated 'poor' as they exceeded the national guideline of 2mm/yr (Tables 1, 2).

Table 1. Summary of condition ratings for sediment plate monitoring.

Indicator	Unit	Very Good	Good	Fair	Poor
Sedimentation rate[1]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[2]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD[3]	mm	≥ 50	20 to < 50	10 to < 20	< 10

Condition ratings adapted from: [1]Townsend and Lohrer (2015), [2]Robertson et al. (2016), [3]FGDC (2012) – references in Forrest et al. (2022).

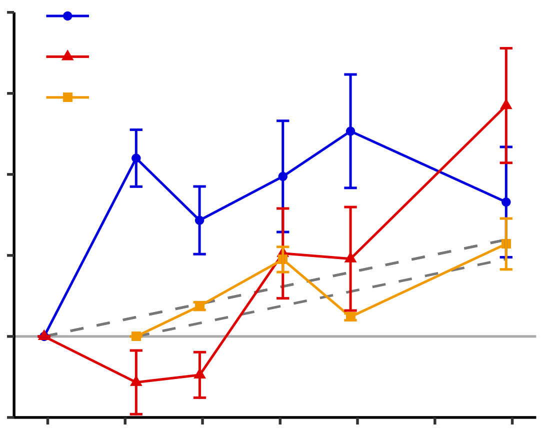


Fig. 2. Change in mean sediment depth over buried plates (±SE) relative to baseline depths. The dashed grey lines show sediment accrual at the national guideline upper limit of 2mm/yr.

Sediment mud content and oxygenation

The monitoring sites in Kaikorai Estuary describe three distinct regions of sediment mud-content, as follows:

- Well-flushed lower estuary Site A is mostly mobile sand-dominated sediment, with around 11% mud-content (rating 'fair'; Table 3).
- Mid-estuary Site B is in an area of very soft mud-dominated sediment (around 78% mud-content, rated 'poor').
- Upper estuary Site D sits around 38% mud-content (also rated 'poor').

Table 3. Sedimentation, grain size and aRPD results up to December 2023*.

Site	Survey	Sed rate mm/yr	Gravel %	Sand %	Mud %	aRPD mm
A	Dec-2017	na	0.1	85.7	14.3	30
	Feb-2019	18.5	0.1	93.0	7.0	70
	Dec-2019	-9.4	0.1	91.8	8.2	38
	Jan-2021	11.1	< 0.1	87.0	13.0	35
	Nov-2021	6.4	< 0.1	89.7	10.3	10
	Dec-2023	-4.4	0.1	88.4	11.6	11
B	Dec-2017	na	0.2	34.8	65.0	0
	Feb-2019	-4.8	0.3	27.8	72.0	5
	Dec-2019	-0.8	0.2	21.9	78.0	3
	Jan-2021	14.0	0.4	13.2	86.4	2
	Nov-2021	-0.8	5.3	11.9	82.8	5
	Dec-2023	9.4	0.1	15.0	85.0	5
D	Feb-2019	na	0.9	57.4	41.7	20
	Dec-2019	4.6	0.6	62.7	36.7	3
	Jan-2021	5.3	0.6	41.5	57.9	2
	Nov-2021	-8.1	0.4	73.4	26.2	15
	Dec-2023	4.5	0.8	71.2	28.0	8

< All values below lab detection limit.
** The estuary was not surveyed in 2022. Due to entrance conditions, water levels did not drain sufficiently at low tide to enable the sites to be accessed.*

The results in Table 3 suggest that mud-content has increased in recent surveys at Site B and decreased at Site D, possibly as sediment is resuspended and deposited further downstream.

Sediment oxygenation has been shallow at all sites in the estuary over the last few years (Table 3), which may in part be linked to sediment mud-content trends, as fine-grained muddy particles can reduce oxygen penetration deeper into the sediment. However, the depth of the aRPD can vary for many reasons. Importantly, none of the sites showed symptoms of gross enrichment (e.g., intense black sediment colour & strong sulfide odour).

CONCLUSIONS

Long-term sedimentation has exceeded the 2mm/yr national guideline value at all sites, although year-to-year changes have been highly variable. Changes at Site A are likely related to bedload sand movement, whereas Site B appears to be in a depositional area that is likely more strongly influenced by catchment inputs. The December 2023 results overall show that the estuary flats remains under pressure from upstream anthropogenic influences. In addition to sedimentation, growths of the opportunistic green macroalgae *Ulva* spp. were again extensive at Site D in December 2023, which is potentially related to elevated catchment nutrient inputs.

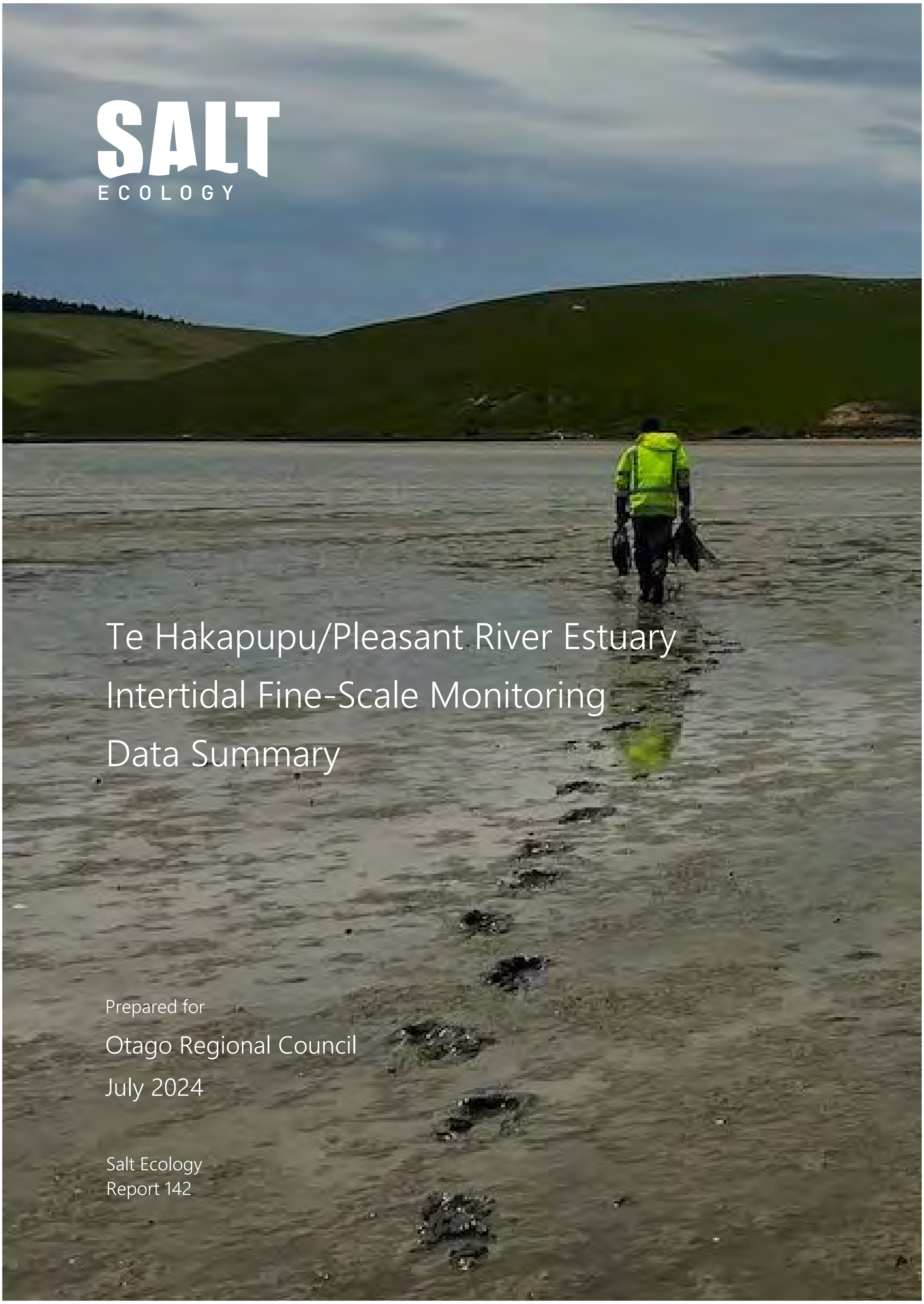
Extensive cover of *Ulva* spp. at Site D in Nov-2023.

RECOMMENDED MONITORING

Ideally, annual monitoring of sedimentation rate, sediment grain size and aRPD depth, would be continued. However, due to ongoing diffuculty in accessing the sites for sampling (due to insuffcient water drainage at low tide), sampling may need to be more opportunistic and linked to periods when the entrance is mechanically opened to enable the estuary to drain. This matter can be further considered as part of a wider estuary programme review to be undertaken by ORC.

REFERENCE

Forrest BM, Stevens LM, Rabel H. 2020. Fine scale intertidal monitoring of Kaikorai Estuary. Salt Ecology Report 042, prepared for Otago Regional Council, June 2020. 42p.



SALT ECOLOGY

Te Hakapupu/Pleasant River Estuary Intertidal Fine-Scale Monitoring Data Summary

Prepared for

Otago Regional Council

July 2024

Salt Ecology
Report 142

Cover photo: Northern upper mud flats of Pleasant River Estuary, December 2023.

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SALT ECOLOGY

For the People
Mō ngā tāngata

Te Hakapupu/Pleasant River Intertidal Fine-Scale Monitoring Data Summary

Prepared by

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for

Otago Regional Council
July 2024

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For the environment
Mō te taiao

SALT ECOLOGY

GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
Hg	Mercury
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of Environment (Monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
Zn	Zinc

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for his support in undertaking this work and review of the report, and to Leigh Stevens and Sabine O'Neill-Stevens (Salt Ecology) for field assistance. Leigh Stevens reviewed the draft report review.

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TABLES

1. INTRODUCTION

In November 2021 and 2022, and December 2023, Otago Regional Council (ORC) undertook three ecological and sediment quality surveys across two monitoring sites in Te Hakapupu/Pleasant River Estuary (hereafter Pleasant River; Fig. 1).

A report was produced on the first survey (Forrest et al. 2022), with data from the two subsequent surveys archived. This report provides a high-level summary of the data for all three surveys, to support a planned review of ORC's estuary State of the Environment (SOE) monitoring programme.

Fig. 1. Location of the two fine-scale monitoring sites in Pleasant River Estuary. The schematic depicts the sediment sample and macrofauna core collection. Site information and GPS positions are provided in Forrest et al. (2022).

2. METHODS

The survey methods are described in Forrest et al. (2022) and were based on the 'fine-scale' approach in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). Monitoring indicators and methods are described in Appendix 1, and included:

Sediment quality indicators: Sediment mud content, oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients and organic content, and selected trace contaminants.

Sediment aRPD was measured in the field. For the other variables, three samples (each composited from 3-4 sub-samples of the surface 20mm of sediment) were collected and sent to Hill Labs for analysis. Annual sedimentation rates have also been measured, with results separately described in Rabel (2024).

Biotic indicators: Surface-dwelling snails and macroalgae, and benthic macrofauna. Macrofauna sampling was undertaken using nine cores (130mm diameter, 150mm deep, ~2L volume, sieved to 0.5mm).

Macrofauna species taxonomy and counts were made by NIWA for all surveys. The data analysis methods are described in Forrest et al. (2022). Macrofauna assessment included calculation of scores for the international biotic health index 'AMBI'.

To assess estuary health, results for most indicators are evaluated against 'condition ratings' described in Appendix 2.

3. KEY FINDINGS

An overall summary of results, with condition ratings applied where available, is provided in Table 1.

3.1 SEDIMENT QUALITY

Sediment quality data are collated in Appendix 3. Sediment at both sites primarily comprised muddy sand (25-50% mud), with the mud content rated 'Poor' across all surveys (Fig. 2, Table 1). Mud content has been relatively stable at Site B, but increased at Site A from 38% mud in 2021 to 51% mud in 2023.

The moderately high and variable mud content at Site A likely reflects its location on a relatively elevated flat on the outer bend of the main channel. Fine sediment deposition appears greater here than on the surrounding lower estuary flats which have stronger tidal flows and are generally sandier.

Similarly, the generally sheltered and less well-flushed upper estuary (including at Site B) also has large areas of mud-elevated substrates (Roberts et al. 2022).

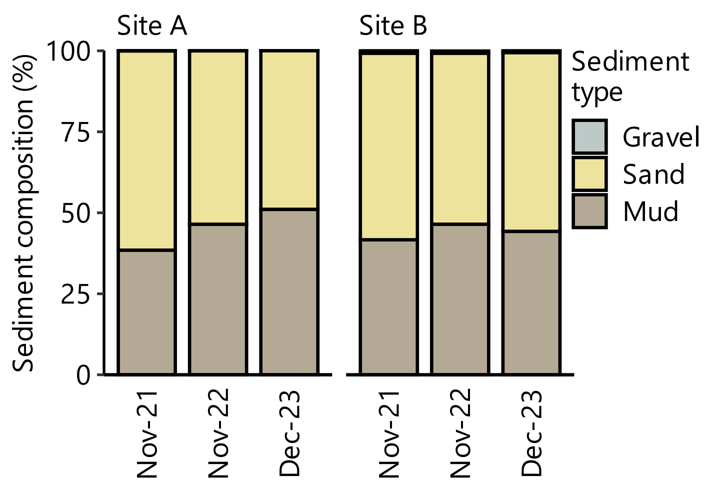

Fig. 2. Sediment particle grain size analysis showing percentage composition of mud (<63μm), sand (<2mm to ≥63μm) and gravel (≥2mm) from composite samples (n=3) at fine-scale sites.

Sediment oxygenation was shallow at both sites across all surveys, and was rated 'Poor' (Fig. 3). Sediment core photos (see next page) illustrate the aRPD transition between oxygenated brown sediment near the surface and darker oxygen-depleted sediment deeper in the core (Fig. 4). This transition was not uniform with lighter brown/orange sediment around infauna burrows reflecting variable oxygenation as a result of bioturbation (Fig. 4).

Site A in the lower estuary, December 2023.

Site B in the upper estuary, December 2023.

Although elevated mud-content and shallow aRPD depths provide an indication of degraded sediment conditions, there were no signs of excessive enrichment; i.e., intense black-coloured sediment with a strong sulphide ('rotten egg') odour.

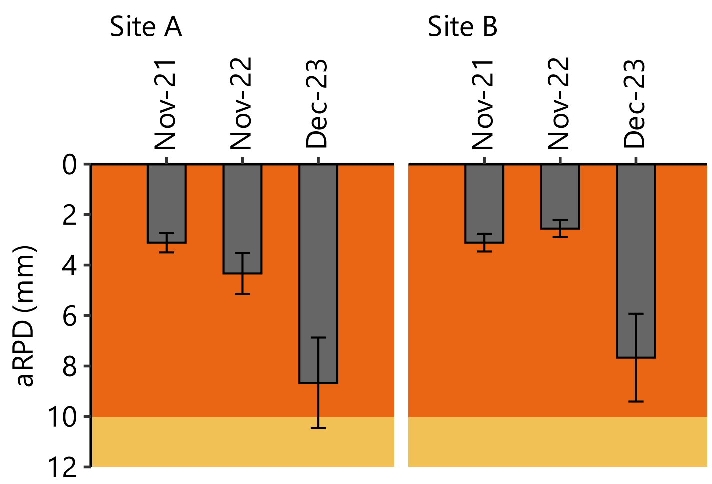

Fig. 3. Mean (±SE, n=9) aRPD depth, relative to condition ratings.

Very Good	Good	Fair	Poor

Table 1. Summary of mean values of key indicators at fine-scale monitoring Sites A and B in Pleasant River Estuary. Values are rated against condition scores of ecological health, where available (Appendix 2). See Glossary for definition of indicators.

Site	Year	Mud %	aRPD mm	TN mg/kg	TP mg/kg	TOC %	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	Rich. na	Abun. na	AMBI na
A	Nov-21	38.5	3	900	483	0.69	4.5	0.04	8.7	2.8	< 0.02	5.1	3.7	22.3	21	960	3.6
	Nov-22	46.5	4	733	437	0.53	4.5	0.036	8.5	2.8	< 0.02	5.2	3.5	22.7	19	490	2.8
	Dec-23	51.0	9	857[1]	537	0.60	5.7	0.041	10.1	3.4	< 0.02	6.4	4.2	27.0	17	348	2.9
B	Nov-21	41.7	3	450*	440	0.40	4.3	0.039	7.7	2.4	< 0.02	4.5	3.2	23.3	16	435	3.5
	Nov-22	46.5	3	<500	407	0.31	4.1	0.036	6.9	2.2	< 0.02	4.1	2.8	21.7	15	251	3.0
	Dec-23	44.2	8	530[1]	437	0.26	4.4	0.037	7.1	2.1	< 0.02	4.2	2.8	23.0	12	256	2.9

[1]Sample mean includes raw values
** Sample mean includes values below lab detection limits*
< All values below lab detection limit

Very Good	Good	Fair	Poor

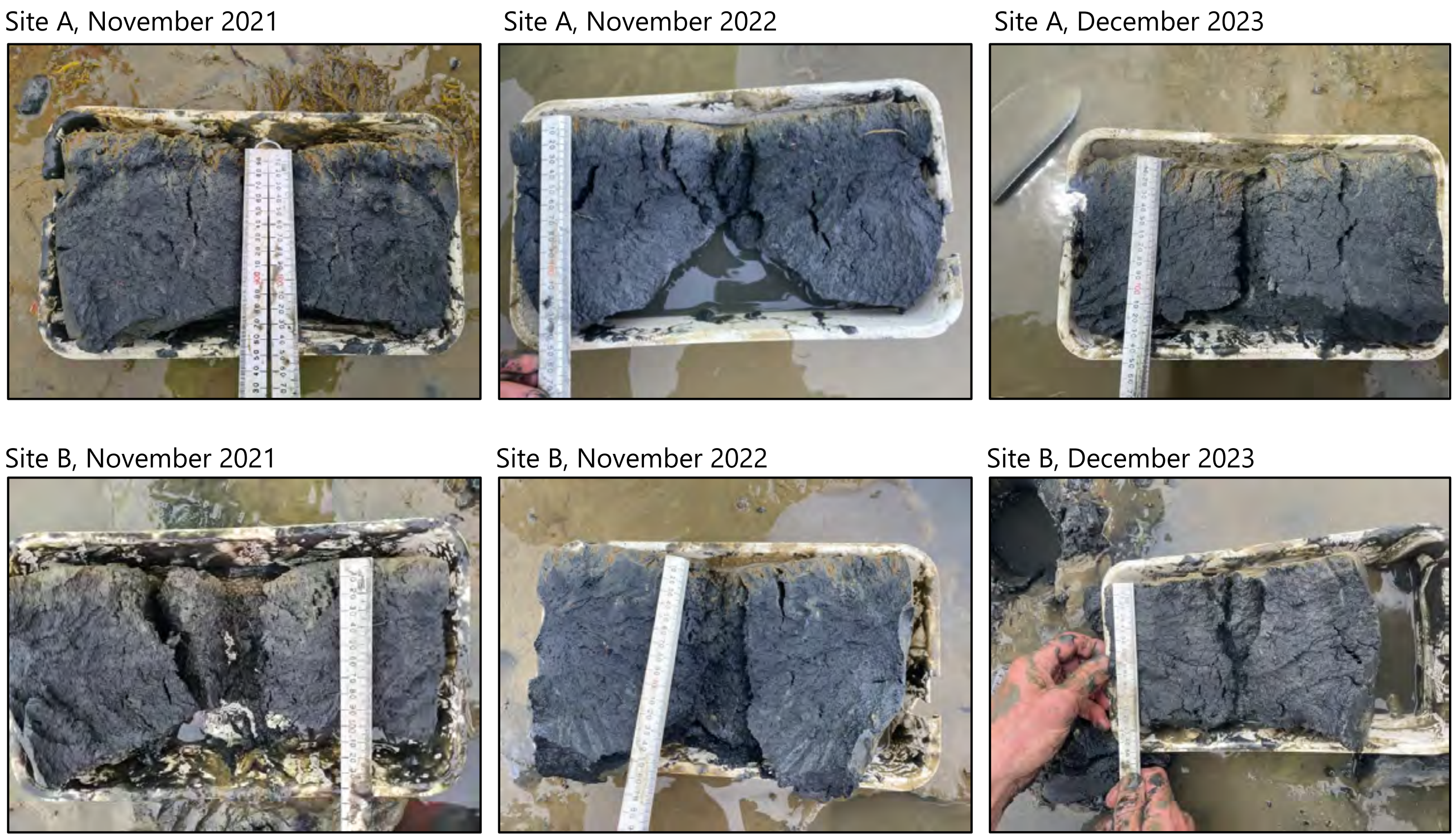

Fig. 4. Sediment core profiles from Site A and B. Oxygen-depleted sediment is illustrated by the deeper grey/black colour.

Laboratory analyses revealed low levels of organic matter (measured as Total Organic Carbon, TOC), corresponding to ratings of 'Good' and 'Very good' at Sites A and B respectively (Fig. 5). Nutrients were also low, with total nitrogen (TN) rated 'Good' at both sites, although levels were higher at Site A than Site B (Fig. 5).

Sediment trace metal concentrations were very low in all three surveys, and were rated 'Very good'. All values were less than half of the ANZG (2018) Default Guideline Value (DGV) which indicates *"…the concentrations below which there is a low risk of unacceptable effects occurring"* (Table 1, Fig. 6).

Overall, the results indicate low concentrations of catchment-sourced contaminants in the estuary.

Site A in the lower estuary, December 2023.

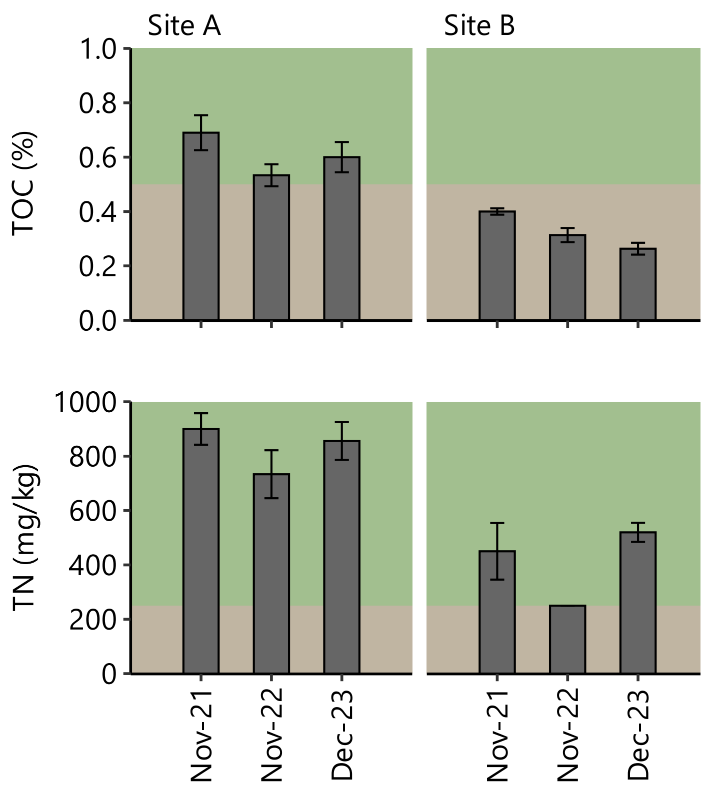

Fig. 5. Mean (±SE, n=3) total organic carbon (TOC) and total nitrogen (TN), relative to condition ratings. TN values at Site B in 2022 were all less than routine laboratory method detection limits and the value plotted is 50% of the detection limit.

Very Good	Good	Fair	Poor

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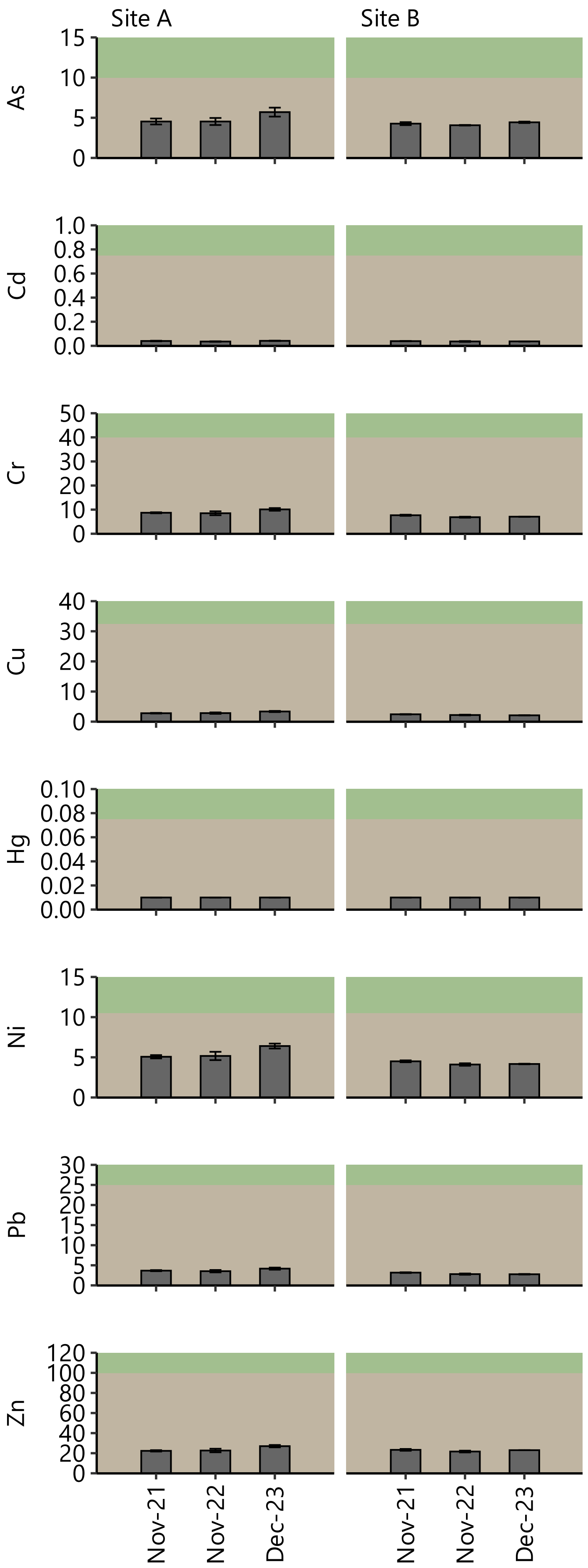


Fig. 6. Mean (±SE, n=3) trace metal concentrations, relative to condition ratings. The 'Very good' / 'Good' boundary represents 50% of the ANZG (2018) sediment quality Default Guideline Value (DGV). Hg values were less than routine laboratory method detection limits and values plotted are 50% of the detection limit.

3.2 BIOTA

Surface dwelling epibiota

Epibiota comprised three conspicuous species. The mud whelk *Cominella glandiformis* was common across both sites. The horn snail *Zeacumantus subcarinatus* (a small mud snail that grazes on microalgae and seaweed) was abundant at Site B, yet generally absent at Site A. The mudflat topshell *Diloma subrostratum* was more abundant at lower estuary Site A (Table 2).

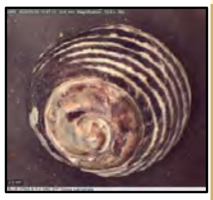
Two opportunistic (aka 'nuisance') seaweeds have been recorded within the estuary: the green 'sea lettuce' *Ulva* spp. and the red seaweed *Gracilaria* spp. (Roberts et al. 2022). Both species were generally sparse at fine-scale sites, with *Gracilaria* spp. cover reducing at Site A between 2021 and 2023 (Table 2).

Seagrass *Zostera muelleri* was absent at Site B, and <1% cover at Site A, having first established there in November 2022 and increasing slightly in extent by December 2023 (Table 2).

The seaweed *Gracilaria* spp. was common (15% cover) across Site A in November 2021, but had reduced to 1% cover in 2023.

Ecologically-important seagrass was first observed at Site A in November 2022.

Table 2. SACFOR scores for epibiota (S=super abundant, A=abundant, C=common, F=frequent, O=occasional, R=rare), based on the categories in Appendix 1.

Species	Common name	Functional description	Image	Site A Nov-2021	Site A Dec-2022	Site A Nov-2023	Site B Nov-2021	Site B Dec-2022	Site B Nov-2023
Invertebrates									
Cominella glandiformis	Mud whelk	Carnivore and scavenger		C (21)	Absent	C (25)	C (25)	Absent	C (15)
Diloma subrostratum	Mudflat topshell	Grazer and deposit feeder		F (3)	F (5)	F (4)	O (1)	O (1)	O (1)
Zeacumantus subcarinatus	Horn snail	Grazer		Absent	F (7)	Absent	A (250)	A (320)	A (700)
Macroalgae									
Gracilaria spp.	Red seaweed	Primary producer		C (15%)	F (2%)	O (1%)	R (0.5%)	F (5%)	R (0.25%)
Ulva spp.	Green seaweed/ Sea lettuce	Primary producer		R (0.1%)	R (0.1%)	R (0.5)	R (0.05%)	R (0.05%)	Absent
Seagrass									
Zostera muelleri	Seagrass	Primary producer		Absent	R (0.01%)	R (0.25%)	Absent	Absent	Absent

Sediment-dwelling macrofauna

Macrofauna core species and their abundances are summarised in Appendix 4. Macrofauna were moderately diverse and included a range of sensitive to more hardy species. Key points are as follows:

- A total of 55 species or higher macrofauna taxa have been recorded from the two sites over the three surveys. Thirteen main taxonomic groups are represented, with polychaete worms by far the most abundant, and high numbers of amphipods, bivalves, and gastropods (Appendix 4).
- Mean species richness was higher at Site A, in the lower estuary (average ~19 taxa per core), than at Site B in the upper estuary (~14 taxa per core). The highest species richness was recorded in 2021 at both sites (Fig. 7a).
- By far the most abundant species were the polychaetes *Paradoneis lyra* (eco-group EG-III), *Boccardia syrtis* (EG-II), and *Capitella cf. capitata* (EG-V) which dominated the community in all surveys (Table 3).
- The highest abundance occurred in 2021 at Site A, with a mean of 960 organisms per core (Fig. 7b).

This result was driven primarily by high densities of the polychaetes *Capitella cf. capitata* (EG-V) and *Boccardia syrtis* (EG-II), and the amphipod *Paracalliope novizelandiae* (EG-I), which may have been associated with elevated nuisance macroalgal growth recorded from the estuary in 2021 (see Roberts et al. 2022).

- Mean values of the biotic index AMBI corresponded to a condition rating of 'Fair' at both sites in 2021, but improved to a rating of 'Good' in subsequent years, primarily due to a reduction in numbers of the hardy polychaete *Capitella cf. capitata* (EG-V). (Table 1, Fig. 8).
- Fig. 9a shows that across all three baseline years, most taxa consisted of a suite of sensitive (EG-I) to moderately sensitive (EG-III) organisms.

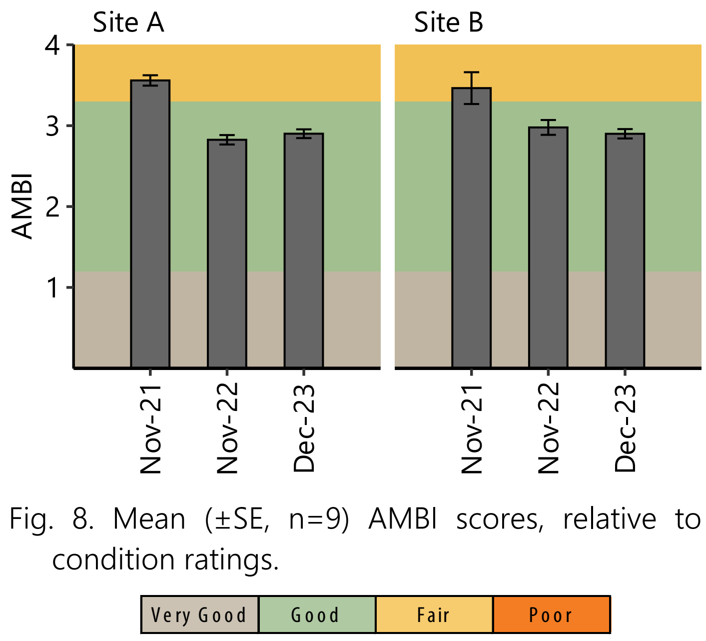


Fig. 8. Mean (±SE, n=9) AMBI scores, relative to condition ratings.

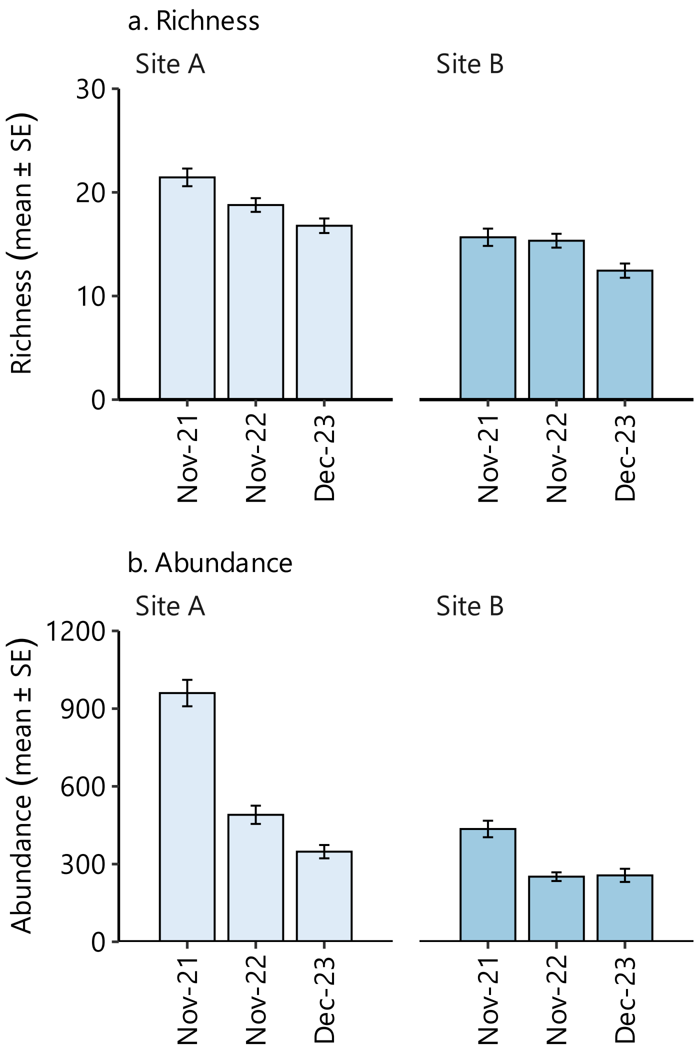


Fig. 7. Mean (±SE, n=9) macrofauna taxon richness and abundance per core.

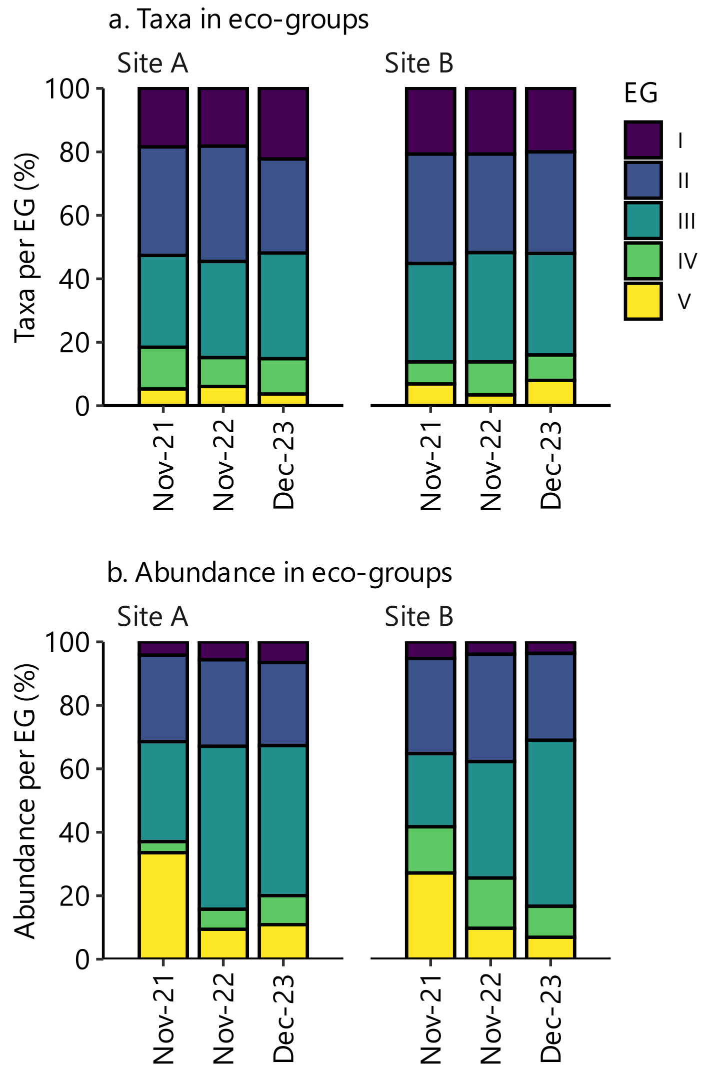


Fig. 9. Contribution to site richness and abundances of macrofauna species in eco-groups (EG) ranging from sensitive (EG-I) to resilient (EG-V).

Table 3. Dominant sediment-dwelling macrofauna at Sites A and B. Numbers are site-aggregated total abundances.

Main group	Taxa	EG	Site A Nov-21	Site A Nov-22	Site A Dec-23	Site B Nov-21	Site B Nov-22	Site B Dec-23	Description
Polychaeta	*Paradoneis lyra*	III	2413	2001	1261	778	759	1146	Common paraonid worm considered to be reasonably tolerant of muddy sediment and organic enrichment. Paraonids are considered to be deposit feeders, possibly selectively feeding on microscopic diatoms and protozoans.
Polychaeta	*Capitella cf. capitata*	V	2894	411	341	1063	221	156	Subsurface deposit feeder, occurs down to about 10 cm sediment depth. Common indicator of organic enrichment or other forms of disturbance. Is a dominant inhabitant of sediments polluted heavily with organic matter.
Polychaeta	*Boccardia syrtis*	II	1825	942	644	927	652	537	A small surface deposit-feeding spionid. Found in a wide range of sand/mud habitats. Lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Sensitive to organic enrichment.
Polychaeta	*Scolecolepides benhami*	IV	261	245	239	564	351	221	A spionid, surface deposit feeder. It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark.
Polychaeta	*Prionospio aucklandica*	III	182	149	145	40	15	22	A surface deposit-feeding spionid common in harbours and estuaries. Associated mainly with muddy sands, but occurs across a range of mud contents.
Polychaeta	*Microphthalmus riseri*	II	324	74	63	61	0	13	A little-known polychaete worm from Family Phyllodocidae.
Polychaeta	*Scoloplos cylindrifer*	I	180	90	56	105	67	43	Belongs to Family Orbiniidae which are thread-like burrowers. Common in intertidal sands of estuaries. Long, slender, sand-dwelling unselective deposit feeders. Pollution and mud intolerant.
Polychaeta	*Sabellidae*	I	14	139	117	93	1	5	Referred to as fan or feather-duster worms and are so-called from the appearance of the feeding appendages, which comprise a crown of two semicircular fans of stiff filaments projected from their tube.
Anthozoa	*Edwardsia* sp.	II	73	108	39	126	19	1	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
Amphipoda	*Paracalliope novizealandiae*	I	156	7	16	2	7	33	Amphipods are shrimp-like crustaceans. This species is common in New Zealand estuaries. Despite a sensitive (EG-I) classification (based on *Paracalliope sp.*), this New Zealand species appears to tolerate muddy habitats.
Bivalvia	*Arthritica* sp. 5	III	26	59	40	61	31	26	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.
Gastropoda	*Zeacumantus subcarinatus*	II	0	1	0	37	64	70	Can be common in soft sediment and rocky habitats. Grazes on microalgae and seaweed. Can be abundant on sediment surface but highly patchy across estuaries.

A cursory analysis of overall macrofauna community composition differences among sites and surveys was undertaken. A multivariate method was used to 'group' sites according to their similarity in macrofauna composition (Fig. 10), and revealed the following:

- Macrofauna differences between the two sites were not pronounced, with samples tightly grouped and displaying a 75% similarity in community composition between sites and across most years.
- Site B was differentiated from Site A mainly by the presence of *Zeacumantus subcarinatus*.
- In 2021, Site A was differentiated from all other samples due to the high abundance of many dominant or co-dominant taxa (e.g., *Capitella cf. capitata*, *Microphthalmus riseri*, *Boccardia syrtis*) rather than a shift in species composition.

The two sites had similar sediment quality parameters, which likely explains the similarity in community composition between sites. The analysis indicated that the sediment parameters potentially having the strongest influence on community composition were TOC (Spearman rank correlation coefficient p=0.92) followed by TN (ρ=0.86; see also Fig. 8). However, these parameters were themselves highly correlated (0.88), and concentrations were very low overall (see Fig. 5 and Table 1). As such, despite their apparent association with macrofaunal differences, we suggest that the changes in TOC and TN are unlikely to be ecologically significant in terms of cause-effect.

The multivariate analysis provided no evidence that differences in mud content among sites and surveys was having a strong influence on community composition. Muddy sediment is regarded as one of the key drivers of ecological degradation in New Zealand estuaries (Cummings et al. 2003; Robertson et al. 2015; Berthelsen et al. 2018; Clark et al. 2021). A mud content of around 20-30% is often considered the threshold at which large macrofaunal composition changes become most evident relative to sandier sediments (Robertson et al. 2015; Robertson et al. 2016a; Ward & Roberts 2021; Bulmer et al. 2022; Stevens et al. 2024). As mud contents at the two monitoring sites are consistently above this indicative threshold, it is possible that macrofauna will be insensitive to the relatively small changes in sediment muddiness recorded.

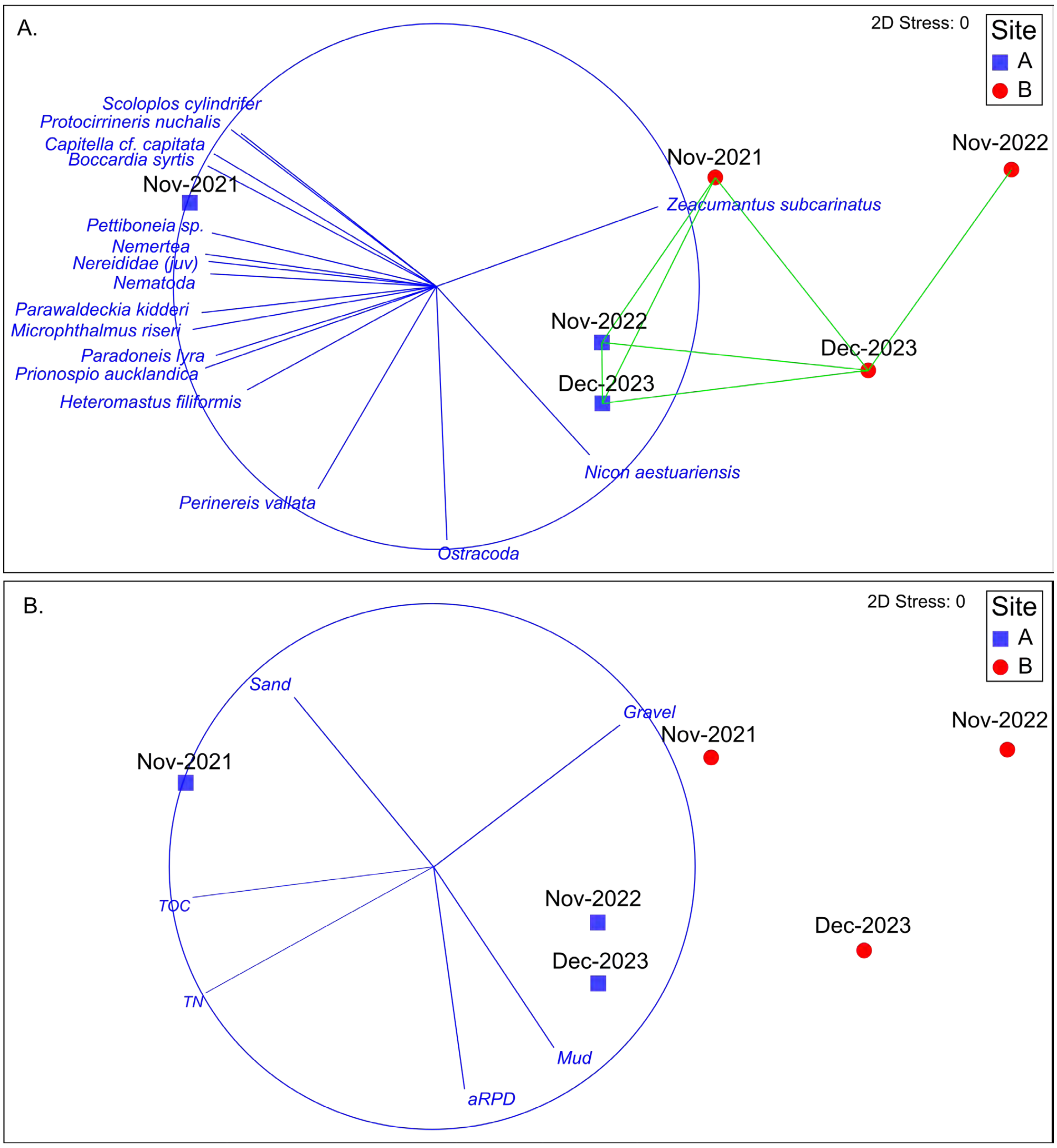


Fig. 10. Non-metric MDS ordination of macrofaunal core samples for data aggregated within each site and survey with vector overlays indicating the association of species (A) and environmental variables (B).

Sample groups closer to each other are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of 0.0 indicates that a 2-dimensional plot provides a reliable representation of differences. The green lines in the top plot (A) connect sample groups with a high similarity (75%) based on the Bray-Curtis measure. The vectors show the direction and strength of association (length of line relative to circle) of the species (A) and measured sediment variables (B) that were most strongly correlated with the pattern of differences.

4. MONITORING AND MANAGEMENT IMPLICATIONS

ORC undertook broad-scale habitat mapping of Pleasant River in 2021 (Roberts et al. 2022), complemented by baseline fine-scale monitoring as described in this report. The 2021 broad-scale survey highlighted that the estuary is facing stresses due to elevated inputs of nutrients and fine muddy sediments, with poor sediment oxygenation in places, and areas with nuisance macroalgal growths. These results suggest catchment sediment and nutrient loads are exceeding the estuary's assimilative capacity in places, consistent with the highly modified catchment comprising mostly pastoral land uses and exotic forest (Roberts et al. 2022).

In contrast, at the fine scale sites, sediment chemistry results indicate low concentrations of organic content, nutrients and contaminants, and the biota appears to be reasonably healthy and more diverse than many other estuaries in ORC's SOE monitoring programme.

One of the reasons for compiling the present summary report was to better understand the utility of the current fine-scale monitoring approach in light of such apparent inconsistency between broad- and fine-scale results. Once data for all Otago estuaries have been collated in a similar way, ORC will be in a better position to review the programme and determine monitoring priorities.

In this broader context, Pleasant River presents some features that will need to be accounted for in the review, particularly the fact that the existing fine-scale sites may not necessarily be representative of the muddier and more highly enriched conditions observed elsewhere.

Nonetheless, Sites A and B are useful baseline sites representative of the estuary mudflats, and these locations are suitable to inform changes in eutrophication symptoms across the estuary's extensive intertidal area. The macrofauna communities had relatively high diversity, generally good AMBI scores and, for the most part, consisted of moderately sensitive taxa in EG-II and III. Relatively consistent community composition across sites and between years provides a stable baseline, increasing the likelihood that future monitoring will detect a shift in community composition due to anthropogenic pressures or restoration efforts within the estuary and catchment area.

However, as the sediment mud content at both fine-scale sites already exceeds the thresholds where macrofauna changes in estuaries are typically most pronounced, it is unclear just how sensitive macrofauna will be to future mud or eutrophication changes in the estuary.

Despite this, the current fine-scale sites appear suitable for monitoring responses to long-term changes in catchment pressures that could lead to estuary-wide habitat changes over decadal time scales, which aligns with the original purpose of the NEMP approach. However, in the context of the immediate pressures on the estuary, the sites are less well suited to monitoring direct catchment effects of eutrophication or sedimentation, as they are not within the parts of the estuary that are currently showing signs of degradation or are at high risk of becoming degraded.

These considerations should be part of ORC's review of the regional estuary SOE programme. The review should consider the specific type of monitoring needed to meet management goals in Pleasant River, and the priorities for monitoring in that location relative to other estuary systems in Otago. Ideally, given sufficient funds and resources, the fine scale approach in Pleasant River would ideally be extended to encompass more vulnerable habitats in the estuary, to better track catchment-related influences.

5. RECOMMENDATIONS

There is merit in continued fine-scale monitoring in Pleasant River Estuary given the acknowledged catchment pressures and degradation captured by broad-scale mapping. However, it is recommended that a decision on the approach taken to future fine-scale and other monitoring needs is determined as part of ORC's planned review of the regional estuary SOE programme.

6. 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.

Berthelsen A, Atalah J, Clark D, Goodwin E, Patterson M, Sinner J 2018. Relationships between biotic indices, multiple stressors and natural variability in New Zealand estuaries. Ecological Indicators 85: 634-643.

Bulmer RH, Stephenson F, Lohrer AM, Lundquist CJ, Madarasz-Smith A, Pilditch CA, Thrush SF, Hewitt JE 2022. Informing the management of multiple stressors on estuarine ecosystems using an expert-based Bayesian Network model. Journal of Environmental Management 301: 113576.

Clark DE, Stephenson F, Hewitt JE, Ellis JI, Zaiko A, Berthelsen A, Bulmer RH, Pilditch CA 2021. Influence of land-derived stressors and environmental variability on compositional turnover and diversity of estuarine benthic communities. Marine Ecology Progress Series 666: 1-18.

Cummings V, Thrush S, Hewitt J, Norkko A, Pickmere S 2003. Terrestrial deposits on intertidal sandflats: sediment characteristics as indicators of habitat suitability for recolonising macrofauna. Marine Ecology Progress Series 253: 39-54.

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.

Forrest BM, Roberts KL, Stevens LM 2022. Fine scale intertidal monitoring of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 093, prepared for Otago Regional Council, June 2022. 29p.

Rabel H 2024. Pleasant River (Te Hakapupu) Estuary 2023/2024 Intertidal sediment monitoring summary. Salt Ecology Short Report 043. Prepared for Otago Regional Council, May 2024.

Roberts KL, Stevens L, 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 B, Gardner J, 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 B, 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 L, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016a. NZ Estuary Trophic Index Screening Tool 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 L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016b. 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.

Stevens LM, Roberts KL, Forrest BM, Morrisey D, Zeldis JR, Dudley BD, Mangan S, Lam-Gordillo O, Lundquist C, Lohrer AM, Plew DR 2024. Advice on Indicators, Thresholds and Bands for Estuaries in Aotearoa New Zealand. Salt Ecology Report 141, prepared for Ministry for the Environment, June 2024. 182p.

Ward N, Roberts K 2021. Estuaries and Coast: Classification and Attributes for Southland. Environment Southland publication number 2020-03, Environment Southland: Invercargill. 107p. ISBN 978-0-909043-63-6.

APPENDIX 1. SUMMARY OF NEMP FINE-SCALE INDICATORS

The rationale for each indicator and sampling method is provided. The main 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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Samples sent to Hill Labs for analysis.
Nutrients (nitrogen and phosphorus), and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site. Organic matter measured as Total Organic Carbon (TOC) (note 1). Samples sent to Hill Labs for analysis.
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.	Three composited (3-4 sub-samples) surface scrapes to 20mm sediment depth per site (note 2). Samples sent to Hill Labs for analysis.
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.	Nine sediment cores per site, split vertically, with average depth of aRPD (for each core) 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.	Nine sediment cores per site (130mm diameter, 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 (note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR (note 3).
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR (notes 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 (abundance), macroalgae (%) and microalgae (%) used the 'SACFOR' approach: S=Super abundant (>1000 organisms/m^2, >50% cover), A=Abundant (100-999 organisms/m^2, 20-50% cover), C=Common (10-99 organisms/m^2, 10-19% cover), F=Frequent (2-9 organisms/m^2, 5-9% cover), O=Occasional (0.1-1 organisms/m^2, 1-4% cover), and R=Rare (<0.1 organisms/m^2, <1% cover). See Forrest et al. 2022 for further detail.

4. The 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.

APPENDIX 2. CONDITION RATINGS FOR ASSESSING ESTUARY HEALTH

No rating criteria exist for Total Phosphorus (TP), or macrofauna variables other than AMBI. See Glossary for definition of indicators.

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
TOC[1]	%	<0.5	0.5 to <1	1 to <2	≥2
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. (2016b).

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.

APPENDIX 3. SEDIMENT QUALITY DATA

Values based on a composite sample within each of Zone X (reps X1-3), Y (reps Y4-6) and Z (reps Z7-9), except for aRPD for which the mean and range is shown for 9 replicates.

DGV = Default guideline value for sediment quality (ANZG 2018); GV-High = Guideline Value High.

Site	Survey	Zone	Gravel %	Sand %	Mud %	TOC %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg
A	Nov-21	X	0.2	59.4	40.5	0.79	1000	500	2.7 (2 to 4)	4.8	0.044	9.0	2.9	<0.02	5.4	3.8	23
		Y	<0.1	62.9	37.1	0.71	900	500	3.7 (2 to 5)	5.0	0.036	8.8	2.9	<0.02	5.1	3.8	23
		Z	<0.1	62.1	37.8	0.57	800	450	3.0 (2 to 4)	3.8	0.04	8.3	2.6	<0.02	4.7	3.4	21
	Nov-22	X	<0.1	54.0	45.9	0.54	700	380	3.3 (2 to 5)	4.0	0.036	7.5	2.6	<0.02	4.6	3.1	20
		Y	<0.1	50.2	49.8	0.6	900	500	3.0 (2 to 4)	5.4	0.039	10.1	3.3	<0.02	6.2	4.1	26
		Z	<0.1	56.3	43.7	0.46	600	430	6.7 (10 to 5)	4.2	0.032	7.9	2.6	<0.02	4.7	3.4	22
	Dec-23	X	<0.1	45.9	54.1	0.67	817*	490	11.3 (14 to 5)	5.3	0.04	10.0	3.5	<0.02	6.6	4.2	27
		Y	<0.1	45.0	55.0	0.64	991*	560	10.0 (11 to 3)	6.8	0.044	11.1	3.6	<0.02	6.8	4.6	29
		Z	<0.1	56.0	44.0	0.49	760*	560	4.7 (2 to 6)	5.0	0.04	9.2	3.0	<0.02	5.8	3.7	25
B	Nov-21	X	0.3	59.9	39.8	0.42	600	460	3.3 (2 to 4)	4.4	0.039	7.6	2.5	<0.02	4.5	3.2	23
		Y	1.6	55.6	42.8	0.38	<500	400	3.3 (2 to 5)	3.9	0.037	7.3	2.3	<0.02	4.3	3.0	22
		Z	0.5	57.1	42.4	0.4	500	460	2.7 (2 to 3)	4.5	0.041	8.1	2.5	<0.02	4.7	3.3	25
	Nov-22	X	0.3	55.7	43.9	0.27	<500	430	2.7 (2 to 4)	4.1	0.041	7.0	2.2	<0.02	4.2	2.7	22
		Y	1.3	54.8	43.9	0.31	<500	370	2.3 (2 to 3)	4.0	0.03	6.5	2.0	<0.02	3.8	2.6	20
		Z	0.6	47.7	51.6	0.36	<500	420	2.7 (1 to 4)	4.1	0.038	7.1	2.4	<0.02	4.3	3.1	23
	Dec-23	X	0.6	51.4	47.9	0.29	489*	420	4.3 (1 to 2)	4.3	0.037	7.1	2.1	<0.02	4.2	2.9	23
		Y	0.5	54.1	45.5	0.28	600	440	10.0 (10 to 5)	4.6	0.037	7.0	2.1	<0.02	4.2	2.7	23
		Z	0.7	60.0	39.3	0.22	500	450	8.7 (12 to 2)	4.4	0.036	7.1	2.1	<0.02	4.1	2.7	23
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

< value below lab detection limits

*Raw value used as lab technician error increased detection limit for these samples

APPENDIX 4. MACROFAUNA CORE DATA SUMMED ACROSS NINE REPLICATES FOR EACH SURVEY AND SITE

Main group	Taxa	EG	November 2021		November 2022		December 2023	
			A	B	A	B	A	B
Amphipoda	Aoridae	I		1				
Amphipoda	*Paracalliope novizealandiae*	I	156	2	7	7	16	33
Amphipoda	*Paracorophium excavatum*	IV	5		1	1	6	
Amphipoda	*Parawaldeckia kidderi*	II	48	1	1		29	
Amphipoda	*Proharpinia* sp.	I	1					
Amphipoda	*Protorchestia* sp.	II	1					
Amphipoda	*Torridoharpinia hurleyi*	I		2				
Anthozoa	*Edwardsia* sp.	II	73	126	108	19	39	1
Bivalvia	*Arthritica* sp. 5	III	26	61	59	31	40	26
Bivalvia	*Austrovenus stutchburyi*	II	4	2	4	4	2	4
Bivalvia	*Lasaea parengaensis*	II	15	7	25	10	28	5
Bivalvia	*Linucula hartvigiana*	II	3					
Bivalvia	*Macomona liliana*	II			1			
Copepoda	Copepoda	II		10	29	13	6	1
Cumacea	*Colurostylis lemurum*	II	5		2	1		1
Decapoda	*Hemiplax hirtipes*	III	2	2	6	6		
Gastropoda	*Cominella glandiformis*	III	11	6	11	11	12	2
Gastropoda	Dotidae	na	2					
Gastropoda	*Notoacmea* spp.	II	1					
Gastropoda	*Potamopyrgus estuarinus*	IV	1					
Gastropoda	*Zeacumantus subcarinatus*	II		37	1	64		70
Nematoda	Nematoda	III	18	2	4	1	2	4
Nemertea	Nemertea	III	29	14	13	2	15	1
Oligochaeta	Naididae	V	4	3	6			4
Ostracoda	Ostracoda	I			3		3	1
Polychaeta	?Orbiniidae	na	1					
Polychaeta	*Abarenicola* sp.	I			7		3	
Polychaeta	*Aricidea* sp.	I				5		
Polychaeta	*Boccardia proboscidea*	IV	3					
Polychaeta	*Boccardia syrtis*	II	1825	927	942	652	644	537
Polychaeta	*Capitella cf. capitata*	V	2894	1063	411	221	341	156
Polychaeta	Flabelligeridae	II				1		
Polychaeta	*Glycera* spp.	II	1					
Polychaeta	*Heteromastus filiformis*	IV	31	5	32	6	41	4
Polychaeta	*Lagis australis*	III				1		
Polychaeta	*Levinsenia gracilis*	III				4		
Polychaeta	*Macroclymenella stewartensis*	II	2		2			
Polychaeta	Maldanidae (juv)	I	1					
Polychaeta	*Microphthalmus riseri*	II	324	61	74		63	13
Polychaeta	*Microspio maori*	I	1	2	2	6		1
Polychaeta	*Naineris naineris-A*	I	5				9	
Polychaeta	*Neanthes* sp.	III			12			
Polychaeta	*Nereididae* (juv)	III	29				1	
Polychaeta	*Nicon aestuariensis*	III			1	1	1	1
Polychaeta	*Orbinia papillosa*	I				2		
Polychaeta	*Paradoneis lyra*	III	2413	778	2001	759	1261	1146
Polychaeta	*Perinereis vallata*	III	2	1	9		5	6
Polychaeta	*Pettiboneia* sp.	II	56	2	15	1	7	
Polychaeta	*Platynereis* sp.	III	1					
Polychaeta	*Prionospio aucklandica*	III	182	40	149	15	145	22
Polychaeta	*Protocirrineris nuchalis*	III	10	1				
Polychaeta	Sabellidae	I	14	93	139	1	117	5
Polychaeta	*Scolecolepides benhami*	IV	261	564	245	351	239	221
Polychaeta	*Scoloplos cylindrifer*	I	180	105	90	67	56	43
Tanaidacea	Tanaidacea	II		1				
	Site abundance		8641	3919	4412	2263	3131	2308
	Site richness		40	29	33	29	27	25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9.7. Blue carbon potential in the Otago Region

Prepared for:	Environmental Science and Policy Comm
Report No.	GOV2464
Activity:	Governance Report
Author:	Sam Thomas, Senior Coastal Scientist
Endorsed by:	Tom Dyer, General Manager Science and Resilience
Date:	4th December 2024

PURPOSE

[1] This report presents the findings of a recent study by Tidal Research and NIWA into blue carbon habitats within the Otago Region. Blue Carbon is carbon that is stored within marine habitats and ecosystems such as salt marshes, seagrass intertidal sandflats, soft sediment and kelp forests.

[2] The study provides information on the importance of the ecosystem services provided by blue carbon habitats and the potential for restoration opportunities throughout the Otago region around estuaries, both currently, and under potential future sea level rise scenarios.

EXECUTIVE SUMMARY

[3] A regional assessment of current blue carbon sequestration rates in the Otago region was produced to understand the current blue carbon storage and sequestration in Otago.

[4] This report "Blue carbon potential in the Otago region" produced a regional assessment of the blue carbon restoration opportunity under baseline and different sea level rise (SLR) scenarios. This information is for use by both landowners and catchment groups who want to undertake Saltmarsh restoration with the information providing guidelines on suitable areas to undertake this work.

[5] This report highlighted that while Otago currently has only an estimated 2.8% of the national blue carbon habitat extent, it has 13% of the land potentially suitable for restoration projects at a national scale.

[6] The potential for blue carbon to be included into the ETS is outlined. How biodiversity and ecosystem services credits could be added to a carbon price are highlighted, based on the use of this scheme in Australia. This is currently being explored in New Zealand.

RECOMMENDATION

That the Committee:

1) ***Receives** this report.*
2) ***Notes** the opportunity available in the Otago region for the potential to increase blue carbon storage, biodiversity and ecosystem services through restoring salt marsh.*
3) ***Notes** that this report is to provide guidance about potential sites for restoration opportunities for landowners and catchment groups, as well as outlining the current benefits of salt marsh restoration and the potential for future credit opportunities.*

BACKGROUND

[7] Otago Regional Council (ORC) has regulatory obligations under the Resource Management Act 1991 (RMA) and the New Zealand Coastal Policy Statement (NZCPS), particularly Policy 11, to protect indigenous biological diversity in the coastal environment. To better understand the coastal environment, ORC commissioned Tidal Research and NIWA to undertake a review of blue carbon estuarine habitats to understand what has been lost, current state, and identify restoration opportunities. Equally this report was produced to provide a resource to landowners and catchment groups who are looking at restoration projects in the region and the benefits achieved by restoring estuarine habitats in the form of improved ecosystem services.

[8] Blue carbon ecosystems (coastal wetlands including mangroves, saltmarshes, and seagrasses – e.g., Figure 1)) have a large capacity to absorb and store carbon, with blue carbon habitats in many locations exceeding the rates of sequestration of terrestrial habitats. The high capacity to sequester carbon is mainly due to the large amount of carbon stored below ground (in low oxygen environments). The carbon storage of these systems is therefore large, however, small shifts in the habitats of these systems such as drainage of salt marsh or degradation of habitat can result in significant reductions in carbon sequestration potential.

Figure 1: Tautuku estuary; In the foreground intertidal flats, with the fringing salt marsh (jointed wire rush in this picture) along the edge of the estuary. Both habitats contain large storage of blue carbon

[9] Not only are blue carbon ecosystems important for carbon storage but they also provide many other ecosystem services. These services include but are not limited to coastal protection (e.g. from flooding and storm surges), water filtration (e.g., via promoting sediment accretion, taking up nutrients and other pollutants), and enhancing biodiversity and abundance. For example, coastal wetlands can trap sediment, reducing the flux of sediment to the estuarine and coastal environments resulting in benefits to

these marine ecosystems. Despite their ecological value, blue carbon ecosystems have undergone huge losses of extent and many of the remaining areas are degraded by threats such as land conversion, development, and pollution.

[10] Understanding the current extent and potential availability of habitat for restoration based on current and potential future sea level rises is important. In many locations throughout New Zealand and Otago there are areas of low-lying drained land that may be suitable for restoration opportunities. However, this also needs to be weighed up against the cost of restoration, current land use value, and the cost of maintenance of stop banks/pumps when determining whether an area maybe suitable for restoration.

[11] There are significant opportunities for coastal blue carbon, and the potential for a blue carbon market within the NZ Emissions Trading Scheme (ETS), which is being explored by the climate change commission, though a blue carbon market and associated carbon price are not in place currently. For Landowners, blue carbon projects could be an option to generate income from marginal land or land that is vulnerable to sea level rise. Combining carbon credits with other ecosystems services (such as biodiversity) could provide further opportunities to improve ecological outcomes, plus the possibility of increased credits. Globally, credits for other ecosystem services are attached as co-benefits to carbon credits (e.g., Queensland Land Restoration Fund, Voluntary Carbon Market), or are independently stacked or stapled onto carbon credits (e.g., Australian Nature Plus, EcoAustralia credits).

DISCUSSION

[12] Saltmarsh and seagrass across the Otago region currently cover a total area of 3184 ha, estimated to sequester 1670 tonnes C per annum. However, there is an estimated further 11,576 ha of drained land that was identified as potentially suitable for blue carbon restoration projects in the Otago region. If this was all to be restored it would store an equivalent to 9880 tC yr-1, indicating significant restorative opportunity. The amount of carbon stored does not scale 1 to 1 with area as the different habitats store and sequester different amounts of carbon at different rates. Under the modelled sea level rise (SLR) scenarios of 0.2m, 0.4m and 1.4m the amount habitat suitable for restoration would increase by 329ha, 941ha and 1038ha respectively. However, under the SLR scenario of 1.4m a lot of this habitat would be unsuitable as it would be either submerged or not provide the conditions for salt marsh habitat.

[13] The financial cost involved in transitioning land to blue carbon habitat is high due to costs such as loss of productive land, removing flood gates or walls, planting, blocking drains and then management of weeds while natives establish. It is important to identify areas that provide the greatest ecosystem returns for investment. The most abundant land use type for restoration opportunity within the Otago Region is privately held, high and low performing grasslands (excluding existing wetland environments). Tidal restoration of these areas under a blue carbon scheme could align with the BlueCAM methodology for estimating carbon reductions in Australia. To maximise uptake of blue carbon projects, a strategic approach is to focus on low producing land adjacent to estuaries and coasts and work with landowners and catchment groups on restoration efforts. Larger projects that require elevation modification or removal of structures for flooding and alterations of drainage would require more incentives to achieve and longer-term planning due to costs involved.

[14] Although there is currently not a carbon market in New Zealand that recognises blue carbon, the spot emission unit price in New Zealand (ETS NZU; price per metric tonne of carbon) was ~NZD$50 in June 2024, equivalent to approximately $196 per ha per year of saltmarsh restored based on the BLUECAM approach[1]. This amount may not be enough compared to profitability of other land uses (e.g., sheep and beef farming), and the costs of restorative actions may not incentivise changes in land use for restoration of blue carbon habitats. However, current costs and benefits may change in the future as climate change impacts begin to impact/effect coastal marginal land and carbon prices may increase

[15] This project highlights how the extra benefits of blue carbon habitats are often overlooked despite the significant economic benefits provided by these systems through services such as nutrient filtration. There is considerable variation observed in the economic valuations of the ecosystem services provided. Most of the economic models for the services are based on overseas research which complicates the use in New Zealand. However, a holistic approach to how ecosystem services could be better included in valuation metrics and management decision making is the Queensland Land Restoration Fund which is a co-benefits scheme that delivers additional environmental (e.g., biodiversity), socio-economic (e.g., generation of economic benefits) and First Nations co-benefits to carbon projects. The incorporation of co-benefits by the Land Restoration Fund resulted in an increase of ~120-410 % in the contracted price compared to the unit price for carbon alone (based on median land restoration fund contracted price per unit of carbon and the ACCU carbon spot price for the year in which the land restoration fund rounds closed).

[16] If this approach was taken in New Zealand and accounting for the NZU price (~NZD$50), and consideration of co-benefits alongside carbon credits it could result in unit prices of ~NZD$805 per ha per year. This sort of approach could be implemented in New Zealand, which would enable the wider range of ecosystem services and values of blue carbon ecosystems to be included in valuation metrics, without requiring specific valuations on each individual service. The implementation of a biodiversity credit scheme is currently being explored in New Zealand and could prove to be a promising avenue for promoting the protection and restoration of coastal wetlands. Biodiversity credits could be packaged with carbon credits to enhance blue carbon restoration value over other forms of carbon abatement that may not have the same level of co-benefits. To put this in context for the Otago Region, if you retired 30 ha of low value grasslands to restore saltmarsh in the shag river using the BLUECAM approach, then the carbon abatement value would return $5,890 per annum (at $196 per ha per year). If you incorporated co-benefits (such as biodiversity) into the fund which resulted in a similar increase in value to that of the Queensland Land Restoration Fund, the return could increase to $24,150 per annum (at $805 per ha per year).

[17] Currently while a blue carbon and ecosystem/biodiversity credit system is being explored, this information can be used to help promote blue carbon habitat restoration with landowners and catchment groups given the benefits these systems provide.

[1] Calculations were based on 1 tonne of C being worth ~$50 based on NZ spot prices, but it should be 1 tonne of CO_2, therefore, to get to 1 tonne of CO_2 the C values need to be multiplied by 3.67 to get to CO_2 and the subsequent $ values

OPTIONS

[18] NIL

CONSIDERATIONS

Strategic Framework and Policy Considerations

[19] This report provides information on the current blue carbon storage and sequestration rates in Otago for estuarine ecosystems. It provides information on the benefits of salt marsh and the restoration options for salt marsh habitats. This report can be used to help inform strategy around salt marsh restoration in Otago. It can be used as a tool with implementation to work with landowners and catchment groups who might want to start restoring salt marsh in their areas.

[20] This information can be used to help inform the Regional Coast Plan review

Financial Considerations

[21] This work was a one-off project and was within budgets. There is potential for extra targeted estuary projects based on that study which is budgeted for within the coastal/estuarine budget.

Significance and Engagement

[22] N/A

Legislative and Risk Considerations

[23] N/A

Climate Change Considerations

[24] Understanding the current storage of blue carbon within Otago's estuarine ecosystems and potential for future blue carbon storage under different sea level rise scenarios allows for appropriate management actions to be enacted to build resilience against climate change.

Communications Considerations

[25] Communication between landowners and catchment groups will occur on a project-by-project basis as interest in projects arises

NEXT STEPS

[26] To work internally with Environmental implementation and externally with catchment groups and landowners to provide information on areas suitable for salt marsh restoration and areas for future restoration to help with planning in different catchments.

[27] To undertake a more detailed analysis of carbon storage and sequestration in an Otago estuary to provide more refined regional data on carbon storage and sequestration. In conjunction with this an analysis and research into ecosystem services will be undertaken to provide more regional data for management decisions in a local context.

[28] At a national level, this report and the information gathered for this report will be made available for the national blue carbon working group and the Coastal Special Interest Group.

ATTACHMENTS

1. Blue carbon potential in the Otago Region Final updated [**9.7.1** - 29 pages]

Blue carbon potential in the Otago Region

Prepared for Otago Regional Council

June 2024

Tidal Research

NIWA
Taihoro Nukurangi

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Date: 25/06/24

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Contents

1 About the Respondent

This is a Proposal by Tidal Research Ltd (the Respondent) to supply the Requirements as the lead organisation on this proposal.

Trading name: Tidal Research Limited

Physical address: 17 Beach Haven Road, Beach Haven, Auckland

Business website: http://www.tidalresearch.co.nz/

Type of entity (legal status): A New Zealand Limited company

Company number: 8760187

Country of residence: New Zealand

GST registration number: 139-328-744

2 Summary

Blue carbon ecosystems (coastal wetlands including saltmarshes and seagrasses) have high capacity to absorb and store carbon. In addition to carbon sequestration, coastal wetland ecosystems provide a myriad of other important ecosystem services. These include, but are not limited to, providing coastal protection (e.g., from flooding, storm surges), water filtration (e.g., via. promoting sediment accretion, taking up nutrients and other pollutants), and enhancing biodiversity (e.g., via. habitat provision). The long-term storage of carbon provided by blue carbon ecosystems makes protection and restoration of these ecosystems an important natural or nature-based solution to reduce greenhouse gas emissions, which can contribute as part of a package of measures to mitigate the effects of climate change.

This report summarises a spatial analysis and literature review of blue carbon habitats within the Otago Region to: 1. Produce a regional assessment of current blue carbon sequestration rates; 2. Produce a regional assessment of the blue carbon restoration opportunity under baseline and Sea Level Rise (SLR) scenarios; and 3. Identify other key ecosystem services provided by blue carbon ecosystems that could be used to inform management decision making.

Saltmarsh and seagrass across the Otago region covered a total area of 3184 ha, estimated to sequester 1670 tonnes C per annum. A further 11,576 ha of drained land was identified as potentially suitable for blue carbon restoration projects throughout the Otago Region, the vast majority of which was above mid-tide, in areas which are easier to drain and keep dry and suitable for saltmarsh restoration (equivalent to 9880 tC yr^{-1} if restored). While the Otago region only contains an estimated 2.8% of the national blue carbon habitat extent, the region contains approximately 13% of the land potentially suitable for restoration projects at a national scale, indicating significant restorative opportunity. SLR within the Otago Region was estimated to increase the amount of area suitable for tidal restoration by 329 ha under a SLR of 0.2 m, 941 ha under a SLR of 0.4 m and 1038 ha under a SLR of 1.4 m. The majority of the coastal areas predicted to be inundated under sea level rise were in elevations suitable for saltmarsh restoration under SLR 0.2 m and SLR 0.4 m scenarios. However, under the SLR 1.4 m scenario, the majority of the area was expected to be lower intertidal areas, below the elevation suitable for saltmarsh, with some areas permanently submerged/subtidal.

Given the costs involved in transitioning land to blue carbon habitat, it is critical to identify areas that provide the greatest ecosystem returns for investment. The most abundant land use type for restoration opportunity within the Otago Region under present day and under different SLR scenarios was privately held high performing grasslands, followed by low producing grasslands (excluding existing wetland environments). To maximise uptake of blue carbon projects, a strategic approach would be to prioritise converting lower value grasslands or croplands, situated at suitable elevations for saltmarshes, into blue carbon habitats via restoration efforts (while also considering wider ecosystem benefits).

A literature review was also undertaken to summarise the benefits of blue carbon ecosystems for coastal protection, water filtration and biodiversity. Considerable variation was observed in economic valuations, with most of the economic models based on overseas research, which complicates their use in valuation mechanisms for New Zealand. In Queensland, the Land Restoration Fund is a government run co-benefits scheme that deliver additional environmental (e.g., biodiversity), socio-economic (e.g., generation of economic benefits) and First Nations co-benefits to carbon projects. Other voluntary market credits which blend biodiversity credit and carbon credits have also been established which enable private financing mechanisms (e.g. EcoAustralia). A similar approach could be implemented in New Zealand, which would enable the

wider range of ecosystem services and values of blue carbon ecosystems to be included in valuation metrics and management decision making, without requiring specific valuations on each individual service.

3 Background

3.1. Introduction

Blue carbon ecosystems (coastal wetlands including mangroves, saltmarshes, and seagrasses) have high capacity to absorb and store carbon (Kelleway et al. 2016, Arias-Ortiz et al. 2018, Ewers Lewis et al. 2018, Alongi 2020, Bulmer et al. 2020). In many locations carbon sequestration from blue carbon habitats greatly exceeds the rate of carbon sequestration from terrestrial ecosystems. This high capacity to sequester carbon is mainly due to the large amount of carbon stored below ground (in low oxygen environments), which can stay captured in the sediment for long time periods (sometimes thousands of years). The resulting carbon stores are large, and the carbon cycling behaviour differs by habitat type and condition (Kelleway et al. 2016, Arias-Ortiz et al. 2018, Ewers Lewis et al. 2018, Alongi 2020, Bulmer et al. 2020). Thus, even small shifts in the proportions of different habitat types within an estuary or coastal ecosystem can lead to large shifts in its overall carbon storage and sequestration capacity, and associated reduction in greenhouse gas (GHG) emissions (Doughty et al. 2015, Kelleway et al. 2016, Bulmer et al. 2020).

The long-term storage of carbon makes protection and restoration of blue carbon ecosystems an important natural or nature-based solution to reduce greenhouse gas emissions, which can contribute as part of a package of measures to mitigate the effects of climate change (Kelleway et al. 2016, Arias-Ortiz et al. 2018, Ewers Lewis et al. 2018, Alongi 2020, Bulmer et al. 2020). In addition to carbon sequestration, blue carbon ecosystems provide a myriad of other important ecosystem services. These include, but are not limited to, providing coastal protection (e.g., from flooding, storm surges), water filtration (e.g., via. promoting sediment accretion, taking up nutrients and other pollutants), and enhancing biodiversity (e.g., via. habitat provision) (Barbier et al. 2010, Horstman et al. 2018). For example, wetlands in New Zealand are estimated to reduce surface erosion by 60-80% (Basher et al. 2019b), reducing the transport of sediment to the estuarine and coastal environment and supporting a myriad of cascading ecosystem benefits to marine ecosystems (Macreadie et al. 2021).

Despite their value, blue carbon ecosystems have undergone huge losses of extent and many of the remaining areas are degraded by threats such as land conversion, development, and pollution. Saltmarsh ecosystems have lost between 25% and 50% of their historical coverage worldwide (Duarte et al. 2009, Crooks et al. 2011). In New Zealand, Ausseil et al. (2011) estimate that only 18.4% of saline wetlands remain when compared to historic pre-human extents. Similarly, seagrass meadows globally have declined by 19 % since 1880 (DUNIC et al. 2020). These threats will only be exacerbated by worsening climate change, with sea level rise predicted to lead to migration of coastal ecosystems inland and loss of coastal habitats where migration is not possible (Rullens et al. 2022a).

Loss and degradation of blue carbon ecosystems reduces the capacity of these habitats to sequester carbon and the provision of other ecosystem services. Conversely, the enhancement or restoration of coastal blue carbon ecosystems has the potential to reduce emissions from degraded areas and increase carbon sequestration (Suyadi et al. 2020, Macreadie et al. 2021, Lovelock et al. 2022). A key step for improving the management of blue carbon ecosystems and enhancing carbon sequestration potential is to quantify their distribution and associated carbon sequestration and emission rates (Bulmer et al. 2024).

In addition to identifying present day distributions of blue carbon habitats, in many locations throughout New Zealand there is low lying, drained land (e.g., in low producing farmland) that may be suitable for coastal restoration projects. Mapping areas that may be suitable for restoration offers the ability to prioritise restoration actions that enhance not only blue carbon sequestration, but also other important ecosystem services provided by blue carbon ecosystems. Areas of restoration opportunity are currently below Mean High Water Spring (i.e., drained), yet are prevented from being tidally inundated through structures such as stop banks and pumping. Tidal restoration via the removal of pumps and seawalls may facilitate the restoration of saltmarsh and other coastal habitats. The elevation profile of the land, its current use (e.g., pasture vs housing vs infrastructure etc), as well as the cost of restoration vs. maintenance of stop banks/pumps, are key considerations in determining whether an area may be viable for restorative action (Bulmer et al. 2024). When Sea Level Rise (SLR) scenarios are considered, the area of potential restoration opportunities will increase, however, the magnitude of the increase will be strongly influenced by the elevation profile of the land and factors such as subsidence and accretion rates. SLR will also drive changes in estuarine and coastal habitat extents, with the potential for intertidal squeeze reducing the area of intertidal space suitable for habitats such as saltmarsh, seagrass, or shellfish beds and reducing their extents. Restoration of low-lying lands to maintain the extent of key estuarine and coastal habitats (and the associated services they provide) is therefore particularly important in the face of SLR.

New Zealand has a long coastline with significant opportunities for coastal blue carbon, and potential for a blue carbon market within the NZ Emissions Trading Scheme (ETS) is being explored, though a blue carbon market and associated carbon price are not yet in place. For landowners, blue carbon projects could generate revenue on marginal coastal land via tidal restoration on land that is currently drained or on land that is predicted to be tidally influenced under sea level rise. For government, blue carbon projects could contribute to meeting domestic and international climate change targets, such as the target set to reach net-zero emissions by 2050 under the Climate Change Response Act 2002 (Stewart-Sinclair et al. 2024). Bundling carbon credits with other ecosystem services (such as biodiversity) may provide further opportunities to enhance ecological outcomes, in addition to increasing possible credit valuations. Globally, credits for other ecosystem services are attached as co-benefits to carbon credits (e.g., Queensland Land Restoration Fund, Voluntary Carbon Market), or are independently stacked or stapled onto carbon credits (e.g., Australian Nature Plus, EcoAustralia credits) (Ministry for the Environment - Helping nature and people thrive: Exploring a biodiversity credit system for Aotearoa New Zealand – Discussion document).

3.2. Requirements/Scope

Otago Regional Council (ORC) has asked Tidal Research Ltd and partners to conduct a spatial analysis and literature review of blue carbon habitats within the Otago Region to:

- Produce a regional assessment of current blue carbon sequestration rates.
- Produce a regional assessment of the blue carbon restoration opportunity.
- Identify other key ecosystem services provided by blue carbon ecosystems that could be used to inform management decision making.

4 Methods

Disclaimer: It is important to note the spatial maps generated for this project, including sea level rise projections, were generated for the purposes of assessing regional scale blue carbon sequestration opportunities as per the methodology and caveats described in this report, rather than to be used for other purposes such as providing high resolution mapping to inform decisions at an individual property scale (which would require further investigation).

4.1. Blue carbon spatial extent

To investigate the Blue Carbon spatial extent in the Otago region, we performed a spatial analysis of the current Blue Carbon Ecosystem (BCE) habitats across the Otago region. We leveraged Blue

Carbon extents (i.e., Saltmarsh, Seagrass, Macroalgae) from existing habitat maps previously commissioned by the Otago Regional Council (Salt Ecology, Habitat maps, Broad Scale Reports). The pre-existing habitat maps only included information constrained to the estuary boundary extent within the Otago region, and some locations had no data (e.g., Otago Harbour). To supplement the data across the extent of the Otago region, fill the data gaps, and adjust the Mean High Water Spring (MHWS), we combined the pre-existent Otago habitat maps with the BCE habitats developed at National scale (Bulmer et al. 2024). Briefly, the National BCE habitats were constructed using Sentinel-2 satellite imagery to identify the BCE habitats. BCE habitats were classified using a machine learning (ML) approach in ArcGIS Pro v.3.1. Classification procedures were performed at National scale based on a per-pixel basis using support vector machines (SVM) trained using >200 training samples per class-habitat (i.e., Seagrass, Saltmarsh, Unvegetated) for areas below MHWS. Blue Carbon spatial extent (area, ha) was calculated using a geometry calculation analysis for each of the BC habitats based on the combined Otago region layer.

4.2. Carbon sequestration and emission factors

Blue carbon sequestration, stocks, and greenhouse gas emissions from saltmarsh, seagrass, and unvegetated sediment were retrieved from a recently compiled national dataset (Bulmer et al. 2024). In brief, this dataset included sediment cores and benthic flux chamber incubation measurements from a range of locations throughout New Zealand, as well as comparable data from Southern Australia (which has many of the same coastal wetland species). A brief literature search was also conducted to determine whether additional sediment carbon sequestration or stock data was available from the Otago Region, however no core data was found, consistent with observations by Ho et al. (2023).

Blue carbon sequestration, stocks, and greenhouse gas emission data were used as input parameters to inform blue carbon abatement calculations using the Australian BLUECAM methodology, and average carbon metrics are provided in Table 2 (Lovelock et al. 2021a, Hagger et al. 2022b, Lovelock et al. 2023). The BLUECAM approach is the basis for the national Australian carbon credit system for coastal wetland restoration, and is used to calculate carbon abatement accounts for the potential change in carbon sequestration due to restoration of blue carbon habitat (including carbon stored within living vegetation and soil). It also accounts for the change (generally reduction) in greenhouse gas emissions (CH_4 and N_20) due to increased salinity levels in both soil and water (Supplement S1).

To estimate carbon sequestration rates in blue carbon ecosystems (saltmarsh, seagrass) the following assumptions were applied. For restored blue carbon ecosystems, mature above ground biomass was assumed to occur after approximately 25 years (Lovelock et al. 2021a). The majority of below ground biomass was assumed to be accounted for in Sediment Carbon Accumulation Rates (SCAR) (given that methods used in the field and laboratory to quantify soil carbon stocks typically integrate fine roots into the soil organic carbon stocks). Greenhouse gas emissions (CH_4, N_2O, CO_2) were assumed to be negligible, as they represented <0.02 tC ha^{-1} yr^{-1} when converted to C (Table 2), and CO_2 emissions were assumed to be balanced by primary productivity (as per Lovelock et al. 2021). For existing blue carbon ecosystems, above ground biomass was not included in carbon sequestration rates as it was assumed that existing habitats had already reached maturity and therefore carbon accumulation rates are based entirely on SCAR. Macroalgae was assumed to have a carbon sequestration rate of zero, given organic matter was assumed to be broken down and cycled throughout the system rather than stored in the sediment.

Using the above approach, the following habitat carbon sequestration rates based on mean values from Bulmer et al. 2024 were calculated.

Restored blue carbon ecosystems:

- Saltmarsh = 4.51 (above ground biomass)/25 years = 0.18 (above ground biomass) tC ha^{-1} yr^{-1} + 0.89 (SCAR) tC ha^{-1} yr^{-1} = 1.07 tC ha^{-1} yr^{-1}
- Seagrass = 0.57 above ground biomass)/25 years = 0.02 (above ground biomass) tC ha^{-1} yr^{-1} + 0.32 (SCAR) tC ha^{-1} yr^{-1} = 0.34 tC ha^{-1} yr^{-1}

Existing blue carbon ecosystems:

- Saltmarsh = 0.89 (SCAR) tC ha^{-1} yr^{-1}
- Seagrass = 0.32 (SCAR) tC ha^{-1} yr^{-1}

4.3. Blue carbon sequestration rates for the Otago Region

Blue carbon sequestration rates for the Otago Region (including variability) were estimated using a combination of the spatial analysis (section 3.1) and the collated carbon sequestration/emission factors (section 3.2).

4.4. Blue carbon restoration opportunity for the Otago Region

Blue carbon restoration opportunity within New Zealand was mapped as per the methods described in Bulmer et al. (2024). In brief, the approach involved identifying areas of terrestrial land currently below mean high water spring (MHWS) tide levels using digital elevation models. Areas of blue carbon opportunity are considered to be drained land within tidal area of tidal influence, which could be tidally restored by removing a tidal barrier (i.e., a sea wall).

Tidal data from standard and secondary ports was used to determine water levels (https://www.linz.govt.nz/products-services/tides-and-tidal-streams/tide-predictions), where tidal heights from each region were averaged to generate a tidal range for the region for MHWS (mean high water spring tides), MHWN (mean high water neap tides), MSL (mean sea level), MLWN (mean low water neap tides), and MLWS (mean low water spring tides). Since tidal data were averaged at a regional level, there will be areas of local variation where a finer tidal resolution would be more accurate, however for defining areas that have potential for tidal inundation this scale is adequate. For all tidal height data, local vertical datums (LVD) were converted to the New Zealand vertical datum (NZVD - https://www.linz.govt.nz/guidance/geodetic-system/coordinate-systems-used-new-zealand/vertical-datums/local-mean-sea-level-datums), since tidal data use the local datum for mean sea level while the digital elevation models are provided in NZVD2016.

The average tidal range was used to extract tidal areas from the digital elevation model (Regional 1-m resolution LiDAR DEM - https://data.linz.govt.nz/). This tidal layer was then classified into tidal zones as follows: 1) low intertidal (MLWS to MLWN); 2) low-mid intertidal (MLWN to MSL); 3) mid-upper intertidal (MSL to MHWN); and 4) upper intertidal (MHWN to MHWS). From this tidal zone layer, we then removed all areas that are currently inundated using Otago Regional Council's estuary boundary in order to identify areas that are drained.

The area of drained land that was in each tidal zone was also determined, to identify what type of blue carbon habitat these areas would be suitable for. For example, saltmarsh species typically occupy the higher intertidal zones that experience less inundation than lower intertidal areas (i.e., zone 3 or 4). Seagrass and unvegetated mud or sandflats are more commonly observed in the lower intertidal (zones 1 and 2) and shallow subtidal areas of estuaries and the coasts.

Drained areas within the tidal zone were then overlaid with national land use maps (LUCAS, 2016 - https://data.mfe.govt.nz/layer/52375-lucas-nz-land-use-map-1990-2008-2012-2016-v008/) to explore the land use in potential blue carbon sites. The most recent layer (2016) was used, and land uses that were not suitable for tidal restoration were excluded, which included "wetland – open water", "settlements", and "other". Since these data are from 2016, there are likely areas that could have changed land use in the intervening years.

4.5 Blue carbon opportunity under sea level rise

To explore how the area available for blue carbon projects changes under sea level rise, the restoration opportunity analysis was repeated using sea level rise scenarios from Salt Ecology's 2023 report, which were based on Ministry for the Environment guidance (MfE 2017) for sea level rise and predicted an increase in sea level of 0.2 m, 0.6 m, and 1.4 m (Stevens 2023). In areas predicted to be inundated under each of these scenarios, the area of current blue carbon opportunity was removed to calculate the additional areas available. Current land uses were then identified as described above and summarised tidal zones using Salt Ecology's three classifications: Saltmarsh zone (i.e., upper intertidal), Intertidal excluding saltmarsh (the rest of the tidal zone), and subtidal.

4.5. Other ecosystem services

In order to better understand ecosystem services other than carbon sequestration provided by blue carbon ecosystems within the Otago region, a short literature review was conducted on the following key ecosystem services in coastal wetland habitats: water filtration, biodiversity, coastal protection. Where possible, literature that includes a quantification of the ecosystem service was sourced with the intention it could be used in future spatial analysis. To enhance the relevance of the information, the literature review was restricted to New Zealand literature and global reviews. Additionally, economic valuations of these ecosystem services were also reviewed. Valuations were converted to 2022 US dollar per hectare per year using exchange rates from Penn world tables (https://www.rug.nl/ggdc/productivity/pwt/) and by correcting for inflation rates for the country in which the study took place (https://databank.worldbank.org/reports.aspx?source=World-Development-Indicators). Valuations were then converted to 2022 NZ dollars per hectare per year using the yearly average exchange rate for 2022.

5 Results

5.1 Blue carbon spatial extent and carbon sequestration

Saltmarsh, seagrass, and macroalgae habitats across the Otago region covered a total area of 3584 ha (Table 1; Figure 1). Seagrass habitat covered the largest area 2041 ha, while saltmarsh habitat covered 1143 ha (Table 1; Figure 1). Large extents of seagrass were observed in Otago Harbour, Papanui Inlet and Hoopers Inlet.

By adjusting habitat extents by carbon sequestration rates (see section 4.2; Supplementary Table 1) results suggest that blue carbon habitats (saltmarsh and seagrass) in the Otago Region sequester 1670 tonnes C per annum.

Table 1. Spatial extent and associated carbon sequestration of the saltmarsh, seagrass and macroalgae recorded in the Otago region.

Habitat classification	Area (ha)	Carbon sequestration (tC yr^{-1})
Saltmarsh	1143.2	1017.4
Seagrass	2041.3	653.2
Macroalgae	400.2	n/a
Total	3584.7	1670.6

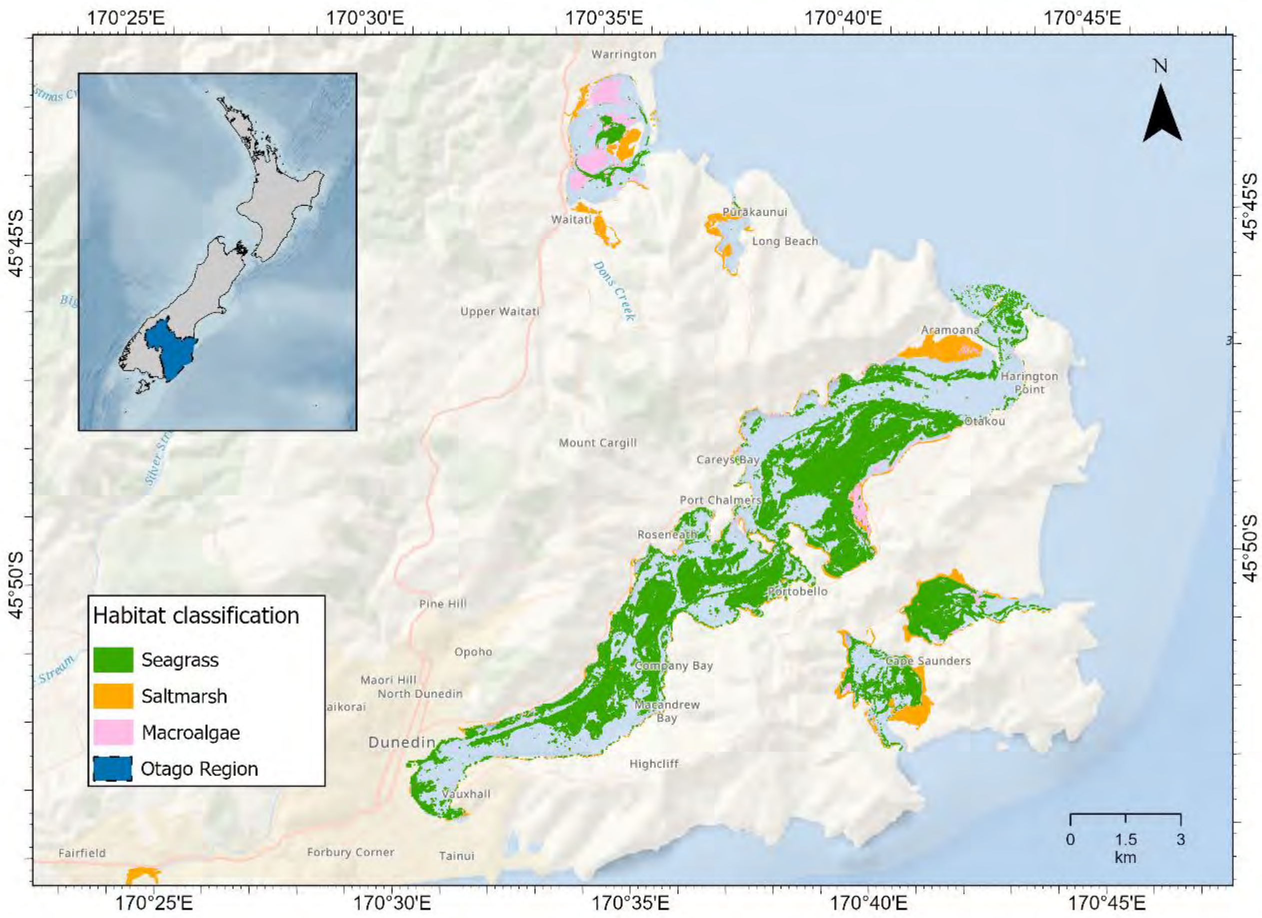


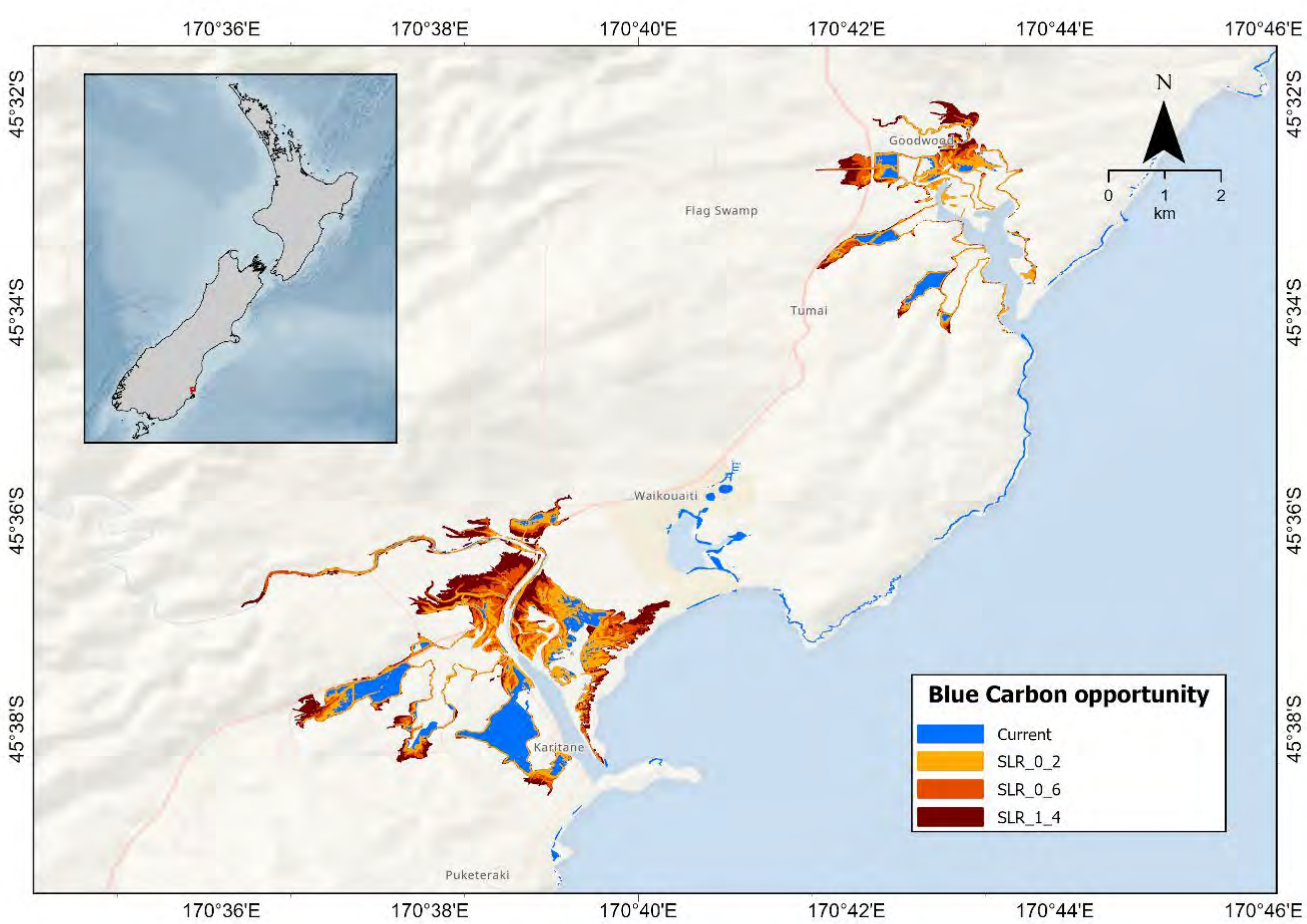
Figure 1. Map of the Otago region showing the Blue Carbon habitats extent (i.e., Seagrass, Saltmarsh) as well as Macroalgae.

5.2 Blue carbon restoration opportunity for the Otago Region

Tidal zones

There was a total of 11,576 ha of drained land available for blue carbon projects in the Otago region, the vast majority above mid-tide (Figure 2). Of this, 3,499 ha was in the high intertidal zone (zone 4), which is at an elevation and tidal regime suitable for saltmarsh. If all of this area were restored, this would total 3,743 tC yr^{-1} of carbon (at a rate of 1.07 tC ha^{-1} yr^{-1}). It is possible that the upper-mid tide area (zone 3) could also be suitable for saltmarsh habitat, giving a further 4,644 ha of potential area for restoration (and an estimated 4,970 tC yr^{-1}).

Below mid-tide (tidal zones 1 and 2) there was a total of 3,433 ha available for blue carbon projects (516 and 2,917 ha respectively), at an elevation suitable for seagrass or unvegetated habitats. Collectively, this could represent 1,167 tC yr^{-1} if all of this area were restored to seagrass (at a rate of 0.34 tC ha^{-1} yr^{-1}).



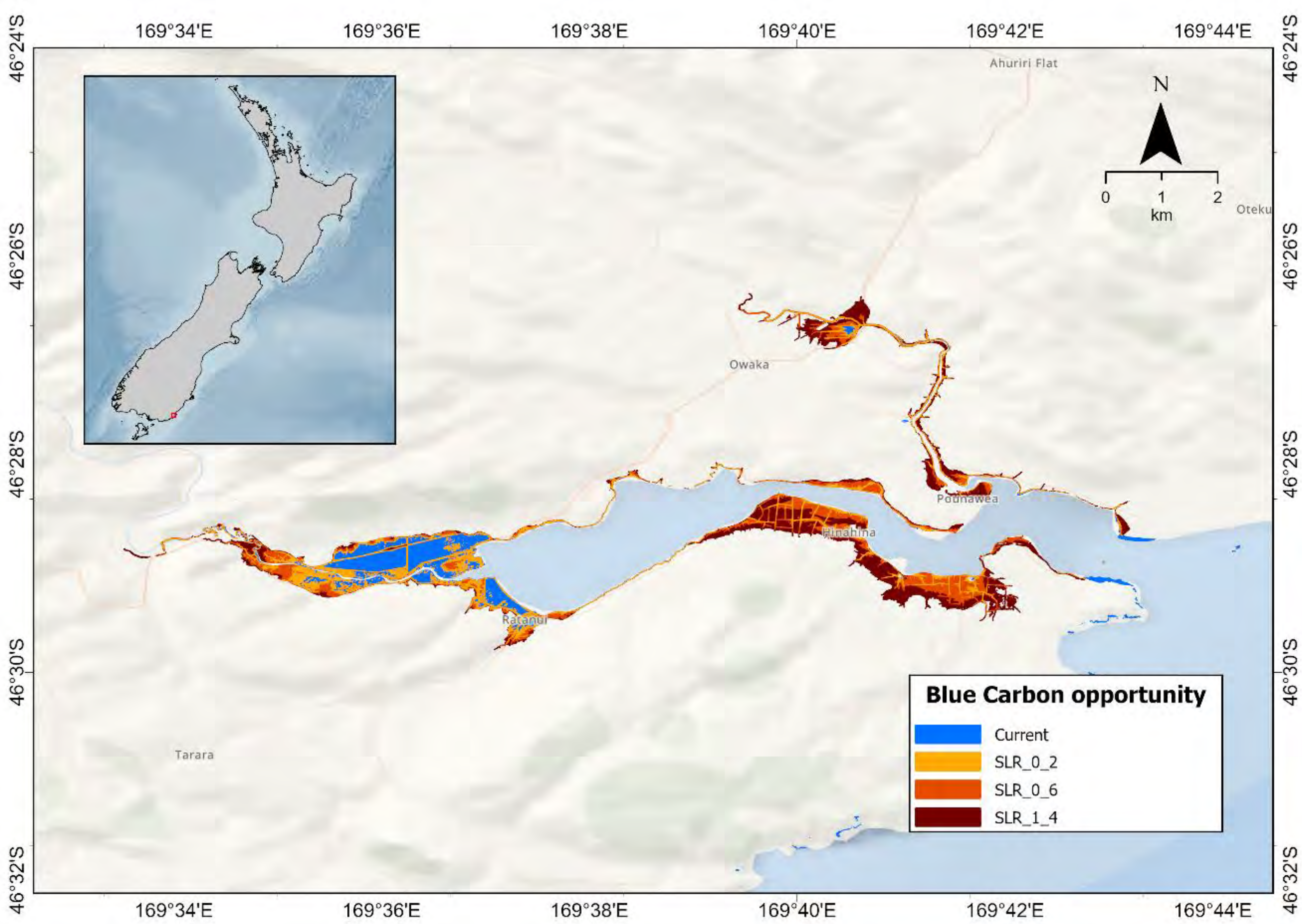


Figure 2: Map of blue carbon opportunity in Waikouaiti and Pleasant River (top) and the Catlins (bottom) estuaries in the Otago region under present conditions and under sea level rise scenarios of 0.2 m, 0. 6 m and 1.4 m.

Land uses

The predominant land use of potential blue carbon areas was in high producing grassland (Table 2). A further 979 ha of other grassland (low producing and with woody biomass) was also identified. This suggests that the most likely mechanism for blue carbon projects in the Otago region would be in tidally restoring coastally drained grassland. There was also more than 1000 ha of wetland, which is most likely already saline and could be restored if degraded, or conserved if not already protected.

Table 2: Land use in areas of blue carbon opportunity (i.e., drained areas that could be tidally restored) in the Otago region.

Land use (2016)	Area (ha)
Grassland - High producing	9,138
Wetland - Vegetated non forest	1,358
Grassland - Low producing	822
Grassland - With woody biomass	157
Natural Forest	44
Planted Forest - Pre 1990	29
Cropland - Orchards and vineyards (perennial)	16
Cropland - Annual	7
Post 1989 Forest	5

5.3 Blue carbon opportunity under sea level rise

Under the three sea level rise scenarios defined in Salt Ecology (2023), the additional area of blue carbon opportunity increased by a total of 328 ha under the 0.2 m scenario, 941 ha under the 0.6 m scenario, and 1,688 ha under the 1.4m scenario.

Land uses

Breaking down the addition areas of blue carbon opportunity into land use type, most areas were grassland (high producing, low producing, or with woody biomass) or wetland. Other land uses such as forest and cropland made up a smaller proportion of area likely to be affected by future sea level rise (Table 3).

Table 3: Land use in areas of blue carbon opportunity (i.e., drained areas that could be tidally restored) in the Otago region under three sea level rise scenarios.

Land uses (ha)	SLR 0.2 m	SLR 0.6 m	SLR 1.4 m
Grassland - High producing	99	349	740
Wetland - Vegetated non forest	148	318	409
Grassland - Low producing	45	132	213
Natural Forest	19	77	152
Grassland - With woody biomass	12	40	80
Planted Forest - Pre 1990	3	14	45
Post 1989 Forest	2	8	27
Cropland – Annual	1	4	22

Tidal zones

The majority of the coastal areas predicted to be inundated under sea level rise were in elevations suitable for saltmarsh restoration under SLR 0.2 m and SLR 0.4 m scenarios. However, under the SLR 1.4 m scenario, the majority of the area was expected to be lower intertidal areas, below the elevation suitable for saltmarsh, with some areas permanently submerged/subtidal (Table 4).

Table 4: Tidal zones of areas of blue carbon opportunity (i.e., drained areas that could be tidally restored) in the Otago region under three sea level rise scenarios.

Tidal zone	SLR 0.2 m	SLR 0.4 m	SLR 1.4 m
Intertidal (Saltmarsh zone 3 and 4)	308	608	343
Intertidal (zone 1 and 2)	21	333	1,020
Subtidal	0	0	325

5.4 Other ecosystem services

Here we briefly summarise the results of a short literature review conducted on the following key ecosystem services in coastal wetland habitats: water filtration, biodiversity, coastal protection. Further details can be found in Supplementary file ORC_EcosystemServicesLiteratureReview.xlsx.

Saltmarsh habitat

- Water filtration:
  - Experiments on (fresh water) wetland species in New Zealand have shown that constructed wetland habitats can remove 76-88% of suspended solids, 65-92% of ammonium nitrogen and 59-90% of total nitrogen (Tanner 1996). While comparable experiments have not yet been conducted in saline saltmarsh species in NZ, experiments on *Juncus kraussii* show this common NZ saltmarsh species reduces total nitrogen inputs by up to 69% (Lymbery et al. 2006). This is consistent with research from the USA, where saltmarsh has been shown to respond to elevated nutrient loading by increasing nutrient removal, with up to four times higher rates of nutrient removal when plants were exposed to increased inorganic nitrogen loading (Nelson and Zavaleta 2012). Internationally, the value of water filtration services provided by saltmarsh (predominantly waste treatment) is estimated to exceed \$350,000 per ha^{-1} yr^{-1} (Costanza et al. 2014).
- Biodiversity:
  - Saltmarsh in the USA is estimated to increase the abundance of 20-25 fish species and 40 invertebrate species (including support of commercially important species), estimated to increase biomass of fish and invertebrates by 12.2 t yr^{-1} ha^{-1} of saltmarsh (zu Ermgassen et al. 2021). In New Zealand, saltmarsh habitats are known to be important for galaxiid fishes that have a large contribution to whitebait fisheries (Handley 2022). Costanza et al. (2014) estimated the economic value of saltmarsh as habitat and refugia for biodiversity to exceed \$37,000 ha^{-1} yr^{-1}.
- Coastal protection:
  - In a review of 75 studies, Shepard et al, 2011 identified that salt marsh vegetation had a significant positive effect on wave attenuation and shoreline stabilisation (Shepard et al. 2011). Narayan et al. (2016) estimated cost to replace the coastal protection services of saltmarsh with engineering alternatives at \$20,000 USD ha^{-1}, while Barbier et al. (2010) estimate the economic value of reduced damage from hurricanes due to protection by saltmarsh to be valued at over \$19,000 ha^{-1} yr^{-1}.

Seagrass habitat

- Water filtration:
  - Seagrass in New Zealand play an important role cycling and processing nutrients in the sediment and water column (Bulmer et al. 2018, Drylie et al. 2018), with 35-65% lower nutrient efflux than adjacent unvegetated habitats (Bulmer et al. 2018). Seagrass nutrient cycling and primary production plays an important role supporting coastal food chains (Heck et al. 2008) and by lowering nutrient concentrations (Bulmer et al. 2018), which reduces the likelihood of adverse macroalgae and phytoplankton blooms (Nelson et al. 2015). Seagrass have also been shown to promote the settlement of sediment out of the water column and can enhance the stabilisation of fine sediment to the seafloor. In New Zealand, this has been shown through sediment mud contents (< 63 um) in seagrass beds being 2.8-3.0 times

higher compared to adjacent or past sandflat habitats (Heiss et al. 2000, Lundquist et al. 2018). The nutrient cycling service provided by seagrass meadows is estimated to be valued at over \$57,000 ha^{-1} yr^{-1} (Costanza et al. 2014).

- Biodiversity:
  - Macrofaunal biodiversity and abundance have also been observed to increase with seagrass colonisation over mudflats (by 1.4 and 4.7 times, respectively) (Lundquist et al. 2018). Seagrass, particularly subtidal seagrass and other structured habitat types, have been shown to provide important habitat for fish, including commercially important species such as snapper (Morrison et al. 2014, Parsons et al. 2016). In Australia, seagrass role as habitat and a nursery for commercially important fish species has been estimated to be valued at \$6,700 ha^{-1} yr^{-1} (Jänes et al. 2021).
- Coastal protection:
  - Seagrass also play an important role in coastal protection, with modelling in Europe suggesting that seagrass meadows are capable of reducing both current velocities and significant wave heights in the order of up to 30% in the deeper areas and above 90% in the shallow areas (Jacob et al. 2023). Low canopy seagrass (such as *Zostera muelleri* in Indonesia) have also been shown to play an important role immobilising sediment due to wave action and lowering beach erosion rates (Christianen et al. 2013). This is consistent with research by Heiss et al. (2000) who found that current velocities above seagrass were 3.7 times higher than those inside the seagrass meadows. Seagrass meadows also play a role in reducing sediment erosion, with erosion control services provided by seagrass estimated to be valued at \$55,000 ha^{-1} yr^{-1} (Barbier et al. 2010).

Unvegetated (shellfish bed)

- Water filtration:
  - Shellfish filter the water column, depositing organic rich sediment on the seafloor, as well as move and mix sediment particles, impacting sediment biochemistry and topography at the sediment water interface (Thrush et al. 2020). Unvegetated sediment habitats undertake an important role cycling nutrients between the sediment and the overlying water-column, leading to the removal of excess nutrients (Thrush et al. 2021). Common shellfish species such as *Austrovenus stutchburyi* (cockles) and *Macomona liliana* enhance microphytobenthic production rates through ammonium release (Sandwell et al. 2009), however these services are known to be threatened by impacts such as sediment transport and deposition which increases mud content in estuaries and coasts (Thomas et al. 2022). Similar observations have been made for mussels, which used to cover large areas of estuaries and coastlines throughout New Zealand (Hillman et al. 2021). Restoration of unvegetated habitats with green-lipped mussels have also been found to show increased rates of denitrification, a biogeochemical process that allows nitrogen to be transformed and removed from the system under dark conditions, with higher rates compared to unvegetated habitats (e.g., by up to 199%). Economic estimates of these services are not readily available, however the nitrogen removal service by restored mussel beds are estimated by Hillman et al. (2021) to be 105% higher than adjacent unvegetated sediment habitats.

- Biodiversity:

- No economic valuation was able to be sourced for the value of shellfish beds for biodiversity, however a significant body of literature has documented the role of shellfish beds as a biodiversity enhancer. For example, in unvegetated sediments that had been restored to green-lipped mussel beds, Sea et al. (2022) found abundances of mobile individuals increased by up to 20 times. This mirrors the results found by McLeod et al. (2014) who found that compared to adjacent unvegetated sediments, mussel beds had higher densities of invertebrates as well as small fish (by 3.5 and 13.7 times, respectively). Shellfish beds such as horse mussel reefs are recognised as key habitats for commercially important fish species including juvenile snapper and trevally (Morrison et al. 2014).

- Coastal protection:
  - Shellfish beds (including *Austrovenus* and *Macomona*) can mitigate shoreline erosion through sediment stabilisation (Smaal et al. 2019, Rullens et al. 2022b). While economic valuations for these services were not readily available, shellfish such as oyster reefs have been identified as an alternative to traditional coastal defences, with the advantage that they may also keep pace with sea level rise and provide other co-benefits (Morris et al. 2019).

6 Discussion

This project provides a regional scale analysis of blue carbon habitat extent, restoration opportunity, and carbon sequestration potential for the Otago Region. In addition, SLR scenarios were explored to determine how restoration opportunity may change through time and to guide management to assist decision making. As estuarine and coastal ecosystems provide numerous other ecosystem services and benefits, a literature review was also undertaken to summarise the benefits of these habitats for coastal protection, water filtration and biodiversity.

Saltmarsh and seagrass across the Otago region covered a total area of 3184 ha, estimated to sequester 1670 tonnes C per annum. In contrast, at a national scale, New Zealand estuaries and coastal areas contain approximately 20,932 ha of saltmarsh, 30,533 ha of mangrove and 61,340 ha of seagrass, estimated to sequester a total of approximately 57,800 tC yr^{-1} (Bulmer et al. 2024). A further 11,576 ha of drained land was identified as potentially suitable for blue carbon restoration projects throughout the Otago Region, the vast majority of which was above mid-tide, in areas which are easier to drain and keep dry and suitable for saltmarsh restoration (equivalent to 9880 tC yr^{-1} if restored). This compares to 87,861 ha of land potentially suitable for blue carbon projects at a national scale (Bulmer et al. 2024). While the Otago region only contains an estimated 2.8% of the national blue carbon habitat extent, the region contains approximately 13% of the land potentially suitable for restoration projects at a national scale, indicating significant restorative opportunity.

SLR within the Otago Region was estimated to increase the amount of area suitable for tidal restoration by 329 ha under a SLR of 0.2 m, 941 ha under a SLR of 0.4 m and 1038 ha under a SLR of 1.4 m. The majority of the coastal areas predicted to be inundated under sea level rise were in elevations suitable for saltmarsh restoration under SLR 0.2 m and SLR 0.4 m scenarios. However, under the SLR 1.4 m scenario, the majority of the area was expected to be located in lower intertidal areas, below the elevation suitable for saltmarsh, with some areas permanently submerged/subtidal. This is important for blue carbon opportunity as the intertidal area that excludes saltmarsh are more likely to be suitable for seagrass or unvegetated habitats. As areas become increasingly inundated due to sea level rise, the habitat type which may be suitable for that elevation profile may change. Understanding this dynamic is important so that management decision making can account and support natural transitions in habitats through time.

Given the costs involved in transitioning land to blue carbon habitat, it is critical to identify areas that provide the greatest ecosystem returns for investment. The most abundant land use type for restoration opportunity within the Otago Region under present day and SLR scenarios was privately held high performing grasslands, followed by low producing grasslands (excluding existing wetland environments). As described in Bulmer et al. 2024, tidal restoration of these areas under a blue carbon scheme could align with the BlueCAM methodology for estimating carbon reductions in Australia (Lovelock et al. 2021a, Hagger et al. 2022b, Lovelock et al. 2023). To maximise uptake of blue carbon projects, a strategic approach would be to prioritise converting lower value grasslands or croplands adjacent to estuaries and coasts, situated at suitable elevations for saltmarshes, into blue carbon habitats via restoration efforts (Stewart-Sinclair et al. 2024). Areas which require elevation modification (e.g., to move from an elevation suitable for seagrass to an elevation suitable for saltmarsh) are likely to incur considerably greater costs than areas with the elevation already suitable for saltmarsh. In lower elevation regions, there may be opportunities to restore seagrass over marginal farmlands, contingent upon sediment characteristics and water clarity, which may influence the success of such restoration efforts (e.g., seagrass in Tauranga Harbour, New Zealand has been observed to be constrained to a surface mud content of less than 35% (Crawshaw 2020).

The financial cost of restoration of grasslands will depend upon the type of grassland (e.g., high vs. low producing) and the type of farming occurring on the land (e.g., sheep, beef, or dairy farming). The average annual profit for all grazing land uses in New Zealand in 2020-21 was $165.4 per ha ($115,422 per farm with an average farm size of 698 ha; Beef and Lamb New Zealand (2022)). There are also likely to be differences in net carbon emission rates associated with different land uses, for example high producing farmlands is also likely to have higher enteric emissions from stock. Other land uses such as cropping, or plantation forestry will have different baseline emissions as well as ecological and economic factors to consider. These opportunity costs would have to be considered in a cost-benefit analysis alongside upfront restoration costs (including permitting) and maintenance.

Saltmarsh restoration also incurs costs to undertake the restoration activity. While saltmarsh restoration is underway at many sites around New Zealand, most restoration sites are pilot projects and as a result costs are likely to be higher than if restoration actions were more routinely undertaken. The Bay of Plenty Regional Council has been trialling saltmarsh restoration projects at five sites ranging in size from 20-30 ha throughout the region. Costs range from an average of $30,000 per ha, with the highest around $190,000 per ha and the lowest around $20,000 per ha. Costs ranged primarily based on the amount of consulting required (engineering fees etc.), and if the restoration is a 'rewet, plant and walk away' type of approach or requiring additional interventions such as modifying depth and tidal influence. These costs did not include the cost of the land (*Crawshaw, pers. comm.*). Internationally, Bayraktarov et al. (2016) estimated the average restoration costs of mangrove and saltmarsh were $52,000 and $151,000 USD per ha, respectively, which is considerably higher than costs emerging from trials from the Bay of Plenty. However, their review highlights orders of magnitude differences in costs across projects, suggesting that much can be learned from low-cost projects that have had successful restoration outcomes (Bayraktarov et al. 2016).

While a carbon market is currently not set up in New Zealand to recognise blue carbon, the spot emission unit price in New Zealand (ETS NZU; price per metric tonne of carbon) was ~NZD$50 in June 2024, equivalent to approximately $196 per ha per year of saltmarsh restored based on the BLUECAM approach. Compared to the profitability of other land uses (e.g., sheep and beef farming), and the costs of restorative actions, this price may not be enough to incentivise changes in land use for restoration of blue carbon habitats. However, current costs and benefits may change in the future as climate change impacts begin to impact/effect coastal marginal land and carbon prices may increase.

It is also important to acknowledge that there are many other ecosystem services, functions, and values provided by blue carbon habitats outside of carbon abatement. For example, wetlands are estimated to reduce sediment surface erosion by 60-80% (Basher et al. 2019a), contribute to nutrient and sediment filtration and trapping, mitigate against flooding and storm impacts (Horstman et al. 2014), as well as provide a myriad of other ecosystem services and benefits that have cascading impacts including improving the health of marine ecosystems (Macreadie et al. 2021). By quantifying the additional ecosystem services and benefits blue carbon habitats provide, it is possible to differentiate them from other carbon abatement actions (e.g., pine plantations), even if the carbon abatement value is comparable. Better quantification of ecosystem services provided by coastal habitats will also enable their ecological benefits (and costs of their loss) to be better weighed up against social, cultural and economic considerations and values.

In this project, we provide a summary of three additional ecosystem services provided by coastal ecosystems (coastal protection, water filtration, and biodiversity) to enable these to be better considered in management decision making. Our literature review demonstrates that blue carbon habitats provide a range of ecosystem services and benefits that provide significant economic benefits that are typically overlooked. However, considerable variation was observed in economic valuations of the ecosystem services provided by blue carbon habitats, with most of the economic models based on overseas research, which complicates their use in valuation mechanisms for New Zealand. While providing a single number to value each of the ecosystem services provided by blue carbon ecosystems is complex and unlikely to be an accurate representation of the value of these ecosystems, other more holistic approaches provide an example of how ecosystem services could be better included in valuation metrics and management decision making. In Queensland, the Land Restoration Fund is a co-benefits scheme that deliver additional environmental (e.g., biodiversity), socio-economic (e.g., generation of economic benefits) and First Nations co-benefits to carbon projects. The incorporation of co-benefits by the Land Restoration Fund resulted in an increase of ~120-410 % in the contracted price compared to the unit price for carbon alone (based on median land restoration fund contracted price per unit of carbon (https://www.qld.gov.au/environment/climate/climate-change/land-restoration-fund/funded-projects/investment-rounds-report) and the ACCU carbon spot price for the year in which the land restoration fund rounds closed). Considering this increase and the NZU price (~NZD$50), the consideration of co-benefits alongside carbon credits in New Zealand could result in unit prices of ~NZD$805 per ha per year. A similar approach could be implemented in New Zealand, which would enable the wider range of ecosystem services and values of blue carbon ecosystems to be included in valuation metrics, without requiring specific valuations on each individual service. The implementation of a biodiversity credit scheme is currently being explored in New Zealand (Waterford et al. 2022) and could prove to be a promising avenue for promoting the protection and restoration of coastal wetlands. Biodiversity credits could be packaged with carbon credits to enhance blue carbon restoration value over other forms of carbon abatement that may not have the same level of co-benefits. To put this in context for the Otago Region, if you retired 30 ha of low value grasslands to restore saltmarsh in the shag river using the BLUECAM approach, then the carbon abatement value would return $5,890 per annum (at $196 per ha per year). If you incorporated co-benefits (such as biodiversity) into the fund which resulted in a similar increase in value to that of the Queensland Land Restoration Fund, the return could increase to $24,150 per annum (at $805 per ha per year).

Caveats and considerations in the interpretation of these results are explored in Bulmer et al. (2024). In brief:

- *Data layers* – Data layers used and created within this analysis are considered a reliable and robust resource if viewed at appropriate scales. They are not intended to be used to show land/habitat cover at an individual property scale, but instead provide larger scale insights in land cover and change through time. For example, the Land Use and Carbon Accounting System (LUCAS) dataset, which is used in the restoration opportunity analysis, was developed to enable New Zealand to meet its reporting and accounting obligations to the United Nations Framework on Climate Change (UNFCCC), and under Article 3.3 of the Kyoto Protocol (the first commitment period (CP-1), 2008–2012).
- *Coastal/estuarine boundaries and areas of blue carbon restoration opportunity* – This study followed a similar approach to identify blue carbon restoration opportunity as applied in Australia's BLUECAM methodology (Lovelock et al. 2021a, Hagger et al. 2022b, Lovelock et al. 2023). This methodology analyses DEMs and uses local tide data (where available) to identify areas below mean high spring tide. Many regions or estuaries have limited tidal gauge data available. Because tidal ranges change within regions and within estuaries, adjustments based on limited available tidal gauges are a simplification of the tidal ranges observed and will have some associated error, particularly as distance from tidal gauges increase. To

account for potential error in tidal adjustments, a mean spring high tide adjustment was applied (rather than highest astronomical tide) within the restoration opportunity analysis. However, this means that the estimates of estuarine extent and restoration opportunity are likely to be conservative and under-estimate the potential area of tidal influence. Improved mapping of the area of tidal inundation would improve accuracy for determining suitable areas for restoration. For example, although hydrodynamic modelling is unlikely to be practical at large spatial scales, hydrodynamic modelling at select locations could provide greater accuracy if required. NIWA are developing a revised SLR/MHWS model which aims to substantially improve the current spatial resolution of estimates, allowing greater confidence in finer scale predictions. Once these outputs are available, the approach detailed in this report could be repeated.

- The present LINZ coastal boundary excludes large areas of coastal habitats and harbours, which complicates mapping efforts. Moving forward, any improvements in the delineation of the coastal boundary will improve blue carbon habitat mapping efforts. For example, Gerbeaux and Hume (2022) provide recent clarifications on estuary landward and seaward boundaries.

Here we identify gaps where further research is needed to improve our understanding of blue carbon potential in Otago, as follows:

- No coring data was available from blue carbon habitats in Otago, and very little exists from the South Island (other than the top of the South). Carbon sequestration rates from blue carbon habitats have been shown to differ between and within estuaries due to differences in sediment input and organic matter accumulation. Differences in climate have also been associated with differences in carbon sequestration rates. Collation of addition carbon sequestration data from the Otago region would enable regional specific blue carbon sequestration values to be calculated, and assess whether there are regional differences compared to elsewhere in the country.
- There is likely to be regionally specific ecosystem services or values that are key considerations in management decision making. Various tools have now been developed to help obtain this type of information (https://www.sustainableseaschallenge.co.nz/tools-and-resources/roadmaps-to-ebm/). For example, Bayesian Network models can use both empirical datasets as well as expert opinion and local values to inform management actions of interest (e.g., the use of Bayesian Networks in Kakanui Estuary) and could be applied for to the Otago Region to inform blue carbon management strategies.
- Assessment of wider ecosystem services could be further improved by additional targeted data collection and analysis. For instance, data on nutrient cycling from seagrass and unvegetated habitats have been compiled as part of the Ministry of Business, Innovation and Employment Smart Idea project (C01X2109) "Carbon sequestration via Aotearoa's estuarine environments: Implications for greenhouse gas budgets and are now in the process of being written up into an associated paper. This type of data will provide revised estimates of the role blue carbon habitats in New Zealand play in the primary production and the cycling nutrients and could inform spatial map layers.
- Spatially mapping other ecosystem services (in addition to blue carbon) provides an opportunity to identify areas where multiple ecosystem benefits could be maximised in management decisions (e.g., (Rullens et al. 2022b)), and could inform ecosystem bundling credits.

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8 References

Alongi, D. M. 2020. Global Significance of Mangrove Blue Carbon in Climate Change Mitigation. Sci **2**:67.

Arias-Ortiz, A., P. Masqué, J. Garcia-Orellana, O. Serrano, I. Mazarrasa, N. Marbà, C. E. Lovelock, P. S. Lavery, and C. M. Duarte. 2018. Reviews and syntheses: 210Pb-derived sediment and carbon accumulation rates in vegetated coastal ecosystems – setting the record straight. Biogeosciences **15**:6791-6818.

Ausseil, A.-G. E., W. Lindsay C, P. Gerbeaux, R. T. T S, and J. R. Leathwick. 2011. Applying systematic conservation planning principles to palustrine and inland saline wetlands of New Zealand. Freshwater Biology **56**:142-161.

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2010. The value of estuarine and coastal ecosystem services. Ecological Monographs **81**:169-193.

Basher, L., U. Djanibekov, T. Soliman, and P. Walsh. 2019a. National modelling of impacts of proposed sediment attributes: literature review and feasibility study. Contract Report: LC3445. Prepared for: Ministry for the Environment by Manaaki Whenua – Landcare Research.

Basher, L., U. Djanibekov, T. Soliman, and P. Walsh. 2019b. National modelling of impacts of proposed sediment attributes: literature review and feasibility study. Contract Report: LC3445. Prepared for: Ministry for the Environment by Manaaki Whenua – Landcare Research. .

Bayraktarov, E., M. I. Saunders, S. Abdullah, M. Mills, J. Beher, H. P. Possingham, P. J. Mumby, and C. E. Lovelock. 2016. The cost and feasibility of marine coastal restoration. Ecological Applications **26**:1055-1074.

Beef and Lamb New Zealand. 2022. New Season Outlook 2022-23. Beef and Lamb New Zealand.

Bulmer, R. H., F. Stephenson, H. F. E. Jones, M. Townsend, J. R. Hillman, L. Schwendenmann, and C. J. Lundquist. 2020. Blue Carbon Stocks and Cross-Habitat Subsidies. Frontiers in Marine Science **7**.

Bulmer, R. H., P. Stewart-Sinclair, O. Lam-Gordillo, S. Mangan, L. Schwendenmann, and C. J. Lundquist. 2024. Spatial variability in blue carbon habitats in Aotearoa New Zealand – opportunities for conservation and restoration. Restoration Ecology, Accepted.

Bulmer, R. H., M. Townsend, T. Drylie, and A. M. Lohrer. 2018. Elevated Turbidity and the Nutrient Removal Capacity of Seagrass. Frontiers in Marine Science **5**.

Christianen, M. J. A., J. van Belzen, P. M. J. Herman, M. M. van Katwijk, L. P. M. Lamers, P. J. M. van Leent, and T. J. Bouma. 2013. Low-Canopy Seagrass Beds Still Provide Important Coastal Protection Services. PLoS ONE **8**:e62413.

Costanza, R., R. de Groot, P. Sutton, S. van der Ploeg, S. J. Anderson, I. Kubiszewski, S. Farber, and R. K. Turner. 2014. Changes in the global value of ecosystem services. Global Environmental Change **26**:152-158.

Crawshaw, J. 2020. Seagrass health monitoring in Tauranga Harbour. Bay of Plenty Regional Council Environmental Publication 2020/08.

Crooks, S., D. Herr, J. Tamelander, D. Laffoley, and J. Vandever. 2011. Mitigating climate change through restoration and management of coastal wetlands and near-shore marine ecosystems: challenges and opportunities. Environment Department Papers. Marine Ecosystem Series.

Doughty, C., J. A. Langley, W. Walker, I. Feller, R. Schaub, and S. Chapman. 2015. Mangrove range expansion rapidly increases coastal wetland carbon storage. Estuaries and Coasts:1-12.

Drylie, T. P., A. M. Lohrer, H. R. Needham, R. H. Bulmer, and C. A. Pilditch. 2018. Benthic primary production in emerged intertidal habitats provides resilience to high water column turbidity. Journal of Sea Research **142**:101-112.

Duarte, C. M., J. Culbertson, W. C. Dennison, R. Fulweiler, T. Hughes, E. Kinney, N. Marbá, S. Nixon, E. Peacock, and S. Smith. 2009. Global loss of coastal habitats: Rates, causes and consequences. Fundación BBVA Madrid, Spain.

Ewers Lewis, C. J., P. E. Carnell, J. Sanderman, J. A. Baldock, and P. I. Macreadie. 2018. Variability and Vulnerability of Coastal 'Blue Carbon' Stocks: A Case Study from Southeast Australia. Ecosystems **21**:263-279.

Gerbeaux, P., and T. M. Hume. 2022. What constitutes a wetland in the New Zealand Coastal Marine Area? – a scientific perspective. New Zealand Journal of Marine and Freshwater Research **56**:333-339.

Hagger, V., P. Stewart-Sinclair, R. Rossini, N. J. Waltham, M. Ronan, M. F. Adame, P. Lavery, W. Glamore, and C. E. Lovelock. 2022a. Coastal Wetland Restoration for Blue Carbon in Australia. https://www.nespmarinecoastal.edu.au/wp-content/uploads/2023/02/20230201-Project-1.15-Final-Report.pdf Accessed Sept 2023.

Hagger, V., P. Stewart-Sinclair, R. Rossini, N. J. Waltham, M. Ronan, M. F. Adame, P. Lavery, W. Glamore, and C. E. Lovelock. 2022b. Coastal Wetland Restoration for Blue Carbon in Australia. https://www.nespmarinecoastal.edu.au/wp-content/uploads/2023/02/20230201-Project-1.15-Final-Report.pdf Accessed Sept 2023.

Handley, S. J. 2022. Technical options for marine coastal habitat restoration in Te Tauihu. Prepared for Marlborough District Council, Nelson City Council, Tasman District Council. June 2022.

Heck, K. L., T. J. B. Carruthers, C. M. Duarte, A. R. Hughes, G. Kendrick, R. J. Orth, and S. W. Williams. 2008. Trophic Transfers from Seagrass Meadows Subsidize Diverse Marine and Terrestrial Consumers. Ecosystems **11**:1198-1210.

Heiss, W. M., A. M. Smith, and P. K. Probert. 2000. Influence of the small intertidal seagrass Zostera novazelandica on linear water flow and sediment texture. New Zealand Journal of Marine and Freshwater Research **34**:689-694.

Hillman, J. R., T. A. O'Meara, A. M. Lohrer, and S. F. Thrush. 2021. Influence of restored mussel reefs on denitrification in marine sediments. Journal of Sea Research **175**:102099.

Horstman, E. M., C. M. Dohmen-Janssen, P. M. F. Narra, N. J. F. van den Berg, M. Siemerink, and S. J. M. H. Hulscher. 2014. Wave attenuation in mangroves: A quantitative approach to field observations. Coastal Engineering **94**:47-62.

Horstman, E. M., C. J. Lundquist, K. R. Bryan, R. H. Bulmer, J. C. Mullarney, and D. J. Stokes. 2018. The Dynamics of Expanding Mangroves in New Zealand. Pages 23-51 *in* C. Makowski and C. W. Finkl, editors. Threats to Mangrove Forests: Hazards, Vulnerability, and Management. Springer International Publishing, Cham.

Jacob, B., T. Dolch, A. Wurpts, and J. Staneva. 2023. Evaluation of seagrass as a nature-based solution for coastal protection in the German Wadden Sea. Ocean Dynamics **73**:699-727.

Jänes, H., P. Carnell, M. Young, D. Ierodiaconou, G. P. Jenkins, P. Hamer, P. S. E. Zu Ermgassen, J. R. Gair, and P. I. Macreadie. 2021. Seagrass valuation from fish abundance, biomass and recreational catch. Ecological Indicators **130**:108097.

Kelleway, J. J., N. Saintilan, P. I. Macreadie, C. G. Skilbeck, A. Zawadzki, and P. J. Ralph. 2016. Seventy years of continuous encroachment substantially increases 'blue carbon' capacity as mangroves replace intertidal salt marshes. Global Change Biology **22**:1097-1109.

Lovelock, C. E., M. F. Adame, J. Bradley, S. Dittmann, V. Hagger, S. M. Hickey, L. B. Hutley, A. Jones, J. J. Kelleway, and P. S. Lavery. 2022. An Australian blue carbon method to estimate climate change mitigation benefits of coastal wetland restoration. Restoration Ecology:e13739.

Lovelock, C. E., M. F. Adame, J. Bradley, S. Dittmann, V. Hagger, S. M. Hickey, L. B. Hutley, A. Jones, J. J. Kelleway, P. S. Lavery, P. I. Macreadie, D. T. Maher, S. McGinley, A. McGlashan, S. Perry, L. Mosley, K. Rogers, and J. Z. Sippo. 2023. An Australian blue carbon method to estimate climate change mitigation benefits of coastal wetland restoration. Restoration Ecology **31**:e13739.

Lovelock, C. E., J. Sippo, M. F. Adame, S. Dittmann, S. Hickey, L. Hutley, A. Jones, J. Kelleway, L. Paul, and P. Macreadie. 2021a. Blue Carbon Accounting Model (BlueCAM) Technical Overview. Prepared for the Clean Energy Regulator, 31 August 2021 https://www.cleanenergyregulator.gov.au/DocumentAssets/Pages/Blue-carbon-accounting-model-BlueCAM-technical-overview.aspx Accessed Sept 2023.

Lovelock, C. E., J. Sippo, M. F. Adame, S. Dittmann, S. Hickey, L. Hutley, A. Jones, J. Kelleway, L. Paul, and P. Macreadie. 2021b. Blue Carbon Accounting Model (BlueCAM) Technical Overview.

Lundquist, C. J., T. C. Jones, S. M. Parkes, and R. H. Bulmer. 2018. Changes in benthic community structure and sediment characteristics after natural recolonisation of the seagrass Zostera muelleri. Scientific Reports **8**:13250.

Lymbery, A. J., R. G. Doupé, T. Bennett, and M. R. Starcevich. 2006. Efficacy of a subsurface-flow wetland using the estuarine sedge Juncus kraussii to treat effluent from inland saline aquaculture. Aquacultural Engineering **34**:1-7.

Macreadie, P. I., M. D. P. Costa, T. B. Atwood, D. A. Friess, J. J. Kelleway, H. Kennedy, C. E. Lovelock, O. Serrano, and C. M. Duarte. 2021. Blue carbon as a natural climate solution. Nature Reviews Earth & Environment **2**:826-839.

McLeod, I. M., D. M. Parsons, M. A. Morrison, S. G. Van Dijken, and R. B. Taylor. 2014. Mussel reefs on soft sediments: a severely reduced but important habitat for macroinvertebrates and fishes in New Zealand. New Zealand Journal of Marine and Freshwater Research **48**:48-59.

MfE. 2017. Preparing for coastal change – A summary of coastal hazards and climate change guidance for local government. https://environment.govt.nz/publications/preparing-for-coastal-change-a-summary-of-coastal-hazards-and-climate-change-guidance-for-local-government/.

Morris, R. L., D. M. Bilkovic, M. K. Boswell, D. Bushek, J. Cebrian, J. Goff, K. M. Kibler, M. K. La Peyre, G. McClenachan, J. Moody, P. Sacks, J. P. Shinn, E. L. Sparks, N. A. Temple, L. J. Walters, B. M. Webb, and S. E. Swearer. 2019. The application of oyster reefs in shoreline protection: Are we over-engineering for an ecosystem engineer? Journal of Applied Ecology **56**:1703-1711.

Morrison, M., M. L. Lowe, C. M. Grant, P. J. Smith, G. Carbines, J. Reef, S. J. Bury, and J. Brown. 2014. Seagrass meadows as biodiversity and productivity hotspots. New Zealand Aquatic Environment and Biodiversity Report No. 137. 147p. Prepared by NIWA for the Ministry of Primary Industries.

Narayan, S., M. W. Beck, B. G. Reguero, I. J. Losada, B. van Wesenbeeck, N. Pontee, J. N. Sanchirico, J. C. Ingram, G.-M. Lange, and K. A. Burks-Copes. 2016. The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. PLoS ONE **11**:e0154735.

Nelson, J. L., and E. S. Zavaleta. 2012. Salt Marsh as a Coastal Filter for the Oceans: Changes in Function with Experimental Increases in Nitrogen Loading and Sea-Level Rise. PLoS ONE **7**:e38558.

Nelson, W. A., K. F. Neill, and R. D'Archino. 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**:472-491.

Parsons, D. M., D. Buckthought, C. Middleton, and G. MacKay. 2016. Relative abundance of snapper (Chrysophrys auratus) across habitats within an estuarine system. New Zealand Journal of Marine and Freshwater Research **50**:358-370.

Rullens, V., S. Mangan, F. Stephenson, D. E. Clark, R. H. Bulmer, A. Berthelsen, J. Crawshaw, R. V. Gladstone-Gallagher, S. Thomas, and J. I. Ellis. 2022a. Understanding the consequences of sea level rise: the ecological implications of losing intertidal habitat. New Zealand Journal of Marine and Freshwater Research **56**:353-370.

Rullens, V., M. Townsend, A. M. Lohrer, F. Stephenson, and C. A. Pilditch. 2022b. Who is contributing where? Predicting ecosystem service multifunctionality for shellfish species through ecological principles. Science of The Total Environment **808**:152147.

Sandwell, D. R., C. A. Pilditch, and A. M. Lohrer. 2009. Density dependent effects of an infaunal suspension-feeding bivalve (*Austrovenus stutchburyi*) on sandflat nutrient fluxes and microphytobenthic productivity. Journal of Experimental Marine Biology and Ecology **373**:16-25.

Sea, M. A., J. R. Hillman, and S. F. Thrush. 2022. Enhancing multiple scales of seafloor biodiversity with mussel restoration. Scientific Reports **12**:5027.

Shepard, C. C., C. M. Crain, and M. W. Beck. 2011. The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. PLoS ONE **6**:e27374.

Smaal, A. C., J. G. Ferreira, J. Grant, J. K. Petersen, and Ø. Strand. 2019. Goods and services of marine bivalves. Springer Nature.

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 by Leigh Stevens for Otago Regional Council, October 2023.

Stewart-Sinclair, P. J., R. H. Bulmer, E. Macpherson, and C. J. Lundquist. 2024. Enabling coastal blue carbon in Aotearoa New Zealand: opportunities and challenges. Frontiers in Marine Science **11**.

Suyadi, J. Gao, C. J. Lundquist, and L. Schwendenmann. 2020. Aboveground Carbon Stocks in Rapidly Expanding Mangroves in New Zealand: Regional Assessment and Economic Valuation of Blue Carbon. Estuaries and Coasts **43**:1456-1469.

Tanner, C. C. 1996. Plants for constructed wetland treatment systems — A comparison of the growth and nutrient uptake of eight emergent species. Ecological Engineering **7**:59-83.

Thomas, S., C. A. Pilditch, S. F. Thrush, and C. Savage. 2022. Ecosystem function responses to nutrient enrichment mediated by mud content in soft sediment habitats. New Zealand Journal of Marine and Freshwater Research **56**:491-508.

Thrush, S., J. Hewitt, C. Pilditch, and A. Norkko. 2021. Ecology of coastal marine sediments: form, function, and change in the Anthropocene. Oxford University Press.

Thrush, S. F., J. Hewitt, R. V. Gladstone-Gallagher, C. Savage, C. J. Lundquist, T. O'Meara, A. Viellard, J. R. Hillman, S. Mangan, E. Douglas, D. E. Clark, A. Lohrer, and C. A. Pilditch. 2020. Cumulative stressors reduce the self-regulating capacity of coastal ecosystems (in press). Ecological Applications.

Waterford, L., V. FitzSimons, A. M. Martijn Wilder, H. Reid, L. Drake, and H. Campbell. 2022. Investigating the use of biodiversity markets to scale financing of nature-based solutions in Aotearoa New Zealand. Summary Report: Prepared by Pollination for the Aotearoa New Zealand Ministry for the Environment.

zu Ermgassen, P. S. E., B. DeAngelis, J. R. Gair, S. z. Ermgassen, R. Baker, A. Daniels, T. C. MacDonald, K. Meckley, S. Powers, M. Ribera, L. P. Rozas, and J. H. Grabowski. 2021. Estimating and Applying Fish and Invertebrate Density and Production Enhancement from Seagrass, Salt Marsh Edge, and Oyster Reef Nursery Habitats in the Gulf of Mexico. Estuaries and Coasts **44**:1588-1603.

9 Supplementary materials

Supplementary table 1: Estimates of sediment organic carbon accumulation rate (sequestration), stocks and greenhouse gas emissions at sites across ***Aotearoa and Australia****.*

	Habitat type	Mean	SE	Min	Max	Number of sites	Source	Source notes
Sediment Carbon Accumulation Rate (tC ha^{-1} yr^{-1})	Saltmarsh	0.89	0.15	0.74	1.05	2	Bulmer et al. 2024	Collected from two locations within Whangārei harbour
	Mangrove	0.64	0.25	0.22	2.12	7	Bulmer et al. 2024	Collected from two locations within Whangārei harbour and 5 locations throughout the Auckland Region
	Seagrass	0.04	0.01	0.02	0.05	2	Bulmer et al. 2024	Collected from two locations within Whangārei harbour
	Unvegetated	0.26	0.04	0.02	0.64	18	Bulmer et al. 2024	Collected from three locations within Whangārei harbour and 15 locations throughout the Auckland Region
Sediment Carbon Stock (tC ha^{-1} to 100 cm depth)	Saltmarsh	92.50	12.42	68.62	131.97	5	Bulmer et al. 2024	Collected from two locations within Whangārei harbour and data compiled from Bulmer et al. 2020
	Mangrove	57.44	6.29	30.00	113.97	17	Bulmer et al. 2024	Collected from two locations within Whangārei harbour and data compiled from Bulmer et al. 2020 and Bulmer et al. 2018
	Seagrass	17.22	6.12	7.53	33.09	4	Bulmer et al. 2024	Collected from two locations within Whangārei harbour and data compiled from Bulmer et al. 2020
	Unvegetated	33.60	3.32	7.56	69.61	22	Bulmer et al. 2024	Collected from three locations within Whangārei harbour, 15 locations throughout the Auckland Region, and data compiled from Bulmer et al. 2020
Above Ground Biomass (tC ha^{-1})	Saltmarsh	4.51	1.39	1.58	8.78	5	Bulmer et al. 2024	Collected from two locations within Whangārei harbour and data compiled from Bulmer et al. 2020
	Mangrove	22.36	5.43	2.51	84.88	17	Bulmer et al. 2024	Collected from two locations within Whangārei harbour and data compiled from Bulmer et al. 2020 and Bulmer et al. 2018
	Seagrass	0.11	0.04	0.03	0.23	4	Bulmer et al. 2024	Collected from two locations within Whangārei harbour and data compiled from Bulmer et al. 2020
Habitat Carbon Stock (Above Ground Biomass + Sediment (tC ha^{-1} to 100 cm depth)	Saltmarsh	97.01	13.81	70.2	140.75	5	Bulmer et al. 2024	Combination of the above
	Mangrove	79.8	11.72	32.51	198.85	17	Bulmer et al. 2024	Combination of the above
	Seagrass	17.33	6.16	7.56	33.32	4	Bulmer et al. 2024	Combination of the above
	Unvegetated	33.60	3.32	7.56	69.61	22	Bulmer et al. 2024	Combination of the above

	Habitat type	Mean	SE	Min	Max	Number of sites	Source	Source notes
Sediment Carbon Accumulation Rate (tC ha^{-1} yr^{-1})	Saltmarsh	0.46	0.16				Ross et al. (2023)	Albot et al. (unpublished data) and Berthelsen et al. (2023).
	Mangrove	0.90		0.21	2.12		Ross et al. (2023)	Bulmer et al. (unpublished data)
Sediment Carbon Stock (tC ha^{-1} to 100 cm depth)	Saltmarsh			38.00	57.00		Ross et al. (2023)	Albot et al. (unpublished data) and Berthelsen et al. (2023).
	Mangrove	61.60	6.90				Ross et al. (2023)	Bulmer et al. (unpublished data)
	Seagrass			14.00	27.00		Ross et al. (2023)	The range between Bulmer et al. (unpublished data) and Berthelsen et al. (2023)

	Habitat type	Mean	SE	95% lower CI	95% upper CI	Number of sites	Source	Source notes
Sediment Carbon Accumulation Rate (tC ha^{-1} yr^{-1})	Saltmarsh	0.77	0.22	0.32	1.21	28	Lovelock et al. (2022)	Collected from Australian estuaries
	Mangrove	1.4	0.16	0.95	1.73	48	Lovelock et al. (2022)	Collected from Australian estuaries
	Seagrass	0.32	0.05	0.23	0.42	43	Lovelock et al. (2022)	Collected from Australian estuaries
Emissions CH_4 (kg ha^{-1} yr^{-1})	Saltmarsh	0.11		-0.21	0.44	2	Lovelock et al. (2022)	Collected from temperate Australian estuaries
	Mangrove	2.19		0.91	3.31	3	Lovelock et al. (2022)	Collected from temperate Australian estuaries
	Seagrass	0				1	Lovelock et al. (2022)	Collected from temperate Australian estuaries
Emissions N_2O (kg ha^{-1} yr^{-1})	Saltmarsh	0.13		0.02	0.23	2	Lovelock et al. (2022)	Collected from temperate Australian estuaries
	Mangrove	0.24		0.17	2.75	2	Lovelock et al. (2022)	Collected from temperate Australian estuaries
	Seagrass	0				1	Lovelock et al. (2022)	Collected from temperate Australian estuaries

	Habitat type	Mean	SD	Number of sites	Source	Source notes
Above Ground Biomass (tC ha^{-1})	Saltmarsh	7.89	6.1	49	Lovelock et al. (2022)	Collected from temperate Australian estuaries
	Mangrove	70.4	41	9	Lovelock et al. (2022)	Collected from temperate Australian estuaries
	Seagrass	0.57	0.66	74	Lovelock et al. (2022)	Collected from temperate Australian estuaries

9.8. Regional conservation status of selected fungal taxa in Otago

Prepared for: Environmental Science and Policy Committee

Report No. GOV2456

Activity: Governance Report

Author: Scott Jarvie, Scientist - Biodiversity

Endorsed by: Tom Dyer, General Manager Science and Resilience

Date: 4 December 2024

PURPOSE

[1] This paper documents the regional conservation status of selected fungal species (non-lichenised agarics, boletes and russuloid) in the Otago Region.

EXECUTIVE SUMMARY

[2] This paper outlines regional conservation statuses and their role in monitoring biodiversity and biosecurity.

[3] The first report on the regional conservation status of selected fungal species in Otago is presented.

[4] A total of 331 fungal taxa in the Otago were identified from the national checklist. Nine fungal taxa were assessed as Regionally Threatened (Regionally Critical = 1; Regionally Vulnerable = 8), 203 as Regionally Not Threatened, and 119 as Regionally Data Deficient.

RECOMMENDATION

That the Committee:

1) ***Notes** this report.*
2) ***Notes** that the regional threat assessment for other species groups will continue as part of the terrestrial ecology work programme.*

BACKGROUND – REGIONAL CONSERVATION STATUSES

[5] Regional councils have statutory obligations to protect and maintain indigenous biodiversity under the Resource Management Act 1991 (RMA).

[6] Threat classifications play a key role in biosecurity and biosecurity management. The New Zealand Threat Classification System (NZTCS) is a national system to assess the conservation status of species found in the wild in Aotearoa New Zealand[1]. The system is administered by the Department of Conservation Te Papa Atawhai (DOC) on behalf of all New Zealanders and complements the International Union for Conservation of Nature (IUCN) Red List system.

[7] The NZTCS and IUCN use rules-based approach to assess the risk of extinction based on estimates of population size and trend. These national and international assessments

[1] Includes all terrestrial, freshwater and marine areas within the New Zealand Exclusive Economic Zone, not including the Ross Dependency in Antartica.

are used to inform conservation action, target resources, and monitor biodiversity trends and conservation effectiveness.

[8] Regional council ecologists from Te Uru Kahika (Regional and Unitary Councils Aotearoa) are working with DOC to develop a standardised methodology for regional threat assessments[2]. The methodology uses a similar rule-based approach to the NZTCS but takes the size of each region into account for the assessments. Regional threat assessments complement both the NZTCS and the IUCN Red List system.

[9] Qualifiers in threat assessments provide additional information about species. They can help in understanding the basis for assessments and can provide useful information to support management decisions.

[10] Regional threat assessments help local authorities manage and protect biodiversity within their regions. For example, knowledge of threatened species present at a site is of particular importance for consenting processes and systematic conservation planning.

[11] Regional conservation statuses can also guide local authority funding decisions relating to biosecurity and/or biodiversity management. Information regarding the species present, as well as their threat status, can aid decision-making processes. For example, identification of priority sites to guide biodiversity and/or biosecurity management actions could occur to ensure appropriate activities inform ecological restoration initiatives.

[12] In addition, regional conservations statuses can be used to raise the profile of species in the region by catalysing work to produce educations resources and events. For example, the recent Reptile Awareness Day held in conjunction with Tūhura Otago Museum, University of Otago – Ōtākou Whakaihu Waka, Southern Lakes Sanctuary and an independent consultant arose out of previous threat assessments.

[13] The ORC has previously completed regional conservation status assessments for amphibians, bats, birds, indigenous vascular plants, and reptiles[3].

DISCUSSION – REGIONAL CONSERVATION STATUS OF SELECTED FUNGAL SPECIES IN THE OTAGO REGION

[14] The regional conservation status for selected fungal species (non-lichenised agarics, boletes and russuloid) in the Otago has recently been completed (Attachment 1).

[15] For the fungal taxa, a general methodology for assessing the threat of extinction of fungal species was described at the regional level, and a list of selected species from the national assessment presented.

[16] A total of 331 selected species of fungal species were identified in Otago. This includes nine fungal taxa assessed as Regionally Threatened (Regionally Critical = 1; Regionally Vulnerable = 8), 203 as Regionally Not Threatened, and 119 as Regionally Data Deficient.

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[2] A manual to document the methodology will be published as a national guideline. Dr Jarvie will be a co-author of the manual.

[3] Amphibians and indigenous vascular plants: https://www.orc.govt.nz/media/beugmwjc/20240627-esp-agenda.pdf; bats: https://www.orc.govt.nz/media/15330/2023-10-11-esp-agenda.pdf; reptiles: https://www.orc.govt.nz/media/14694/minutes-environmental-science-and-policy-20230426.pdf; birds: https://www.orc.govt.nz/media/cuajacpl/20240926-esp-agenda.pdf

[17] For the Regionally Threatened species, five had their holotype locality in Otago; this is where the species is described from and has considerable scientific merit. Type specimens such as holotype localities have a critical role in taxonomic research, underpinning decisions on the designation of new species resulting from splitting of existing species concepts and the amalgamation of different names as synonyms of a single species. In turn these decisions have consequences for assessing species distributions and associated rarity and threats.

[18] In the national 2022 report[4] *Deconica baylisiana* is currently the only fungal species listed as Nationally Critical, the most severe threat status being the closest to extinction, and the main population of this species is within Otago – see below for a photograph of it taken by ecologist David Lyttle.

[19] While *Deconica baylisiana* is distinctive fungi species with being a noticeable reddish/orange-adapted species of open herbfields, it was not observed between 1969 and 2013. The rediscovery of it was in the Rock & Pillar Ranges, with an observer posting a photo on the Community Science platform iNaturalist[5]. At the regional and national scale this is an important species, and yet no information on how this species is dispersed, or what additional threats it may face is known. For example, it has been hypothesised that ground-dwelling birds were the primary agents of dispersal, with the bright colours and above-ground fruiting being an adaptation mimicking fruits. However, there has not been any studies investigating this.

[20] Knowledge of fungi lags behind many other species groups, and as a consequence there is limited data on fungi species populations and the changes in, and threats to, those populations. In recent years the increasingly popularity of Community Science platforms, like iNaturalist, has led to an explosion in interest in poorly understood groups like fungi. Although our baseline is increasing, from a scientific perspective it is critical that a professional community remains engaged in biodiversity management to support these kinds of activities through both national and regional efforts.

OPTIONS

[21] This report is for noting and therefore does not present options.

CONSIDERATIONS

[4] https://www.doc.govt.nz/globalassets/documents/science-and-technical/nztcs38entire.pdf

[5] https://www.inaturalist.org/

Strategic Framework and Policy Considerations

[22] The terrestrial ecology programme contributes towards the *Healthy water, soil and coast*, and *Healthy diverse ecosystems* strategic priorities. The work outlined in this paper aligns with visions in ORC's Biodiversity Strategy Plan 2018: Our Living Treasure | Tō tatou Koiora Taoka and visions and outcomes in the Biodiversity Action Plan Te Mahi hei Tiaki I te Koiora 2019–2024.

[23] The regional conservation statuses can be part of the evidence base to inform decisions on the upcoming biodiversity strategy.

Financial Considerations

[24] The process to run regional threat assessments are budgeted and are a planned activity.

Significance and Engagement

[25] Engagement is ongoing with mana whenua, government agencies, stakeholders, and landowners who work in biodiversity management, as well on a project-by-project basis to undertake subsequent surveys.

Legislative and Risk Considerations

[26] ORC has legislative responsibilities to protect significant habitats as a matter of national importance, as well as to maintain indigenous biodiversity. These threat assessments enable the ORC to better understand the status and trends of species in Otago.

Climate Change Considerations

[27] The report included a qualifier for climate change in the assessment process.

Communications Considerations

[28] The regional conservation statuses have a dedicated ORC webpage where the report and accompanying spreadsheets are provided[6]. The reports are also provided to members of the Otago Biodiversity Forum, whose membership include mana whenua, territorial authorities, and other agencies.

[29] Using information from the regional conservation status ORC works with taxonomic experts and Tūhura Otago Museum to develop educational resources. This includes the development of guides and/or posters to make information more accessible to members of the public and be used in community science initiatives.

NEXT STEPS

[30] Regional threat assessments for other groups will continue as part of the biodiversity work programme.

[31] An assessment has started for Onchyophora (peripatus, or velvet worms).

[32] Work is underway to compile lists for other species groups, including freshwater fish, marine mammals, mosses, liverworts and hornworts, and lichens. The compilation of such lists is a precursor to conducting a regional conservation status, although does not necessarily mean assessments will happen. Mana whenua have also been consulted through Aukaha and are particularly interested to have completed assessments for the

[6] https://www.orc.govt.nz/environment/biodiversity/otago-regional-threat-assessments/

freshwater fish and marine mammals, in addition to those already done for reptiles, bats, birds, and indigenous vascular plants.

[33] Publication of the manual for the regional conservation status methodology. The manual is undergoing peer review and will be released by DOC.

ATTACHMENTS

1. Conservation status of selected fungal taxa in Otago [**9.8.1** - 45 pages]

Conservation Status of Selected Species of Non-Lichenised Agarics, Boletes and Russuloid Fungi in Otago

Scott Jarvie, Jerry Cooper

October 2024

Otago Threat Classification Series 7

Otago Regional Council

orc.govt.nz

Conservation status of selected species of non-lichenised agarics, boletes and russuloid fungi in Otago

October 2024 –
Otago Threat Classification Series 7

Scott Jarvie
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Otago Regional Council
Otago Threat Classification Series 7
ISSN 2816-0983 (web PDF)
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Otago Threat Classification Series is a scientific monograph series presenting publications related to the Regional Threats Classification System of groups of taxa in the Otago Region. Most will be lists providing regional threat assessments of members of a plant, animal, or fungi group (e.g., amphibians, bats, birds, fungi, indigenous vascular plants, reptiles), and leverages off national assessments for the New Zealand Threat Classification System within the regional context.

Recommended citation

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Covers and frontispiece image credits

Deconica baylisiana, Threatened – Regionally Critical. Photograph by David Lyttle.

Cortinarius minoscaurus, Threatened – Regionally Vulnerable. Photograph by Jerry Cooper.

Published by Otago Regional Council, PO Box 1954, Ōtepoti Dunedin 9054, Aotearoa New Zealand.

The views published in this report on the conservation statuses reflect the views of an independent panel and are not necessarily the view of the Otago Regional Council.

This publication is available for download from the Otago Regional Council website.

In the interest of forest conservation, we support paperless electronic publishing.

Executive Summary

This report provides the first assessment of the conservation status of selected species of non-lichenised agarics, boletes and russuloid fungi in the Otago Region. A general process for assessing the threat of extinction of fungal taxa is described at the regional level, and a list of selected taxa is presented. A total of 331 fungal taxa in the Otago were identified from the national checklist. Nine fungal taxa were assessed as Regionally Threatened (Regionally Critical = 1; Regionally Vulnerable = 8), 203 as Regionally Not Threatened, and 119 as Regionally Data Deficient.

Table of Contents

Introduction

Threat classifications play an important role in monitoring biodiversity and informing conservation actions. The New Zealand Threat Classification System (NZTCS) is a tool used to assign a threat status to candidate taxa (species, subspecies, varieties, and forma) in Aotearoa New Zealand (Rolfe et al. 2022). The classification system was developed to apply equally to terrestrial, freshwater, and marine biota (flora, fauna, and fungal taxa). The NZTCS scores taxa at the national scale against criteria based on an understanding of population state, size, and trend, while considering population status, impact of threats, recovery potential, and taxonomic certainty. The Department of Conservation | Te Papa Atawhai (DOC) administers the NZTCS in Aotearoa New Zealand, with national assessments used to inform conservation action, target resources, and monitor biodiversity trends and conservation effectiveness.

While DOC is tasked with managing indigenous taxa nationally, regional and district councils have statutory obligations to maintain indigenous biodiversity under the Resource Management Act 1991 (RMA), including to manage the habitats of threatened taxa. The regional threat status of taxa is particularly important in the context of the RMA and in conservation planning. A key requirement of managing the habitats occupied by taxa is to understand regional population sizes and distributions, and to monitor trends and management effectiveness.

The Regional Threat Classification System is a regional system to assess the conservation status of candidate taxa in Aotearoa New Zealand's sixteen geopolitical regions. It is complementary to the NZTCS, using the same categories, status rankings and criteria, adjusted to account for smaller regional scales (Appendix 1 – see other regional conservation statuses listed below for more information). National strongholds and additional regional qualifiers are also considered (Appendix 2 – see other regional conservation statuses listed below). This report is the first regional conservation status assessment of selected species of non-lichenised agarics, boletes and russuloid fungi in the Otago Region. Regional threat assessments have been completed by Otago Regional Council for five taxonomic groups (bats, Jarvie et al. 2023; amphibians, Jarvie 2024; reptiles, Jarvie et al. 2024a; birds, Jarvie et al. 2024b, indigenous vascular plants, Jarvie et al. 2024c), Greater Wellington Regional Council for five taxonomic groups (birds, Crisp et al. 2024; indigenous freshwater fish, Crisp et al. 2022; indigenous vascular plants, Crisp 2020a; reptiles, Crisp et al. 2023b; bats, Crisp et al. 2023b) and Auckland Council for five taxonomic groups (amphibians, Melzer et al. 2022a; reptiles, Melzer et al. 2022b; indigenous vascular plants, Simpkins et al. 2023; bats, Woolly et al. 2023; freshwater fish, Bloxham et al. 2023) as of October 2024.

Methods

The regional threat status of selected species of non-lichenised agarics, boletes and russuloid fungi was assessed by Jerry Cooper in July 2024. The NZTCS was developed for assessing animal and plant populations but was not initially consistently and directly applicable to fungal populations (Molloy et al. 2002; Townsend et al. 2008). In 2021 the NZTCS adopted a modified protocol designed for assessing fungal populations (Cooper et al. 2022) and incorporated into an updated version of the NZTCS (Townsend et al. 2008 cf. Rolfe et al. 2022), based on the International Union for Conservation of Nature (IUCN) Red List system protocol (Dahlberg & Mueller 2011). Due to the large number of fungal taxa present in Aotearoa New Zealand and the limited availability of expertise, the national panel implemented a preliminary selection mechanism to reduce the number of candidate taxa taken forward into the NZTCS detailed assessment process (Cooper et al. 2022).

The 2021 fungal assessment at the national scale provides the set of the candidate taxa to be assessed in Otago. Specifically, this includes species in the fungal orders Agaricales, Russulales and Boletales. These orders include many of the larger mushroom species and many that are mycorrhizal with trees. Note that this means it excludes nearly all micro-fungi, plant pathogens, and many larger bracket fungi and some mycorrhizal groups. Moreover, even within the selected orders, certain groups were excluded because of uncertain taxonomy (e.g., puffballs and club-fungi). In common with other regional assessments, any regional fungal assessment of a threatened species can have a higher threat status than the national assessment, but not lower. All species considered nationally Data Deficient or excluded at the national scale remain Data Deficient and excluded at the regional scale because, for fungi at least, there is not enough information about them. See Rolfe et al. 2022 for the definitions of the threat categories and statuses.

To assess the regional status of the species listed nationally with a Not Threatened and Threatened status, data was needed to compare species populations at the national scale with those at the regional scale. Moreover, a thorough assessment would require details of the changes over time of regional population, together with the factors influencing those changes at the sub-regional scale. This detailed analysis would provide the baseline data for estimating the resulting likelihood of regional extinction. The protocol does allow the inference of population sizes from occurrence records and considers the lifestyle of each species (or at least the generic lifestyles) to infer estimates of true population size and including some estimate of potential but non-observed populations. If detailed population-level data is available at a sub-regional scale, then it would be possible to apply this methodology. However, such data does not exist for any fungal taxa in Aotearoa New Zealand. The consequence is that for fungi there is no regional-scale population that would lead to differences between the national assessment and regional assessment using the methodology of Cooper et al. 2022. It is possible, however, to reasonably infer that the ratio of regional populations against national populations correlate with the ratio of regional species occurrences against national occurrences. Thus, the starting point for regional assessment is a compilation of the national and regional occurrence data for fungi. Examination of the national versus regional records has the potential to inform regional re-assessment.

Compilation of national and regional species occurrence data

The source of occurrence data was from the Global Biodiversity Information Facility (GBIF) and the University of Otago (OTA) mycological collection. Because taxon names within datasets can be variable and include synonyms, i.e., they don't always provide the correct current name according to New Zealand authorities, the taxon names were matched against the national fungal checklist maintained in Biota of New Zealand (BiotaNZ) database maintained by Manaaki Whenua – Landcare Research. The matched names were assigned biostatus according to the national checklist as present in Aotearoa New Zealand, absent, endemic, indigenous, or introduced. The subset of endemic/indigenous records was extracted and standardised to the currently accepted name in the BiotaNZ national checklist. Note that records of some species based on occurrence records were excluded from analyses because they represent species not known to occur in Aotearoa New Zealand. These records were primarily associated with collections held overseas that have not recently been reviewed and identified.

Compilation of national and regional status and associated data

For this assessment, the focus is the species listed in Cooper et al. 2022 that have occurrence records in the Otago Region. The subset of occurrence records was extracted by linking the subset of species occurrence records in Otago to the species names listed in Cooper et al. 2022. This provided a set of Otago occurrence records for each nationally listed species.

Where the numbers and ratio of national collections versus Otago collections is 40% or above for a taxon, a note was included to highlight which populations in Otago may be nationally significant (Appendix 4). Specific factors for high ratios that do not support high regional representation may be a consequence of three main factors: 1) species that are poorly defined taxonomically and/or difficult to identify (even by experts) will have been collected infrequently both nationally and regionally, and this skews the ratio data to where collecting effort has been significant. 2) Several species have been described recently, or recently recognised in New Zealand, and we do not have enough information to assess true distribution. 3) Otago University (Prof. David Orlovich) specialises in the study of the family Cortinariaceae and collections of many species are associated with that local targeted survey effort and do not represent an unbiased national distribution. The conclusion from comparing national and regional occurrence records is that there is no basis for a regional-level assessment of threat status as higher than the national status for any of the species considered. In addition, the criteria and qualifiers at the national level remain valid at the regional level.

For the current assessment, the lack of detailed regional un-biased surveys on the location and size of fungal populations means that regionally specific information on historic and predicted estimates of population changes over time are not possible. As a consequence, the assessment of regional threat status provided here is based on the comparison of surrogates for regional versus national population size based on known occurrence records. That comparative data is provided in Appendix 4, Table 1. For any listed species, if the majority of national occurrence records are restricted to Otago, then this suggests that local populations are significant at both the regional and national level. However, there can be several reasons why the number of occurrence records are concentrated in a particular area and this needs to be considered. Inspection of the data provided in Appendix 4 comparing regional versus national metrics on species occurrence records provides no substantive evidence to support regional populations concentrations, except in the case of *Deconica baylisiana*. Consequently, there is no justifiable reason for a higher regional threat status for any of the listed species or their associated qualifiers.

Results

A total of 331 selected species of non-lichenised agarics, boletes and russuloid fungi were identified in the Otago Region (Figure 1). This includes nine fungal taxa assessed as Regionally Threatened (Regionally Critical = 1; Regionally Vulnerable = 8), 203 as Regionally Not Threatened, and 119 as Regionally Data Deficient.

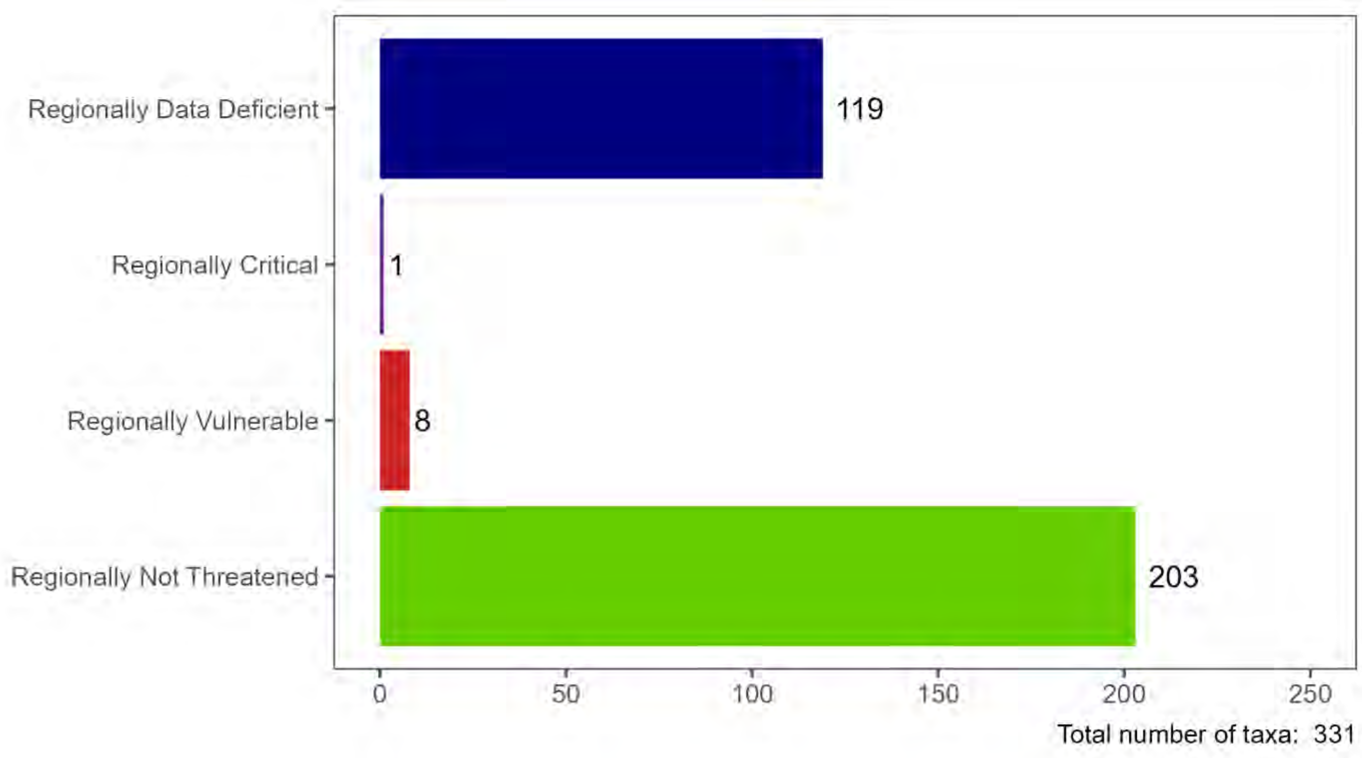


Figure 1: Conservation status of fungal taxa in the Otago Region.

Table 1, below, lists the species that are Regionally Threatened and Table 3 provides geographic details for those species with an Otago holotype locality. All the listed species were described from a single collection (the holotype) except for *Inocybe gilbertoi* where several paratypes were included.

Table 1: Fungal taxa with a Regionally Threatened status the Otago Region.

The source of "occurrences' data are from the Global Biodiversity Information Facility (GBIF) and the University of Otago (OTA) mycological collection. Qualifiers can be found in Appendix 2 and 3. For the full dataset for this regional assessment of non-lichenised agarics, boletes and russuloid fungi in the Otago region see Appendix 4.

Species	# National occurrences	# Otago occurrences	Regional Threat Status	Criteria	Qualifiers	Notes
Deconica baylisiana	10	10	Critical	A(1)	CI, CR, DPS, DPT, RR, NStr, Sp, TL	Distinct species, also present on Rakiura/Stewart Island
Corinarius minoscaurus	8	3	Vulnerable		De, TL	Tea-tree ectomycorrhizal associate
Cortinarius pholiotellus	11	4	Vulnerable		De, TL	Tea-tree ectomycorrhizal associate
Hygrophoropsis umbriceps	11	1	Vulnerable		De, TL	Tea-tree ectomycorrhizal associate
Inocybe gilibertoi	7	1	Vulnerable		De	Tea-tree ectomycorrhizal associate
Mycena flavovirens	42	1	Vulnerable		DPS, DPT	A regional verified outlier
Phylegmacium venicefer	4	1	Vulnerable		De	Tea-tree ectomycorrhizal associate
Russula allochroa	55	2	Vulnerable		De	Tea-tree ectomycorrhizal associate
Thaxterogaster cremeorufus	3	1	Vulnerable		De, TL	Tea-tree ectomycorrhizal associate

Table 2: Type localities of species with a Regionally Threatened status the Otago Region.

Biostatus is from the Biota of New Zealand where endemic refers to Aotearoa New Zealand.

Species	Biostatus	Type locality	Latitude	Longitude	Uncertainty
Deconica baylisiana	Endemic	Otago, Rock and Pillar Range	-45.545	170.003	3000 m
Corinarius minoscaurus	Endemic	Otago, Waipori Falls	-45.893	169.949	3000 m
Cortinarius pholiotellus	Endemic	Otago, Waipori Falls	-45.893	169.949	3000 m
Hygrophoropsis umbriceps	Endemic	North Island			
Inocybe gilibertoi	Endemic	Stewart Island (Paratypes Taranaki, Fiordland, Auckland)			
Mycena flavovirens	Endemic	Australia (on imported fern)			
Phylegmacium venicefer	Endemic	Southland			
Russula allochroa	Endemic	North Island			
Thaxterogaster cremeorufus	Endemic	Otago, Waipori Falls	-45.893	169.949	3000 m

Discussion

Regional threat assessments have been completed by regional councils in Aotearoa New Zealand, with the resulting regional threat lists being used as a tool to help maintain indigenous biodiversity. For example, regional threat lists have been used to advise resource consent applications, inform conservation actions and target resources, as well as monitor biodiversity trends and conservation effectiveness. This report is the first regional threat assessment for fungal taxa in Otago based on a checklist of fungal species verified as present in the region. A total of 331 selected species of non-lichenised agarics, boletes and russuloid fungi in the Otago Region were identified from the national checklist. Nine fungal taxa were assessed as Regionally Threatened (Regionally Critical = 1; Regionally Vulnerable = 8), 203 as Regionally Not Threatened, and 119 as Regionally Data Deficient.

For fungi there is currently no regional-scale additional data on populations that would lead to any differences between a national assessment and a regional assessment using the methodology presented in Cooper et al. 2022. In this report a supplemental methodology for identifying candidate taxa is presented that may have a different (increased) regional threat status relative to the national status. The pragmatic approach requires a comparison of national and local numbers of verified occurrence records. Using that approach no evidence was found to suggest that any of the taxa under consideration should have a different regional threat status.

In the national 2022 report *Deconica baylisiana* is currently the only fungal species listed as Nationally Critical, and the main population of this species is within the Otago Region. At the regional and national scale this an important species, and yet there is no information on how this species is dispersed, or what additional threats it may face, is known. Future work should investigate dispersal mechanisms and threats.

Currently the number of described indigenous fungal species in Aotearoa New Zealand is around 6,000 and we estimate another 14,000 species remain to be described. This regional assessment is based on the national assessment in Cooper et al. 2022. That report covered 961 species which is just 16% of the total described. More work is needed at both the national and regional scale to better understand the status and threats to all our fungal species.

Knowledge of fungi lags behind many other groups, and as a consequence there is limited data on species populations and the changes in, and threats to, those populations. Aotearoa New Zealand also has a very limited pool of experts able to interpret the available data. In recent years, the increasing popularity of Community Science platforms, like iNaturalist, has led to an explosion in interest in poorly understood groups like fungi. Our base-line data is increasing, along with considerable increase in the number of people with the interest and skills to document fungi. Nevertheless, the increasing level of data is associated with variable quality. From a scientific perspective it is critical that the professional community engaged in biodiversity management support these kinds of activities through both national and regional efforts.

Acknowledgement

Thanks to Philippa Crisp and Roger Uys from Greater Wellington Regional Council and Sabine Melzer from Auckland Council for advice on the regional conservation status process, Pascale Michel from the Department of Conservation | Te Papa Atawhai (DOC) for advice on the national assessments and the regional conservation status process, Ciaran Campbell and Tim Ware from the Otago Regional Council for editorial advice and discussion on regional threat assessments, and other Council staff that provided support for these assessments, including Karen Warrington for logistical support. Professor David Orlovich, Otago University – Ōtākou Whakaihu Waka, is thanked for providing access to regional data associated with Otago University Fungarium collections.

References

Bloxham, M., Woolly, J., Dunn, N., Chaffe, A., Melzer, S. (2023). Conservation status of freshwater fishes in Tāmaki Makaurau/Auckland. Auckland Council Technical Report, TR2023/13. 36 p.

Cooper J.A., Buchanan, P.K., Leonard, P., Allison-Cooper, L., Johnston, P., Padamsee, M., McKenzie, M., Michel, P. (2022). Conservation status of selected species of non-lichenised agarics, boletes and russuloid fungi in Aotearoa New Zealand. New Zealand Threat Classification Series 38. Department of Conservation, Wellington. 49p.

Crisp, P. (2020). Conservation status of indigenous vascular plant species in the Wellington region. Greater Wellington Regional Council Publication No. GW/ESCI-G-20/20 Wellington. 39 p.

Crisp, P., Hitchmough, R., Newman, D., Adams, L., Lennon, O., Woolley, C., Hulme-Moir, A., Bell, T., Herbert, S., Spearpoint, O., Nelson, N. (2022a). Conservation status of reptile species in the Wellington region. Greater Wellington Regional Council, Publication No. GW/ESCI-G-23/03, Wellington. 23 p.

Crisp, P., O'Donnell, C., Pryde, M., Ryan, J., Spearpoint, O. (2023). Conservation status of bat species in the Wellington region. Greater Wellington Regional Council, Publication No. GW/ESCI-G-23/01, Wellington. 13 p.

Crisp, P., Robertson, H., McArthur, N., Cotter, S. (2024). Conservation status of bird in the Wellington region. Greater Wellington Regional Council, Publication No. GW/KI-G-23/21, Wellington. 50 p.

Crisp, P., Perrie, A., Morar, A., Royal, C. (2022b). Conservation status of indigenous freshwater fish in the Wellington region. Greater Wellington Regional Council Publication No. GW/ESCI-T-22/02, Wellington. 8 p.

Dahlberg, A., Mueller, G. (2011). Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species. Fungal Ecology 4: 147–162.

Jarvie, S. (2024). Regional conservation status of Otago’s amphibians. Otago Regional Council, Otago Classification Series, 2024/4. 24 p.

Jarvie, S., Barkla, J., Rance, B., Rogers, G., Ewans, R., Thorsen, M (2024c). Regional conservation status of indigenous vascular plants in Otago. Otago Regional Council, Otago Classification Series, 2024/3. 134 p.

Jarvie, S., Davidson-Watts, I., Dennis, G., Gower, C., Pryde, M. (2023). Regional conservation status of bat species in Otago. Otago Regional Council, Otago Threat Classification Series, 2023/2. 19 p.

Jarvie, S., Knox, C., Monks, J.M., Purdie, S., Reardon, J., Campbell, C. (2024a). Regional conservation status of reptile species in Otago. Otago Regional Council, Otago Threat Classification Series, 2024/5. 36 p.

Jarvie, S., McKinlay, B., Palmer, D., Rawlence, N. J., Thomas O. (2024b). Regional conservation status of birds in Otago. Otago Regional Council, Otago Threat Classification Series, 2024/6. 134 p.

Melzer, S., Hitchmough, R., van Winkel, D., Wedding, C., Chapman, S., Rixon, M., Moreno, V., J. Germano, J. (2022a). Conservation status of amphibian species in Tāmaki Makaurau / Auckland. Auckland Council Technical Report, TR2022/4. 16 p.

Melzer, S., Hitchmough, R., van Winkel, D., Wedding, C., Chapman, S., Rixon, M. (2022b). Conservation status of reptile species in Tāmaki Makaurau / Auckland. Auckland Council Technical Report, TR2022/3. 20 p.

Rolfe, J., Hitchmough, R., Michel, P., Makan, T., Cooper, J.A., de Lange, P.J., Townsend, C.A.J., Miskelly, C.M., Molloy, J. (2022). New Zealand Threat Classification System manual 2022. Part 1: Assessments. Department of Conservation, Wellington. 45 p.

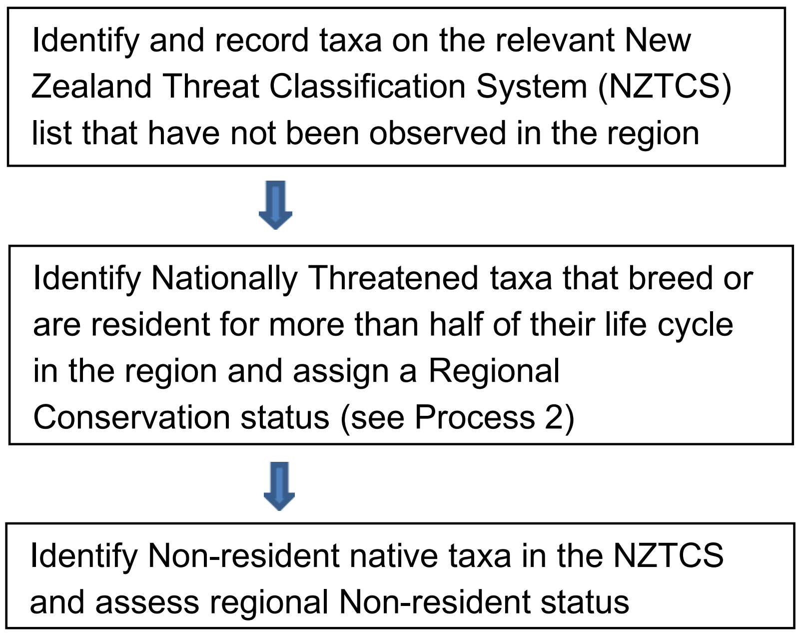
Simpkins, E., Woolly, J., de Lange, P., Kilgour, C., Cameron, E., Melzer, S. (2023). Conservation status of vascular plant species in Tāmaki Makaurau/Auckland. Auckland Council Technical Report, TR2022/19. 17 p.

Townsend, A.J., de Lange, P.J., Duffy, C.A.J., Miskelly, C.M., Molloy, J., Norton, D.A. (2008). New Zealand Threat Classification System manual. Department of Conservation, Wellington. 35 p.

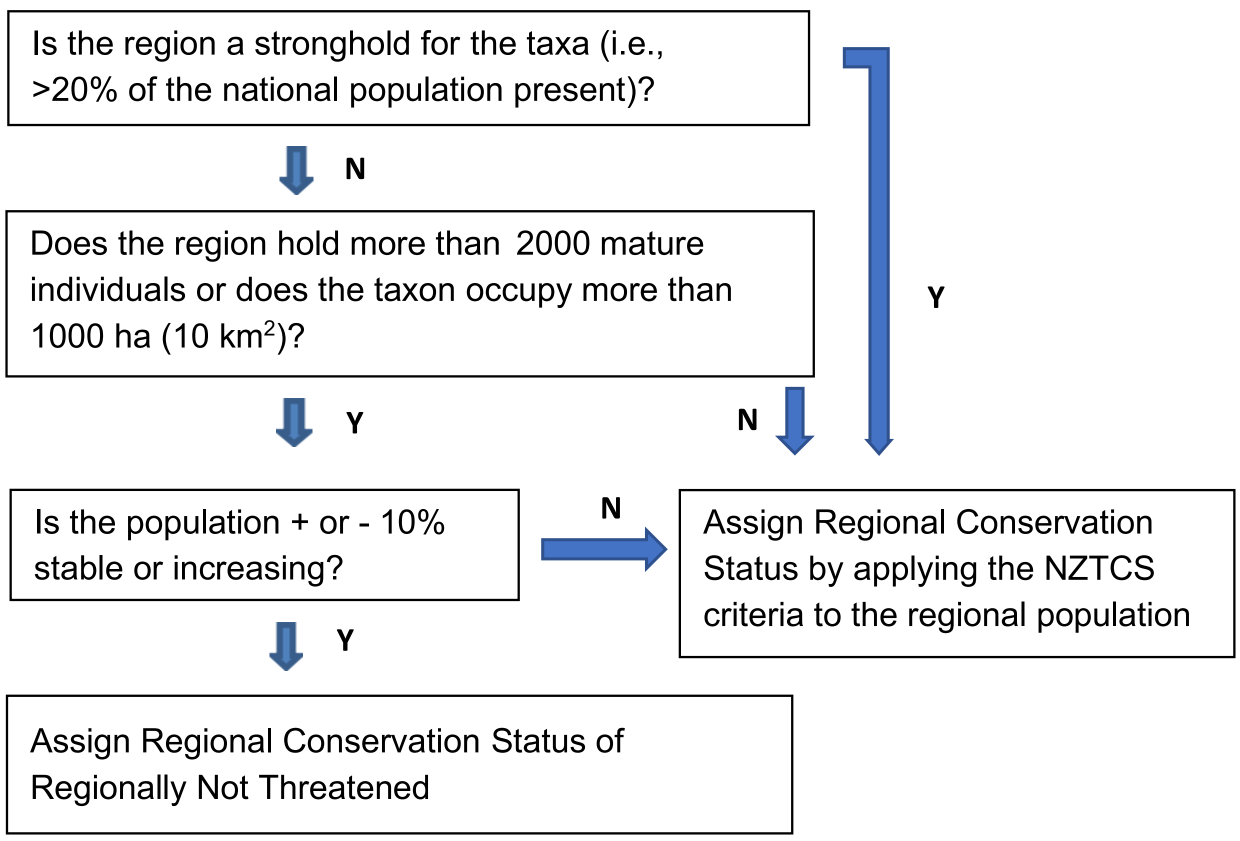
Woolly, J.B., Paris, B., Borkin, K., Davidson-Watts, I., Clarke, D., Davies, F., Burton, C., Melzer, S. (2023). Conservation status of bat species in Tāmaki Makaurau / Auckland. Auckland Council Technical Report, TR2023/4. 18 p.

Appendix 1: Process for determining the regional threat status of taxa

Process 1: Determination of regional threat status



Process 2: Determination of strongholds and Regionally Not Threatened species



Appendix 2: List of Regional Qualifiers for the Regional Threat Classification System

Code	Qualifier	Description
FR	Former Resident	Breeding population (existed for more than 50 years) extirpated from region but continues to arrive as a regional vagrant or migrant. FR and RN are mutually exclusive.
HR	Historical Range	The inferred range (extending in any direction) of the taxon in pre-human times meets its natural limit in the region.
IN	Introduced Native	Introduced to the region, though not known to have previously occurred in it.
NStr	National Stronghold	More than 20% of the national population breeding or resident for more than half their life cycle in the region.
NR	Natural Range	The known range (extending in any direction) of the taxon meets it natural limit in the region.
RE	Regional Endemic	Known to breed only in the region.
RN	Restored Native	Reintroduced to the region after having previously gone extinct there.
TL	Type Locality	The type locality of the taxon is within the region. Ignore if the taxon is or has ever been regionally extinct

Appendix 3: List of National Qualifiers from the New Zealand Threat Classification System (Rolfe et al. 2022)

Code	Qualifier	Qualifier Type	Description
DPR	Data Poor: Recognition	Assessment Process Qualifier	Confidence in the assessment is low because of difficulties determining the identity of taxon in the field and/or in the laboratory. Taxa that are DPR will often be DPS and DPT. In such cases, the taxon is most likely to be Data Deficient.
DPS	Data Poor: Size	Assessment Process Qualifier	Confidence in the assessment is low because of a lack of data on population size.
DPT	Data Poor: Trend	Assessment Process Qualifier	Confidence in the assessment is low because of a lack of data on population trend.
De	Designated	Assessment Process Qualifier	A taxon that the Expert Panel has assigned to what they consider to be the most appropriate status without full application of the criteria. For example, a commercial fish that is being fished down to Biomass Maximum Sustainable yield (BMSy) may meet criteria for 'Declining', however, it could be designated as 'Not Threatened' if the Expert Panel believes that this better describes the taxon's risk of extinction.
IE	Island Endemic	Biological Attribute Qualifier	A taxon whose naturally distribution is restricted to one island archipelago (e.g., Auckland Islands) and is not part of the North or South Islands or Steward Island/Rakiura. This qualifier is equivalent to the 'Natural' Population State value in the database.
NS	Natural State	Biological Attribute Qualifier	A taxon that has a stable or increasing population that is presumed to be in a natural condition, i.e., has not experienced historical human-induced decline.
RR	Range Restricted	Biological Attribute Qualifier	A taxon naturally confined to specific substrates, habitats or geographic areas of less than 100 km^2 (100,000 ha), this is assessed by taking into account the area of occupied habitat of all sub-populations (and summing the areas of habitat if there is more than one sub-population), e.g., Chatham Island forget-me-not (*Myosotidium hortensia*) and Auckland Island snipe (*Coenocorypha aucklandica aucklandica*). This qualifier can apply to any 'Threatened' or 'At Risk' taxon. It is redundant if a taxon is confined to 'One Location' (OL)
Sp	Biologically Sparse	Biological Attribute Qualifier	The taxon naturally occurs within typically small and widely scattered subpopulations. This qualifier can apply to any 'Threatened' or 'At Risk' taxon.

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List of National Qualifiers from the New Zealand Threat Classification System

Code	Qualifier	Qualifier Type	Description
NO	Naturalized Overseas	Population State Qualifier	A New Zealand endemic taxon that has been introduced by human agency to another country (deliberately or accidentally) and has naturalised there, e.g., *Olearia traversiourum* in the Republic of Ireland.
OL	One Location	Population State Qualifier	Found at one location in New Zealand (geographically or ecologically distinct area) of less than 100,000 ha (1000 km2), in which a single event (e.g., a predator irruption) could easily affect all individuals of the taxon, e.g., L'Esperance Rock groundsel (*Senecio esperensis*) and Open Bay leech (*Hirudobdella antipodum*). 'OL' can apply to all 'Threatened', 'At Risk', 'Non-resident Native' – Coloniser and Non-resident Native – Migrant taxa, regardless of whether their restricted distribution in New Zealand is natural or human-induced. Resident native taxa with restricted distributions but where it is unlikely that all sub-populations would be threatened by a single event (e.g., because water channels within an archipelago are larger than known terrestrial predator swimming distances) should be qualified as 'Range Restricted' (RR).
SO	Secure Overseas	Population State Qualifier	The taxon is secure in the parts of its natural range outside New Zealand
SO?	Secure Overseas?	Population State Qualifier	It is uncertain whether a taxon of the same that is secure in the parts of its natural range outside New Zealand is conspecific with the New Zealand taxon.
S?O	Secure? Overseas	Population State Qualifier	It is uncertain whether the taxon is secure in the parts of its natural range outside New Zealand.
TO	Threatened Overseas	Population State Qualifier	The taxon is threatened in the parts of its natural range outside New Zealand.
T?O	Threatened Overseas?	Population State Qualifier	It is uncertain whether a taxon of the same name that is threatened in the parts of its natural range outside New Zealand is conspecific with the New Zealand taxon.
T?O	Threatened? Overseas	Population State Qualifier	It is uncertain whether the taxon is threatened in the parts of its natural range outside New Zealand.

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List of National Qualifiers from the New Zealand Threat Classification System

Code	Qualifier	Qualifier Type	Description
CI	Climate Impact	Pressure Management Qualifier	The taxon is adversely affected by long-term climate trends and/or extreme climatic events. The following questions provide a guide to using the CI Qualifier: Is the taxon adversely affected by long-term changes in the climate, such as an increase in average temperature or sea-level rise? If NO = no Qualifier but needs monitoring and periodic re-evaluation because projected changes to the average climate and sea-level rise may adversely impact the taxon (including via changes to the distribution and prevalence of pests, weeds and predators) in the future. If YES = CI Qualifier Is the taxon adversely affected by extreme climate events, such as a drought, storm or heatwave? If No = no Qualifier but needs monitoring and periodic re-evaluation because projected changes to the climate are likely to increase the frequency and/or severity of these events in the future. If YES = CI Qualifier Use of the Climate Impact Qualifier would indicate the need for more in-depth research, ongoing monitoring of climate impacts, and potentially a climate change adaptation plan for the taxon
CD	Conservation Dependent	Pressure Management Qualifier	The taxon is likely to move to a worse conservation status if current management ceases. The term ‘management’ can include indirect actions that benefit taxa, such as island biosecurity. Management can make a taxon CD only if cessation of the management would result in a worse conservation status. The influence of the benefits of management on the total population must be considered before using CD. The benefit of managing a single subpopulation may not be adequate to trigger CD, but may trigger Partial Decline (PD). Taxa qualified CD may also be PD because of the benefits of management.
CR	Conservation Research Needed	Pressure Management Qualifier	Causes of decline and/or solutions for recovery are poorly understood and research is required.

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List of National Qualifiers from the New Zealand Threat Classification System

Code	Qualifier	Qualifier Type	Description
EW	Extinct In The Wild	Pressure Management Qualifier	The taxon is known only in captivity or cultivation or has been reintroduced to the wild but is not self-sustaining. Assessment of a reintroduced population should be considered only when it is self-sustaining. A population is deemed to be self-sustaining when the following two criteria have been fulfilled: it is expanding or has reached a stable state through natural replenishment and at least half the breeding adults are products of the natural replenishment, and it has been at least 10 years since reintroduction
EF	Extreme Fluctuations	Pressure Management Qualifier	The taxon experiences extreme unnatural population fluctuations, or natural fluctuations overlaying human-induced declines, that increase the threat of extinction. When ranking taxa with extreme fluctuations, the lowest estimate of mature individuals should be used for determining population size, as a precautionary measure.
INC	Increasing	Pressure Management Qualifier	There is an ongoing or forecast increase of > 10% in the total population, taken over the next 10 years or three generations, whichever is longer. This qualifier is redundant for taxa ranked as 'Recovering'.
PD	Partial Decline	Pressure Management Qualifier	The taxon is declining over most of its range, but with one or more secure populations (such as on offshore islands). Partial decline taxa (e.g., North Island kākā *Nestor meridionalis septentrionalis* and Pacific gecko *Dactylocnemis pacificus*) are declining towards a small stable population, for which the Relict qualifier may be appropriate.
PF	Population Fragmentation	Pressure Management Qualifier	Gene flow between subpopulations is hampered as a direct or indirect result of human activity. Naturally disjunct populations are not considered to be 'fragmented'.
PE	Possibly/Presumed Extinct	Pressure Management Qualifier	A taxon that has not been observed for more than 50 years but for which there is little or no evidence to support declaring it extinct. This qualifier might apply to several Data Deficient and Nationally Critical taxa.

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List of National Qualifiers from the New Zealand Threat Classification System

Code	Qualifier	Qualifier Type	Description
RF	Recruitment Failure	Pressure Management Qualifier	The age structure of the current population is such that a catastrophic decline is likely in the future. Failure to produce new progeny or failure of progeny to reach maturity can be masked by apparently healthy populations of mature specimens.
Rel	Relict	Pressure Management Qualifier	The taxon has declined since human arrival to less than 10% of its former range but its population has stabilised. The range of a relictual taxon takes into account the area currently occupied as a ratio of its former extent. Reintroduced and self-sustaining populations within or outside the former known range of a taxon should be considered when determining whether a taxon is relictual. This definition is modified from the definition of the At Risk – Relict category in the NZTCS manual (Townsend et al. 2008). The main difference is that trend is not included in the qualifier definition. This enables the qualifier to be applied to any taxon that has experienced severe range contraction, regardless of whether that contraction continues or has been arrested. This qualifier complements the 'Naturally Uncommon (NU)' qualifier which can be applied to taxa whose abundance has declined but which continue to occupy a substantial part of their natural range.

Appendix 4: Regional assessments of selected fungal taxa

Table A4-1. Species in the Agaricales assessed for this report.

Regional and national qualifiers used in the assessment are abbreviated as follows: CD = Conservation Dependent; CI = Climate Impact; CRN = Conservation Research Needed; DPR = Data Poor Recognition; DPS = Data Poor Size; DPT = Data Poor Trend; De = Designated; FR = Former Range; INC = Increasing; NR = Natural Range Limit; NStr = National Stronghold; OL = One Location; PD = Partial Decline; PF = Population Fragmentation; RE = Regional Endemic; RN = Restored Native; RR = Range Restricted; Sp = Biologically Sparse; TL = Type Locality; TO = Threatened Overseas. Further details about each of these qualifiers can be found at Appendix 2, 3 and https://nztcs.org.nz. National Criteria is Regionally Critical A(1) with further information found in Rolfe et al. 2022 and https://nztcs.org.nz.

The source of "occurrences' data are from the Global Biodiversity Information Facility (GBIF) and the University of Otago (OTA) mycological collection. Qualifiers can be found in Appendix 2 and 3. For the full dataset for this regional assessment of non-lichenised boletes and russuloid fungi in the Otago region see Appendix 4-2 and 4-3.

Biostatus is from the Biota of New Zealand (BiotaNZ) where endemic refers to Aotearoa New Zealand.

Taxa listed in bold text are Regionally Threatened in Otago.

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Agaricus crocodilinus	Uncertain	Not Threatened, safe overseas			7	2	29%	Uncertain Biostatus	
Agaricus horakianus	Indigenous	Not Threatened	Not Threatened	Not Threatened	3	1	33%		DPR
Agaricus horakii	Indigenous	Data Deficient	Data Deficient	Data Deficient	10	2	20%		
Agaricus lanatoniger	Indigenous	Data Deficient	Data Deficient	Data Deficient	9	2	22%		DPR
Agaricus purpureoniger	Endemic	Data Deficient	Data Deficient	Data Deficient	6	2	33%		DPR, OL
Amanita karea	Endemic	Data Deficient	Data Deficient	Data Deficient	48	1	2%		
Amanita nehuta	Endemic	Not Threatened	Not Threatened	Not Threatened	240	31	13%		
Amanita nothofagi	Indigenous	Not Threatened	Not Threatened	Not Threatened	468	24	5%		
Amanita pareparina	Endemic	Not Threatened	Not Threatened	Not Threatened	93	4	4%		
Amanita pekeoides	Endemic	Not Threatened	Not Threatened	Not Threatened	473	70	15%		
Anthracophyllum archeri	Indigenous	Not Threatened	Not Threatened	Not Threatened	74	2	3%		
Armillaria limonea	Indigenous	Not Threatened	Not Threatened	Not Threatened	275	2	1%		
Armillaria novae-zelandiae	Indigenous	Not Threatened	Not Threatened	Not Threatened	1104	224	20%		
Arrhenia rosea	Endemic	Data Deficient	Data Deficient	Data Deficient	4	1	25%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Aureonarius armiae	Endemic	Not Threatened	Not Threatened	Not Threatened	16	8	50%	Otago-specific collecting	
Aureonarius collybianus	Endemic	Not Threatened	Not Threatened	Not Threatened	18	1	6%		
Aureonarius rubrocastaneus	Endemic	Data Deficient	Data Deficient	Data Deficient	5	1	20%		
Aureonarius rubrodactylus	Endemic	Data Deficient	Data Deficient	Data Deficient	23	4	17%		
Austrocortinarius australiensis	Indigenous	Not Threatened	Not Threatened	Not Threatened	68	1	1%		
Bolbitius muscicola	Endemic	Not Threatened	Not Threatened	Not Threatened	120	35	29%		
Britzelmayria multipedata	Uncertain	Not Threatened, safe overseas			3	1	33%	Recently recognised in Aotearoa. Uncertain Biostatus	
Campanella bonii	Endemic	Not Threatened	Not Threatened	Not Threatened	12	1	8%		
Campanella tristis	Indigenous	Not Threatened	Not Threatened	Not Threatened	198	2	1%		
Cantharellula fistulosa	Endemic	Data Deficient	Data Deficient	Data Deficient	7	1	14%		
Clavogaster virescens	Endemic	Not Threatened	Not Threatened	Not Threatened	621	19	3%		
Clitocybe brunneocaperata	Endemic	Data Deficient	Data Deficient	Data Deficient	5	2	40%		
Clitocybula grisella	Indigenous	Data Deficient	Data Deficient	Data Deficient	12	2	17%		DPR
Collybiopsis rimutaka	Endemic	Data Deficient	Data Deficient	Data Deficient	41	2	5%		DPR
Collybiopsis subpruinosa	Uncertain	Not Threatened, safe overseas			123	5	4%	Newly recognised in Aotearoa	
Conchomyces bursiformis	Indigenous	Not Threatened	Not Threatened	Not Threatened	303	69	23%		
Coprinopsis picacea	Indigenous	Data Deficient			3	1	33%	Uncertain Biostatus	
Cortinarius achrous	Endemic	Not Threatened	Not Threatened	Not Threatened	35	7	20%		
Cortinarius aerugineoconicus	Endemic	Data Deficient	Data Deficient	Data Deficient	22	3	14%		
Cortinarius alboroseus	Indigenous	Not Threatened	Not Threatened	Not Threatened	63	4	6%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Cortinarius alienatus	Endemic	Not Threatened	Not Threatened	Not Threatened	49	9	18%		
Cortinarius amblyonis	Endemic	Data Deficient	Data Deficient	Data Deficient	3	2	67%	Otago-specific collecting	
Cortinarius atropileatus	Endemic	Data Deficient			2	1	50%	Recently described	
Cortinarius aurantioferreus	Endemic	Not Threatened	Not Threatened	Not Threatened	5	1	20%		
Cortinarius austrovenetus	Uncertain	Data Deficient			8	5	63%	Newly recognised in Aotearoa	
Cortinarius beeverorum	Endemic	Data Deficient			45	14	31%	Not in 2022 assessment	
Cortinarius bellus	Indigenous	Not Threatened	Not Threatened	Not Threatened	19	2	11%		
Cortinarius calaisopus	Endemic	Data Deficient	Data Deficient	Data Deficient	37	7	19%		
Cortinarius canarius	Indigenous	Not Threatened	Not Threatened	Not Threatened	104	9	9%		
Cortinarius cardinalis	Endemic	Not Threatened	Not Threatened	Not Threatened	66	4	6%		OL
Cortinarius carneipallidus	Endemic	Data Deficient	Data Deficient	Data Deficient	59	2	3%		
Cortinarius cartilagineus	Indigenous	Not Threatened	Not Threatened	Not Threatened	42	7	17%		DPR
Cortinarius castaneodiscus	Endemic		Data Deficient	Data Deficient	39	1	3%		
Cortinarius cesarioanus	Endemic	Data Deficient			10	1	10%	Newly described	
Cortinarius chrysma	Endemic	Data Deficient	Data Deficient	Data Deficient	11	1	9%		DPR
Cortinarius cucumeris	Endemic	Not Threatened	Not Threatened	Not Threatened	15	3	20%		
Cortinarius cypripedii	Endemic	Data Deficient	Data Deficient	Data Deficient	2	2	100%	Otago-specific collecting	
Cortinarius dulciolens	Endemic	Data Deficient	Data Deficient	Data Deficient	20	12	60%		
Cortinarius durifoliorum	Endemic	Data Deficient	Data Deficient	Data Deficient	12	2	17%		
Cortinarius elacatipus	Indigenous	Data Deficient	Data Deficient	Data Deficient	13	3	23%		
Cortinarius elaiochrous	Endemic	Data Deficient	Data Deficient	Data Deficient	40	2	5%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Cortinarius epiphaeus	Endemic	Not Threatened	Not Threatened	Not Threatened	94	5	5%		
Cortinarius indolicus	Endemic	Not Threatened	Not Threatened	Not Threatened	16	2	13%		
Cortinarius indotatus	Endemic	Data Deficient	Data Deficient	Data Deficient	13	3	23%		
Cortinarius ionomataius	Endemic	Not Threatened	Not Threatened	Not Threatened	26	1	4%		
Cortinarius lubricanescens	Endemic	Not Threatened	Not Threatened	Not Threatened	30	1	3%		
Cortinarius luteinus	Endemic	Data Deficient	Data Deficient	Data Deficient	14	4	29%		
Cortinarius majestaticus	Endemic	Not Threatened	Not Threatened	Not Threatened	26	6	23%		
Cortinarius malosinae	Endemic	Not Threatened	Not Threatened	Not Threatened	6	2	33%		
Cortinarius meleagris	Indigenous	Not Threatened	Not Threatened	Not Threatened	44	2	5%		
Cortinarius melimyxa	Endemic	Not Threatened	Not Threatened	Not Threatened	19	2	11%		
Cortinarius minorisporus	Endemic	Data Deficient			10	3	30%	Newly described	
Cortinarius minoscaurus	**Endemic**	**Regionally Vulnerable**	**Threatened**	**Nationally Vulnerable**	**8**	**3**	**38%**	**Tea-tree ECM associate**	**De**
Cortinarius mycenarum	Endemic	Data Deficient	Data Deficient	Data Deficient	8	2	25%		
Cortinarius mysoides	Endemic	Data Deficient	Data Deficient	Data Deficient	7	7	100%	Otago-specific collecting	
Cortinarius naphthalinus	Endemic	Data Deficient	Data Deficient	Data Deficient	9	2	22%		
Cortinarius ophryx	Endemic	Data Deficient	Data Deficient	Data Deficient	14	1	7%		
Cortinarius orixanthus	Endemic	Not Threatened	Not Threatened	Not Threatened	16	2	13%		
Cortinarius palissandrinus	Endemic	Data Deficient	Data Deficient	Data Deficient	25	1	4%		
Cortinarius papaver	Indigenous	Data Deficient	Data Deficient	Data Deficient	12	2	17%		DPR
Cortinarius paraoniti	Endemic	Data Deficient	Data Deficient	Data Deficient	5	1	20%		
Cortinarius paraxanthus	Endemic	Data Deficient	Data Deficient	Data Deficient	26	6	23%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Cortinarius pectochelis	Endemic	Data Deficient	Data Deficient	Data Deficient	6	4	67%		
Cortinarius peraurantiacus	Endemic	Data Deficient			50	2	4%	Not in 2022 assessment	
Cortinarius peraureus	Endemic	Not Threatened	Not Threatened	Not Threatened	39	4	10%		
Cortinarius peraurilis	Endemic	Data Deficient	Data Deficient	Data Deficient	4	2	50%	Otago-specific collecting	
Cortinarius persplendidus	Indigenous	Not Threatened	Not Threatened	Not Threatened	39	3	8%		
Cortinarius phaeomyxa	Endemic	Not Threatened	Not Threatened	Not Threatened	51	4	8%		
Cortinarius purpureocapitatus	Endemic	Data Deficient	Data Deficient	Data Deficient	23	1	4%		DPR
Cortinarius rattinoides	Endemic	Data Deficient	Data Deficient	Data Deficient	8	3	38%		
Cortinarius rotundisporus	Indigenous	Not Threatened	Not Threatened	Not Threatened	164	51	31%		
Cortinarius rugosiceps	Endemic	Data Deficient	Data Deficient	Data Deficient	1	1	100%	Poorly known	
Cortinarius saturniorum	Endemic	Not Threatened	Not Threatened	Not Threatened	24	3	13%		DPR
Cortinarius sciurellus	Endemic	Data Deficient	Data Deficient	Data Deficient	6	3	50%	Otago-specific collecting	
Cortinarius sclerophyllorum	Indigenous	Data Deficient			3	2	67%	Not in 2022 assessment	
Cortinarius subcastanellus	Endemic	Not Threatened	Not Threatened	Not Threatened	57	6	11%		
Cortinarius suecicolor	Endemic	Data Deficient	Data Deficient	Data Deficient	14	1	7%		DPR
Cortinarius taylorianus	Endemic	Not Threatened	Not Threatened	Not Threatened	57	13	23%		
Cortinarius tessiae	Endemic	Not Threatened	Not Threatened	Not Threatened	95	11	12%		
Cortinarius tigrellus	Endemic	Data Deficient	Data Deficient	Data Deficient	3	1	33%		
Cortinarius ursus	Endemic	Data Deficient	Data Deficient	Data Deficient	42	3	7%		
Cortinarius veronicae	Indigenous	Not Threatened	Not Threatened	Not Threatened	33	10	30%		
Cortinarius vinicolor	Endemic	Data Deficient	Data Deficient	Data Deficient	39	2	5%		DPR
Cortinarius violaceovolvatus	Endemic	Data Deficient	Data Deficient	Data Deficient	52	15	29%		DPR

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Cortinarius viridipileatus	Endemic	Data Deficient			12	5	42%	Newly described	
Cortinarius waiporianus	Endemic	Data Deficient	Data Deficient	Data Deficient	36	1	3%		
Cortinarius xenosma	Endemic	Not Threatened	Not Threatened	Not Threatened	17	1	6%		
Crepidotus fuscovelutinus	Endemic	Data Deficient	Data Deficient	Data Deficient	58	15	26%		
Crepidotus gilvidus	Indigenous	Data Deficient	Data Deficient	Data Deficient	16	2	13%		
Crepidotus isabellinus	Endemic	Data Deficient	Data Deficient	Data Deficient	3	2	67%	Poorly known	
Crepidotus lateralipes	Endemic	Data Deficient	Data Deficient	Data Deficient	14	2	14%		
Crepidotus nanicus	Endemic	Data Deficient	Data Deficient	Data Deficient	13	4	31%		DPR
Crepidotus novae-zealandiae	Endemic	Data Deficient	Data Deficient	Data Deficient	12	4	33%		
Crepidotus praecipuus	Indigenous	Data Deficient	Data Deficient	Data Deficient	90	15	17%		
Crinipellis procera	Endemic	Not Threatened	Not Threatened	Not Threatened	179	1	1%		
Cuphophyllus carcharias	Endemic	Data Deficient	Data Deficient	Data Deficient	4	1	25%		
Cyclocybe erebia	Uncertain	Not Threatened, safe overseas			11	1	9%	Uncertain Biostatus in Aotearoa	
Cyclocybe parasitica	Uncertain	Not Threatened	Not Threatened	Not Threatened	1373	91	7%		
Cystinarius eutactus	Endemic	Data Deficient	Data Deficient	Data Deficient	19	2	11%		
Cystinarius subgemmeus	Endemic	Not Threatened	Not Threatened	Not Threatened	16	1	6%		
Cystoderma clastotrichum	Indigenous	Not Threatened	Not Threatened	Not Threatened	47	6	13%		
Cystoderma muscicola	Uncertain	Not Threatened, safe overseas			10	1	10%	Newly recognised in Aotearoa	
Deconica baylisiana	**Endemic**	**Regionally Critical**	**Threatened**	**Nationally Critical**	**10**	**10**	**100%**	**Also found on Rakiura/ Stewart Island**	**Sp, CI, CR, DPS, DPT, RR, NStr, TL**
Deconica citrispora	Indigenous	Data Deficient	Data Deficient	Data Deficient	7	3	43%	Poorly known	

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Descolea phlebophora	Indigenous	Not Threatened	Not Threatened	Not Threatened	42	6	14%		
Entoloma aromaticum	Indigenous	Not Threatened	Not Threatened	Not Threatened	41	3	7%		
Entoloma canoconicum	Endemic	Not Threatened	Not Threatened	Not Threatened	297	4	1%		
Entoloma chloroxanthum	Endemic	Not Threatened	Not Threatened	Not Threatened	27	1	4%		
Entoloma conferendum	Uncertain	Not Threatened	Not Threatened	Not Threatened	21	2	10%		
Entoloma crinitum	Indigenous	Data Deficient	Data Deficient	Data Deficient	19	1	5%		
Entoloma distinctum	Endemic	Data Deficient	Data Deficient	Data Deficient	9	3	33%		DPR
Entoloma glaucoroseum	Endemic	Data Deficient	Data Deficient	Data Deficient	14	1	7%		
Entoloma haastii	Indigenous	Not Threatened	Not Threatened	Not Threatened	69	2	3%		
Entoloma hochstetteri	Indigenous	Not Threatened	Not Threatened	Not Threatened	1310	13	1%		
Entoloma perzonatum	Endemic	Not Threatened			142	19	13%	Newly recognised in Aotearoa	
Entoloma readiae	Uncertain	Data Deficient	Data Deficient	Data Deficient	47	3	6%		
Entoloma translucidum	Indigenous	Not Threatened	Not Threatened	Not Threatened	64	5	8%		
Entoloma uliginicola	Endemic	Not Threatened	Not Threatened	Not Threatened	10	1	10%		
Entoloma viridomarginatum	Indigenous	Not Threatened	Taxonomically indistinct	Taxonomically indistinct	23	2	9%		
Favolaschia pustulosa	Indigenous	Not Threatened	Not Threatened	Not Threatened	232	7	3%		
Flammulaster ciliatus	Indigenous	Data Deficient	Data Deficient	Data Deficient	13	1	8%		
Galerina patagonica	Indigenous	Not Threatened	Not Threatened	Not Threatened	369	56	15%		
Gerronema waikanaense	Endemic	Data Deficient	Data Deficient	Data Deficient	53	3	6%		
Gliophorus graminicolor	Indigenous	Not Threatened	Not Threatened	Not Threatened	117	3	3%		
Gliophorus ostrinus	Endemic	Data Deficient	Data Deficient	Data Deficient	6	1	17%		DPR
Gliophorus pallidus	Indigenous	Not Threatened	Not Threatened	Not Threatened	24	1	4%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Gliophorus viridis	Indigenous	Not Threatened	Not Threatened	Not Threatened	129	2	2%		
Gloiocephala phormiorum	Endemic	Data Deficient	Data Deficient	Data Deficient	14	3	21%		
Gloioxanthomyces chromolimoneus	Endemic	Not Threatened	Not Threatened	Not Threatened	63	1	2%		
Gymnopilus ferruginosus	Indigenous	Data Deficient			36	2	6%	Uncertain Biostatus	
Gymnopus ceraceicola	Endemic	Data Deficient	Data Deficient	Data Deficient	111	11	10%		
Gymnopus cockaynei	Endemic	Data Deficient	Data Deficient	Data Deficient	20	1	5%		DPR
Gymnopus imbricatus	Endemic	Data Deficient	Data Deficient	Data Deficient	51	7	14%		
Gymnopus otagensis	Endemic	Data Deficient	Data Deficient	Data Deficient	16	1	6%		
Gymnopus subsupinus	Indigenous	Data Deficient	Data Deficient	Data Deficient	7	1	14%		DPR
Hebeloma mediorufum	Endemic	Not Threatened	Not Threatened	Not Threatened	32	3	9%		
Hebeloma victoriense	Indigenous	Not Threatened	Not Threatened	Not Threatened	135	1	1%		
Hohenbuehelia luteola	Endemic	Data Deficient	Data Deficient	Data Deficient	32	2	6%		DPR
Humidicutis luteovirens	Endemic	Not Threatened	Not Threatened	Not Threatened	47	4	9%		
Humidicutis mavis	Indigenous	Not Threatened	Not Threatened	Not Threatened	256	19	7%		
Hygrocybe astatogala	Indigenous	Not Threatened	Not Threatened	Not Threatened	242	8	3%		
Hygrocybe blanda	Endemic	Data Deficient	Data Deficient	Data Deficient	25	2	8%		DPR
Hygrocybe cavipes	Endemic	Data Deficient	Data Deficient	Data Deficient	13	1	8%		DPR
Hygrocybe fuscoaurantiaca	Endemic	Data Deficient	Data Deficient	Data Deficient	19	2	11%		DPR
Hygrocybe julietae	Indigenous	Not Threatened	Not Threatened	Not Threatened	41	1	2%		
Hygrocybe keithgeorgei	Endemic	Data Deficient	Data Deficient	Data Deficient	24	1	4%		DPR
Hygrocybe lilaceolamellata	Indigenous	Not Threatened	Not Threatened	Not Threatened	49	3	6%		
Hygrocybe procera	Endemic	Not Threatened	Not Threatened	Not Threatened	42	1	2%		
Hygrocybe striatolutea	Endemic	Not Threatened	Not Threatened	Not Threatened	14	1	7%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Hygronarius viscincisus	Endemic	Data Deficient	Data Deficient	Data Deficient	10	5	50%	Otago-specific collecting	
Hygrophorus involutus	Indigenous	Not Threatened	Not Threatened	Not Threatened	59	1	2%		
Hypholoma acutum	Endemic	Not Threatened	Not Threatened	Not Threatened	398	81	20%		
Hypholoma australianum	Indigenous	Not Threatened	Not Threatened	Not Threatened	134	26	19%		SO
Hypholoma brunneum	Indigenous	Not Threatened	Not Threatened	Not Threatened	512	118	23%		
Inocybe albovestita	Endemic	Not Threatened	Not Threatened	Not Threatened	57	1	2%		
Inocybe gilibertoi	**Endemic**	**Regionally Vulnerable**	**Threatened**	**Nationally Vulnerable**	**7**	**1**	**14%**	**Tea-tree ECM associate**	
Inocybe horakomyces	Indigenous	Not Threatened	Not Threatened	Not Threatened	13	1	8%		SO
Inocybe microsperma	Endemic	Data Deficient	Data Deficient	Data Deficient	1	1	100%	Poorly known	
Inocybe scabriuscula	Endemic	Data Deficient	Data Deficient	Data Deficient	11	1	9%		
Inocybe sylvicola	Indigenous	Not Threatened	Not Threatened	Not Threatened	31	4	13%		SO
Inocybe tenax	Indigenous	Data Deficient	Data Deficient	Data Deficient	13	1	8%		
Inocybe vagata	Indigenous	Data Deficient	Data Deficient	Data Deficient	6	1	17%		
Inocybe viscata	Indigenous	Data Deficient	Data Deficient	Data Deficient	5	1	20%		DPR
Inosperma calamistratoides	Indigenous	Not Threatened	Not Threatened	Not Threatened	40	1	3%		
Kuehneromyces brunneoalbescens	Indigenous	Not Threatened	Not Threatened	Not Threatened	23	2	9%		SO
Laccaria fibrillosa	Endemic	Not Threatened	Not Threatened	Not Threatened	78	6	8%		
Laccaria glabripes	Endemic	Not Threatened	Not Threatened	Not Threatened	116	7	6%		
Laccaria lilacina	Endemic	Data Deficient	Data Deficient	Data Deficient	42	4	10%		
Laccaria masoniae	Endemic	Not Threatened	Not Threatened	Not Threatened	162	11	7%		
Laccaria violaceonigra	Endemic	Not Threatened	Not Threatened	Not Threatened	76	10	13%		
Lacrymaria asperospora	Uncertain	Not Threatened	Not Threatened	Not Threatened	116	17	15%		SO
Lentinula novae-zelandiae	Endemic	Not Threatened	Not Threatened	Not Threatened	137	4	3%		
Lepiota haemorrhagica	Indigenous	Not Threatened	Not Threatened	Not Threatened	6	1	17%		SO

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Lepista antipoda	Endemic	Data Deficient	Data Deficient	Data Deficient	16	1	6%		
Leratiomyces erythrocephalus	Endemic	Not Threatened	Not Threatened	Not Threatened	1463	370	25%		
Leucocoprinus cepistipes	Uncertain	Not Threatened, safe overseas			100	2	2%	Uncertain Biostatus in Aotearoa	
Leucopaxillus eucalyptorum	Indigenous	Not Threatened	Not Threatened	Not Threatened	16	1	6%		SO
Macrolepiota clelandii	Indigenous	Not Threatened	Not Threatened	Not Threatened	456	1	0%		
Marasmiellus candidus	Uncertain	Not Threatened			73	9	12%	Uncertain Biostatus in Aotearoa	
Marasmius croceus	Indigenous	Data Deficient	Data Deficient	Data Deficient	28	1	4%		
Marasmius elegans	Indigenous	Not Threatened	Not Threatened	Not Threatened	51	13	25%		
Mycena acicula	Uncertain	Not Threatened, safe overseas			15	1	7%	Uncertain Biostatus	
Mycena austrofilopes	Indigenous	Not Threatened	Not Threatened	Not Threatened	15	1	7%		SO
Mycena clarkeana	Indigenous	Not Threatened, safe overseas	Not Threatened	Not Threatened	84	40	48%		SO
Mycena filopes	Uncertain	Not Threatened	Introduced and Naturalised	Introduced and Naturalised	17	4	24%		SO
Mycena flavovirens	**Indigenous**	**Regionally Vulnerable**	**Threatened**	**Nationally Vulnerable**	**42**	**1**	**2%**		**DPS, DPT**
Mycena fuscovinacea	Indigenous	Not Threatened	Not Threatened	Not Threatened	25	1	4%		SO
Mycena galericulata	Uncertain	Not Threatened, safe overseas			12	2	17%	Uncertain Biostatus in Aotearoa	
Mycena interrupta	Indigenous	Not Threatened	Not Threatened	Not Threatened	484	74	15%		
Mycena mamaku	Indigenous	Data Deficient	Data Deficient	Data Deficient	12	1	8%		
Mycena mariae	Endemic		Not Threatened	Not Threatened	165	23	14%		
Mycena metata	Uncertain	Not Threatened			19	1	5%	Uncertain Biostatus in Aotearoa, safe overseas	
Mycena parsonsii	Endemic	Not Threatened	Not Threatened	Not Threatened	172	2	1%		
Mycena roseoflava	Indigenous	Not Threatened	Not Threatened	Not Threatened	156	22	14%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Mycena subdebilis	Endemic	Data Deficient	Data Deficient	Data Deficient	17	1	6%		DPR
Mycena subviscosa	Endemic	Not Threatened	Not Threatened	Not Threatened	193	10	5%		
Mycena ura	Indigenous	Not Threatened	Not Threatened	Not Threatened	230	13	6%		
Mycetinis curraniae	Endemic	Not Threatened	Not Threatened	Not Threatened	140	5	4%		
Nivatogastrium lignicola	Endemic	Data Deficient	Data Deficient	Data Deficient	1	1	100%	Poorly known	DPR
Omphalina wellingtonensis	Endemic	Not Threatened	Not Threatened	Not Threatened	39	1	3%		
Oudemansiella australis	Endemic	Not Threatened	Not Threatened	Not Threatened	340	1	0%		
Oudemansiella colensoi	Endemic	Not Threatened	Not Threatened	Not Threatened	23	1	4%		
Phaeocollybia ratticauda	Indigenous	Data Deficient	Data Deficient	Data Deficient	13	1	8%		
Phlegmacium artosum	Endemic	Data Deficient	Data Deficient	Data Deficient	2	1	50%	Poorly known	
Phlegmacium carbonellum	Endemic	Not Threatened	Not Threatened	Not Threatened	7	2	29%		
Phlegmacium cupreonatum	Endemic	Not Threatened	Not Threatened	Not Threatened	24	2	8%		
Phlegmacium exlugubre	Endemic	Data Deficient	Data Deficient	Data Deficient	5	2	40%	Otago-specific collecting	
Phlegmacium rattinum	Endemic	Data Deficient	Data Deficient	Data Deficient	10	3	30%		
Phlegmacium vernicifer	**Endemic**	**Regionally Vulnerable**	**Threatened**	**Nationally Vulnerable**	**4**	**1**	**25%**	**Tea-tree ECM associate**	**De**
Phloeomana minutula	Uncertain	Not Threatened, safe overseas			15	1	7%	Uncertain Biostatus	
Pholiota chrysmoides	Endemic	Data Deficient	Data Deficient	Data Deficient	10	3	30%		DPR
Pholiota glutinosa	Endemic	Not Threatened	Not Threatened	Not Threatened	228	38	17%		
Pholiota multicingulata	Indigenous	Not Threatened	Not Threatened	Not Threatened	102	6	6%		
Pholiota subflammans	Indigenous	Not Threatened	Not Threatened	Not Threatened	214	43	20%		
Pholiotina gracilenta	Endemic	Not Threatened	Not Threatened	Not Threatened	42	3	7%		
Pholiotina novae-zelandiae	Endemic	Data Deficient	Data Deficient	Data Deficient	2	1	50%	Poorly known	DPR

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Pleurella ardesiaca	Indigenous	Not Threatened	Not Threatened	Not Threatened	16	1	6%		
Pleurocollybia cremea	Endemic	Data Deficient	Data Deficient	Data Deficient	14	1	7%		DPR
Pleuroflammula praestans	Indigenous	Data Deficient	Data Deficient	Data Deficient	88	17	19%		
Pleurotus purpureo-olivaceus	Endemic	Not Threatened	Not Threatened	Not Threatened	244	14	6%		
Pluteus concentricus	Endemic	Not Threatened	Not Threatened	Not Threatened	35	7	20%		
Pluteus microspermus	Indigenous	Data Deficient	Data Deficient	Data Deficient	34	4	12%		DPR
Pluteus minor	Endemic	Data Deficient	Data Deficient	Data Deficient	43	1	2%		DPR
Pluteus pauperculus	Indigenous	Not Threatened	Not Threatened	Not Threatened	21	1	5%		
Pluteus perroseus	Indigenous	Not Threatened	Not Threatened	Not Threatened	124	17	14%		
Pluteus readiarum	Endemic	Data Deficient	Data Deficient	Data Deficient	175	22	13%		DPR
Pluteus similis	Uncertain	Data Deficient			40	9	23%	Not in 2022 assessment	
Pluteus velutinornatus	Indigenous	Not Threatened	Not Threatened	Not Threatened	148	19	13%		
Porotheleum albodescendens	Endemic	Data Deficient	Data Deficient	Data Deficient	30	1	3%		
Psathyloma catervatim	Indigenous		Not Threatened	Not Threatened	62	2	3%		
Psathyloma leucocarpum	Endemic	Data Deficient	Data Deficient	Data Deficient	28	5	18%		
Psathyrella echinata	Indigenous	Not Threatened	Not Threatened	Not Threatened	50	17	34%		
Pseudoclitocybe foetida	Endemic	Data Deficient	Data Deficient	Data Deficient	25	1	4%		DPR
Pseudohydropus parafunebris	Endemic	Not Threatened			98	10	10%	Newly described	
Pseudolyophyllum brunneoceraceum	Indigenous	Not Threatened, safe overseas			13	1	8%	Uncertain Biostatus	
Pseudomarasmius efibulatus	Endemic	Data Deficient			2	1	50%	Newly described	
Psilocybe allenii	Uncertain	Not Threatened, safe overseas			4	1	25%	Uncertain Biostatus	

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Psilocybe alutacea	Uncertain	Not Threatened, safe overseas			7	1	14%	Newly recognised in Aotearoa	
Psilocybe makarorae	Endemic	Not Threatened	Not Threatened	Not Threatened	10	2	20%		
Psilocybe semilanceata	Uncertain	Not Threatened, safe overseas			18	4	22%	Uncertain Biostatus	
Resupinatus vinosolividus	Endemic	Not Threatened	Not Threatened	Not Threatened	45	5	11%		
Resupinatus violaceogriseus	Endemic	Not Threatened	Not Threatened	Not Threatened	67	8	12%		
Rhizocybe albida	Endemic	Not Threatened	Not Threatened	Not Threatened	68	4	6%		
Rhodocollybia delicata	Endemic	Data Deficient	Data Deficient	Data Deficient	10	1	10%	Recently re-recognised	
Rhodocollybia incarnata	Endemic	Not Threatened	Not Threatened	Not Threatened	97	11	11%		
Rhodocollybia purpurata	Endemic	Not Threatened	Not Threatened	Not Threatened	36	4	11%		
Rhodocybe dingleyae	Endemic	Data Deficient	Data Deficient	Data Deficient	4	2	50%	Poorly known	DPR
Roridomyces austrororidus	Indigenous	Not Threatened	Not Threatened	Not Threatened	324	59	18%		
Scytinotus longinquus	Indigenous	Not Threatened	Not Threatened	Not Threatened	268	83	31%		
Simocybe phlebophora	Indigenous	Not Threatened	Not Threatened	Not Threatened	58	11	19%		
Singerocybe clitocyboides	Indigenous	Not Threatened	Not Threatened	Not Threatened	43	3	7%		
Stropharia aeruginosa	Uncertain	Not Threatened, safe overseas			4	2	50%	Uncertain Biostatus	
Thaxterogaster alboaggregatus	Indigenous	Not Threatened	Not Threatened	Not Threatened	27	3	11%		
Thaxterogaster australis	Indigenous	Not Threatened	Not Threatened	Not Threatened	9	2	22%		
Thaxterogaster austrovaginatus	Indigenous	Data Deficient			18	8	44%	Newly recognised in Aotearoa	
Thaxterogaster castoreus	Endemic	Not Threatened	Not Threatened	Not Threatened	93	5	5%		
Thaxterogaster chalybeus	Endemic	Not Threatened	Not Threatened	Not Threatened	26	2	8%		

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Species in the Agaricales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Thaxterogaster cremeolina	Endemic	Not Threatened	Not Threatened	Not Threatened	20	3	15%		
Thaxterogaster cremeorufus	**Endemic**	**Regionally Vulnerable**	**Threatened**	**Nationally Vulnerable**	**3**	**1**	**33%**	**Tea-tree ECM associate**	**DPR**
Thaxterogaster cretax	Endemic	Not Threatened	Not Threatened	Not Threatened	20	1	5%		
Thaxterogaster iringa	Endemic	Data Deficient	Data Deficient	Data Deficient	6	3	50%	Otago-specific collecting	
Thaxterogaster ixomolynus	Endemic	Data Deficient	Data Deficient	Data Deficient	5	3	60%	Otago-specific collecting	
Thaxterogaster mariae	Indigenous	Not Threatened	Not Threatened	Not Threatened	30	1	3%		
Thaxterogaster periclymenus	Endemic	Data Deficient	Data Deficient	Data Deficient	9	1	11%		
Thaxterogaster rhipiduranus	Indigenous	Not Threatened	Not Threatened	Not Threatened	23	1	4%		
Thaxterogaster singularis	Endemic	Not Threatened	Not Threatened	Not Threatened	42	3	7%		
Thaxterogaster turcopes	Endemic	Data Deficient	Data Deficient	Data Deficient	11	6	55%	Otago-specific collecting	
Tricholoma elegans	Endemic	Not Threatened	Not Threatened	Not Threatened	50	5	10%		
Tricholoma viridiolivaceum	Indigenous	Not Threatened	Not Threatened	Not Threatened	186	15	8%		
Tricholomopsis ornaticeps	Endemic	Not Threatened	Not Threatened	Not Threatened	143	39	27%		DPR
Tricholomopsis scabra	Indigenous	Not Threatened	Not Threatened	Not Threatened	74	5	7%		
Tubaria rufofulva	Indigenous	Not Threatened	Not Threatened	Not Threatened	11	1	9%		
Tympanella galanthina	Endemic	Not Threatened	Not Threatened	Not Threatened	163	20	12%		
Xeromphalina leonina	Indigenous	Not Threatened	Not Threatened	Not Threatened	23	2	9%		

Table A4-2. Species in the Boletales assessed for this report.

Regional and national qualifiers used in the assessment are abbreviated as follows: CD = Conservation Dependent; CI = Climate Impact; CRN = Conservation Research Needed; DPR = Data Poor Recognition; DPS = Data Poor Size; DPT = Data Poor Trend; De = Designated; FR = Former Range; INC = Increasing; NR = Natural Range Limit; NStr = National Stronghold; OL = One Location; PD = Partial Decline; PF = Population Fragmentation; RE = Regional Endemic; RN = Restored Native; RR = Range Restricted; Sp = Biologically Sparse; TL = Type Locality; TO = Threatened Overseas. Further details about each of these qualifiers can be found at Appendix 2, 3 and https://nztcs.org.nz. National Criteria is Regionally Critical A(1) with further information found in Rolfe et al. 2022 and https://nztcs.org.nz.

The source of "occurrences' data are from the Global Biodiversity Information Facility (GBIF) and the University of Otago (OTA) mycological collection. Qualifiers can be found in Appendix 2 and 3. For the full dataset for this regional assessment of non-lichenised agaricales and russuloid fungi in the Otago region see Appendix 4-1 and 4-3.

Biostatus is from the Biota of New Zealand (BiotaNZ) where endemic refers to Aotearoa New Zealand.

Taxa listed in bold text are Regionally Threatened in Otago.

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Criteria | Qualifiers
Amoenoboletus mcrobbii	Endemic	Not Threatened	Not Threatened	Not Threatened	30	2	7%		
Austroboletus novae-zelandiae	Endemic	Not Threatened	Not Threatened	Not Threatened	223	3	1%		
Austropaxillus mcnabbii	Indigenous	Not Threatened	Not Threatened	Not Threatened	55	2	4%		
Austropaxillus nothofagi	Endemic	Not Threatened	Not Threatened	Not Threatened	48	1	2%		
Calostoma fuscum	Indigenous	Not Threatened	Not Threatened	Not Threatened	36	3	8%		
Calostoma rodwayi	Indigenous	Not Threatened	Not Threatened	Not Threatened	186	18	10%		
Chalciporus aurantiacus	Endemic	Not Threatened	Not Threatened	Not Threatened	26	1	4%		
Fistulinella violaceipora	Indigenous	Not Threatened	Not Threatened	Not Threatened	49	6	12%		
Hygrophoropsis coacta	Endemic	Not Threatened	Not Threatened	Not Threatened	28	1	4%		
Hygrophoropsis umbriceps	**Endemic**	**Regionally Vulnerable**	**Threatened**	**Nationally Vulnerable**	**11**	**1**	**9%**	**Tea-tree ECM associate**	**A(1) | De**
Tylopilus brunneus	Endemic	Not Threatened	Not Threatened	Not Threatened	94	3	3%		
Tylopilus formosus	Endemic	Not Threatened	Not Threatened	Not Threatened	807	73	9%	Not in 2022 assessment	
Xerocomus lentistipitatus	Endemic	Data Deficient	Data Deficient	Data Deficient	12	3	25%		DPR
Xerocomus nothofagi	Endemic	Not Threatened	Not Threatened	Not Threatened	54	9	17%		
Xerocomus squamulosus	Endemic	Not Threatened	Not Threatened	Not Threatened	53	3	6%		

Table A4-3. Species in the Russulales assessed for this report.

Regional and national qualifiers used in the assessment are abbreviated as follows: CD = Conservation Dependent; CI = Climate Impact; CRN = Conservation Research Needed; DPR = Data Poor Recognition; DPS = Data Poor Size; DPT = Data Poor Trend; De = Designated; FR = Former Range; INC = Increasing; NR = Natural Range Limit; NStr = National Stronghold; OL = One Location; PD = Partial Decline; PF = Population Fragmentation; RE = Regional Endemic; RN = Restored Native; RR = Range Restricted; Sp = Biologically Sparse; TL = Type Locality; TO = Threatened Overseas. Further details about each of these qualifiers can be found at Appendix 2, 3 and https://nztcs.org.nz. National Criteria is Regionally Critical A(1) with further information found in Rolfe et al. 2022 and https://nztcs.org.nz.

The source of "occurrences' data are from the Global Biodiversity Information Facility (GBIF) and the University of Otago (OTA) mycological collection. Qualifiers can be found in Appendix 2 and 3. For the full dataset for this regional assessment of non-lichenised agaricales and boletes fungi in the Otago region see Appendix 4-1 and 4-2.

Biostatus is from the Biota of New Zealand (BiotaNZ) where endemic refers to Aotearoa New Zealand.

Taxa listed in bold text are Regionally Threatened in Otago.

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Lactarius tawai	Endemic	Not Threatened	Not Threatened	Not Threatened	68	5	7%		
Lactarius umerensis	Endemic	Not Threatened	Not Threatened	Not Threatened	96	8	8%		
Lactifluus aurantioruber	Endemic	Not Threatened			128	10	8%	Not in 2022 assessment	
Lactifluus clarkeae	Indigenous	Not Threatened			105	20	19%	Not in 2022 assessment	
Lactifluus sepiaceus	Indigenous	Not Threatened	Not Threatened	Not Threatened	56	5	9%		
Lentinellus crawfordiae	Endemic	Not Threatened	Not Threatened	Not Threatened	21	5	24%		
Russula acrolamellata	Endemic	Not Threatened	Not Threatened	Not Threatened	120	7	6%		
Russula allochroa	**Endemic**	**Regionally Vulnerable**	**Threatened**	**Nationally Vulnerable**	**55**	**2**	**4%**	**Tea-tree ECM associate**	**De**
Russula australis	Endemic	Not Threatened	Not Threatened	Not Threatened	46	9	20%		
Russula griseobrunnea	Endemic	Not Threatened	Not Threatened	Not Threatened	66	1	2%		
Russula griseostipitata	Indigenous	Not Threatened	Not Threatened	Not Threatened	87	3	3%		
Russula griseoviolacea	Endemic	Not Threatened	Not Threatened	Not Threatened	67	6	9%		
Russula griseoviridis	Endemic	Not Threatened	Not Threatened	Not Threatened	108	1	1%		
Russula inquinata	Indigenous	Not Threatened	Not Threatened	Not Threatened	35	6	17%		
Russula kermesina	Endemic	Not Threatened	Not Threatened	Not Threatened	200	8	4%		
Russula macrocystidiata	Endemic	Not Threatened	Not Threatened	Not Threatened	104	5	5%		
Russula novae-zelandiae	Endemic	Not Threatened	Not Threatened	Not Threatened	116	11	9%		
Russula pilocystidiata	Endemic	Not Threatened	Not Threatened	Not Threatened	45	1	2%		
Russula pseudoareolata	Indigenous	Not Threatened	Not Threatened	Not Threatened	57	2	4%		
Russula purpureotincta	Endemic	Not Threatened	Not Threatened	Not Threatened	81	5	6%		

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Species in the Russulales assessed for this report continued

Species	Biostatus in Aotearoa	Otago Assessment	National Category	National Status	# National occurrences	# Otago occurrences	% of national records in Otago	Note	Qualifiers
Russula roseopileata	Endemic	Not Threatened	Not Threatened	Not Threatened	159	12	8%		
Russula roseostipitata	Endemic	Not Threatened	Not Threatened	Not Threatened	63	4	6%		
Russula tawai	Endemic	Not Threatened	Not Threatened	Not Threatened	80	4	5%		
Russula tricholomopsis	Endemic	Not Threatened	Not Threatened	Not Threatened	53	6	11%		
Russula umerensis	Endemic	Not Threatened	Not Threatened	Not Threatened	449	3	1%		

Find out more:
www.orc.govt.nz/environment/biodiversity/otago-regional-threat-assessments/
or visit:
www.orc.govt.nz/environment/biodiversity/

Otago Regional Council