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Broadscale Intertidal Habitat Mapping of Blueskin Bay

Prepared for

Otago Regional Council

June 2021

Salt
Ecology
Report 069

RECOMMENDED CITATION

Roberts KL, Scott-Simmonds T, Stevens LM, Forrest BM. 2021. Broadscale Intertidal Habitat Mapping of Blueskin Bay. Salt Ecology Report 069, prepared for Otago Regional Council, June 2021. 44p.

Broadscale Intertidal Habitat Mapping of Blueskin Bay (2021)

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June 2021

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GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
CSR	Current Sedimentation Rate
ETI	Estuarine Trophic Index
HEC	High Enrichment Conditions (HECs) comprise mud-dominated sediments (>50% mud content) with macroalgal cover >50% that is entrained (growing >30mm deep) within the sediment, the combined presence of which may result in adverse ecological outcomes. HECs can also be present in non-algal areas where sediments have an elevated organic content (>1% total organic carbon) and low sediment oxygenation (apparent Redox Potential Discontinuity (aRPD) depth <10mm) as a consequence of algal degradation.
LCDB	Land Cover Data Base
MSL	Mean Sea Level
NSR	Natural Sedimentation Rate
NEMP	National Estuary Monitoring Protocol
ORC	Otago Regional Council
SIDE	Shallow, intertidally dominated estuaries
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for reviewing the draft report. Thank you to Megan Southwick (Salt Ecology) for producing GIS map outputs. The tools used to produce GIS summaries and maps were developed by Megan Southwick (Salt Ecology).

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SUMMARY

Blueskin Bay is a large (690ha) shallow, intertidal-dominated, tidal lagoon type estuary located approximately 25km north of Dunedin on New Zealand's east coast. It drains a catchment that is ~37% indigenous forest and scrub, 21% exotic forest and 28% high producing pasture. Otago Regional Council have included Blueskin Bay in their State of Environment Estuary Monitoring Programme. This report describes the first known intertidal broad scale habitat mapping survey of the estuary conducted in January 2021. The survey involved assessing the dominant substrate and vegetation features present in the estuary including seagrass, salt marsh and macroalgae following methods described in New Zealand's National Estuary Monitoring Protocol (NEMP).

The key broad scale monitoring results for January 2021 are summarised below, and the following table rates them using preliminary criteria for assessing estuary health.

- Intertidal substrate (625.6ha) was sand-dominated (512ha; 82%), with mud-dominated sediments (>50% mud) a minor feature (25.2ha; 3.7%) in localised areas near freshwater inflows and among salt marsh. Shell banks and cockle beds were common in the lower estuary (30.8ha; 4.9% of the intertidal area)
- Extensive seagrass beds were present on the central intertidal flats (33.5ha; 5.2% of the intertidal area), reflecting the low sediment mud content, high water clarity, and relatively low nutrient inputs.
- No significant areas of nuisance macroalgae were recorded. Localised patches of high enrichment conditions (0.6ha; 0.1% of the intertidal area) occurred near channels in the north-west corner of the estuary, comprising entrained *Gracilaria* with >90% cover, high biomass (>1000g/m^2) and associated eutrophic sediments (high organic content, high mud content and low sediment oxygen).
- Salt marsh (35.4ha; 5.7% of the intertidal area) was dominated by herbfield (54%) and grassland (38%). It was most extensive north of Carey's Creek, Rabbit Island, Orokonui Inlet and the outflow of Waitati River.
- The 200m terrestrial margin has been significantly modified for urban, roading and rail infrastructure development (24.6%) and low producing grassland (33.8%).

Overall Blueskin Bay represents an estuary in good health, with high value seagrass and cockle beds present. This is attributable to a combination of small freshwater inflows, high tidal flushing, and catchment sediment and nutrient loads that the estuary is currently able to assimilate.

RECOMMENDATIONS

Broadscale Indicators	Unit	Value	2021
Mud-dominated substrate	% of intertidal area >50% mud	4.0	Good
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.71	Good
Seagrass	% decrease from baseline	-	2021 baseline established
Salt marsh extent (current)	% of intertidal area	5.7	Fair
Historical salt marsh extent	% of historical remaining	50*	Fair
200m terrestrial margin	% densely vegetated	31.7	Fair
High Enrichment Conditions	ha	0.6	Good
High Enrichment Conditions	% of estuary	0.1	Very Good
Sedimentation rate*	CSR:NSR ratio	2.5	Fair
Sedimentation rate*	mm/yr	0.5	Good

Dash represents no data. Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. *Estimated Value

Based on the findings of the current survey it is recommended that ORC consider the following:

1. Repeat the broadscale habitat mapping 5-yearly to track long term changes in estuary condition.
2. Protect and enhance existing salt marsh to prevent further losses and consider restoration in areas of suitable habitat.
3. Review historic imagery to assess changes in important habitats over time (e.g. seagrass and salt marsh).
4. Include Blueskin Bay in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will protect the estuary from degradation.

1. INTRODUCTION

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Monitoring is primarily designed to detect and understand changes in key estuaries over time and determine the effect of catchment influences, especially those due to the input of nutrients and muddy sediments.

The Otago Regional Council (ORC) monitoring programme includes several estuaries such as the Shag River, Waikouaiti River and the Catlins River Estuary. These estuaries are shallow, intertidal-dominated estuaries (SIDEs) meaning they, in general, have a short residence time (<3 days; Robertson et al. 2016a). While their short-residence times mean these estuaries are less susceptible to water column nutrient problems, they have the capacity to retain fine sediments and sediment-bound nutrients in deposition areas making them moderately susceptible to nutrient enrichment and fine sediment impacts.

The National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c) is intended to provide resource managers with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results provide a valuable basis for establishing 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 estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

The current report describes the methods and results of broad scale monitoring undertaken at Blueskin Bay between 12-15 January 2021 (Fig. 1). The primary purpose of the current work was to characterise the presence and extent of seagrass, macroalgae and salt marsh establishing a baseline at which to compare future monitoring.

While previous State of Environment monitoring has not been conducted a range of science studies have been undertaken previously (Brownstein et al. 2013; Kainamu 2010; Leduc et al. 2006; O'Connell-Milne et al. 2020; Otis & Schallenberg 2020; Zhang 2018).

1.1 BACKGROUND TO BLUESKIN BAY

Blueskin Bay is a large (690ha) shallow, intertidally dominated (SIDE) type estuary located approximately 25km north of Dunedin on New Zealand's east coast. The estuary mouth is permanently open to the sea and the main body of the estuary is protected from the open ocean by a sandspit extending from its northern shore.

At low tide, the estuary drains almost completely exposing ~91% of the intertidal area. The estuary is

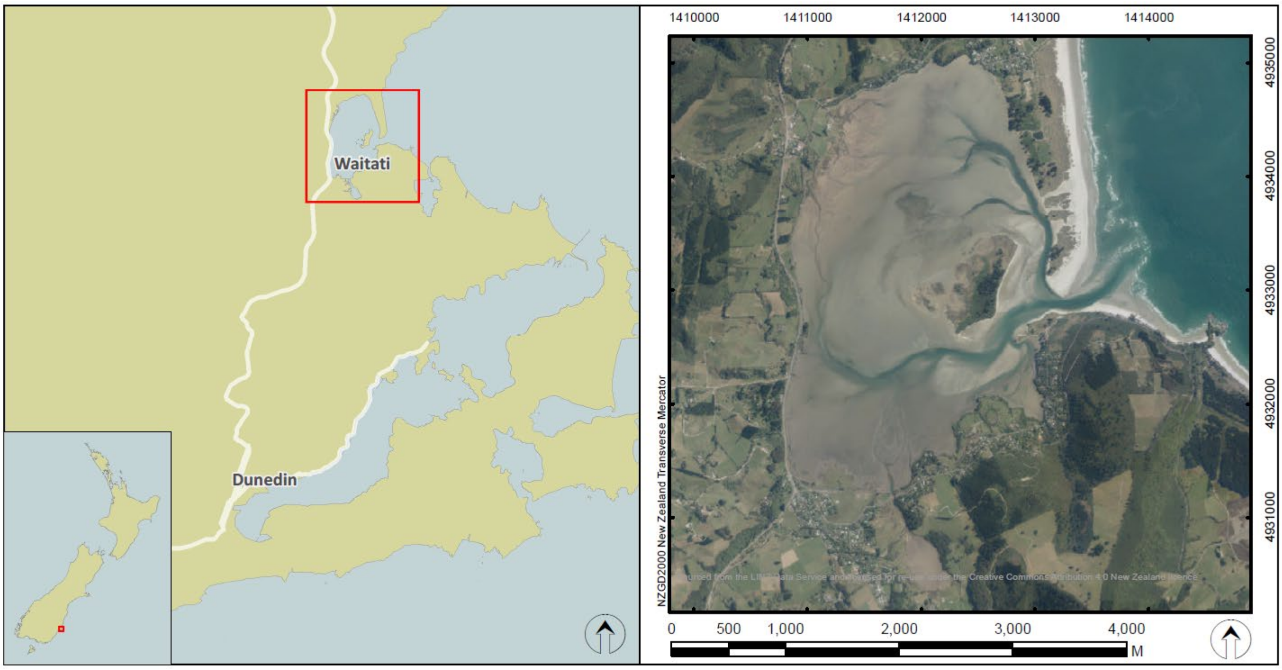


Fig. 1. Location of Blueskin Bay, Otago.

well flushed with the majority of the water exchanged with the ocean on each tidal cycle (O'Connell-Milne et al. 2020; Zhang 2018).

While ~62% of the catchment is densely vegetated (Table 1), the lower catchment is dominated by high producing pasture comprising 28% of the catchment area (Table 1; Fig. 2). Urban development is localised around the estuary margins and includes two settlements: Warrington and Waitati. The Warrington wastewater treatment plant is located on the northern sand spit. This urban and infrastructure development, as well as rail and roading on the estuary margins, has led to historic reclamation and losses of surrounding salt marsh.

Freshwater inputs from the catchment are minimal with flow from Waitati River (south) and Careys Creek (northwest; mean freshwater flow 0.8m^3/s) only making a small contribution to the total estuary volume. Aside from catchment nutrient sources, wastewater from septic tanks seepage and the wastewater treatment plant contribute up to 7% of the total nitrogen load to the estuary (Otis & Schallenberg 2020).

Both Blueskin Bay and the connected Orokonui Inlet are within coastal protection areas in the Otago Regional Plan: Coast, recognised for their Kai Tahu cultural and spiritual values in addition to their estuarine values (Moore, 2015). Rabbit Island, near the estuary mouth, is also considered an outstanding natural feature or landscape in the Otago Regional Plan: Coast (Moore, 2015). The island provides protection for salt marsh on its western side and separates the main channel to the north and south-west.

To our knowledge, nuisance macroalgal blooms have not been reported in Blueskin Bay and extensive seagrass beds are present in the middle of the estuary. The lower estuary supports a healthy supply of cockles, and on occasion oysters. Within Blueskin Bay there are recreational, customary and commercial fishing of cockles (*Austrovenus. stutchburyi*). Several studies have demonstrated that coastal phytoplankton is a primary food source for these filter feeding cockles highlighting the important interaction between estuaries and open coastal waters (Kainamu 2010; O'Connell-Milne et al. 2020; Zhang 2018).

The Bay is also an important habitat for nesting birds and a nursery for fish. Blueskin Bay holds high ecological, cultural and social values.

Cockles collected in Blueskin Bay

Gull eggs in a nest within the saltmarsh habitat

Table 1. Summary of catchment land cover (LCDB 2017/18), Blueskin Bay.

LCDB (2017/18) Catchment Land Cover		Ha	%
1	Built-up Area (settlement)	58.0	0.6
2	Urban Parkland/Open Space	0.9	0.0
5	Transport Infrastructure	5.8	0.1
6	Surface Mine or Dump	3.2	0.0
10	Sand or Gravel	9.9	0.1
16	Gravel or Rock	2.6	0.0
20	Lake or Pond	3.7	0.0
22	Estuarine Open Water	663	6.6
40	High Producing Exotic Grassland	2802	27.8
41	Low Producing Grassland	125	1.2
43	Tall Tussock Grassland	200.3	2.0
45	Herbaceous Freshwater Vegetation	28.8	0.3
46	Herbaceous Saline Vegetation	17.8	0.2
51	Gorse and/or Broom	250.4	2.5
52	Manuka and/or Kanuka	1650	16.3
54	Broadleaved Indigenous Hardwoods	1537	15.2
56	Mixed Exotic Shrubland	43.6	0.4
58	Matagouri or Grey Scrub	6.0	0.1
64	Forest - Harvested	74.8	0.7
68	Deciduous Hardwoods	20.2	0.2
69	Indigenous Forest	489	4.8
71	Exotic Forest	2105	20.8
Grand Total		10097	100
Total densely vegetated area (LCDB classes 45-71)		6223	61.6

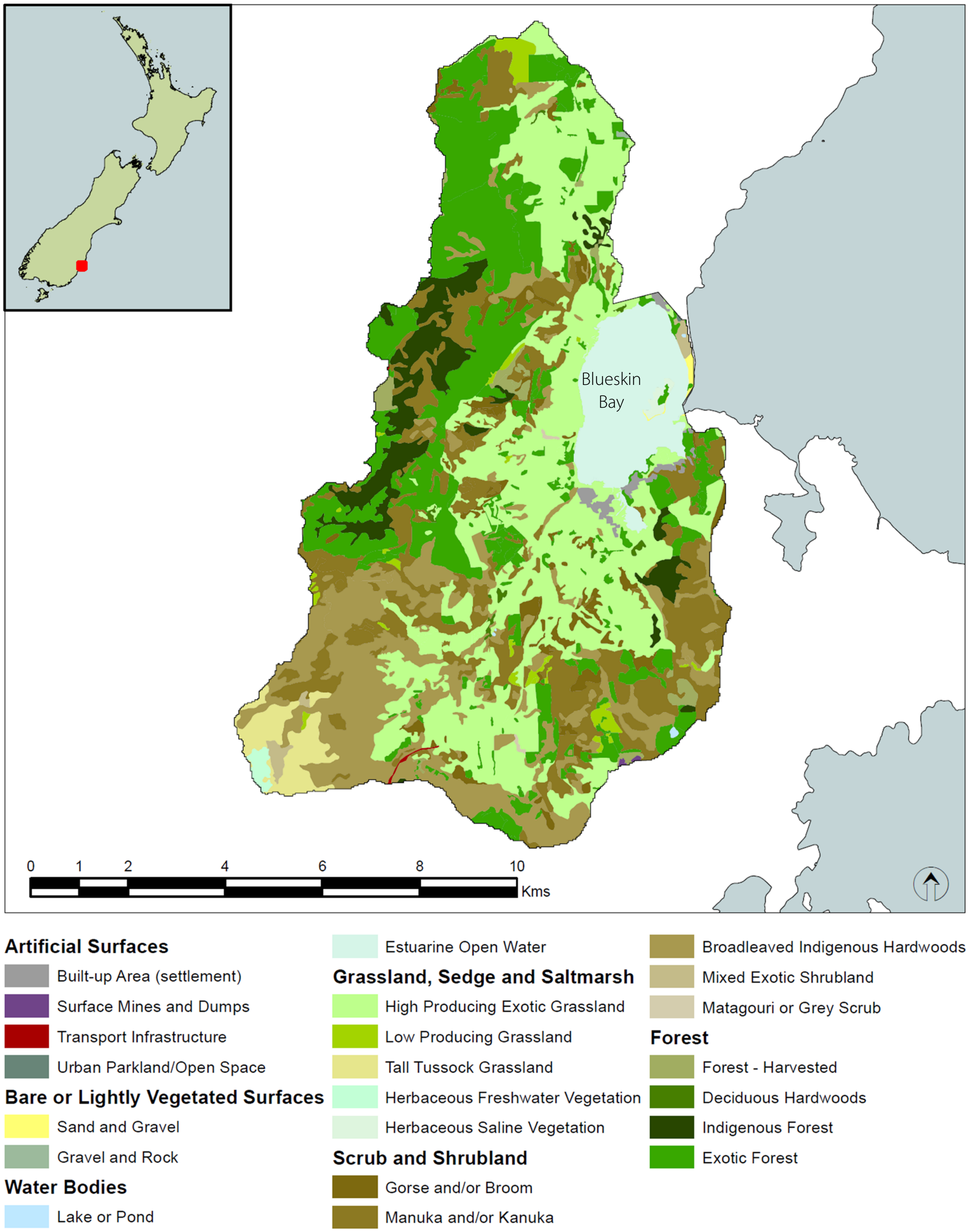


Fig. 2. Blueskin Bay and surrounding catchment land use classifications from LCDB5 (2017/18) database.

2. METHODS

2.1 OVERVIEW

The focus of the current broad scale mapping survey was to establish a baseline of the dominant intertidal and terrestrial margin features in Blueskin Bay, Otago.

2.2 BROADSCALE MAPPING METHODS

Broad-scale surveys involve describing and mapping estuaries according to dominant surface habitat features (substrate and vegetation). The type, presence and extent of 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. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to small scale temporal variation associated with instantaneous water quality measures.

NEMP methods (Appendix 1) were used to map and categorise intertidal estuary substrate and vegetation. The mapping procedure combines aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position and/or size or type of dominant habitats can be monitored by repeating the mapping exercise. Broad-scale mapping is typically carried out during September to May when most plants are still visible and seasonal vegetation has not died back. Aerial photographs are ideally assessed at a scale of less than 1:5000, as at a broader scale it becomes difficult to accurately determine changes over time.

Broad scale mapping of Blueskin Bay in 2021 used 10cm/pixel (0.10m) urban aerial photos flown in 2018-2019 (summer period) and sourced from LINZ online data service. Ground truthing was undertaken between 12th to 15th January 2021 by experienced scientists who assessed the estuary on foot to map the spatial extent of dominant vegetation and substrate. A particular focus was to characterise the spatial extent of muddy sediment (as a key stressor), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats. The latter were estuarine seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the terrestrial margin bordering the estuary. Background information on the ecological significance of opportunistic macroalgae and the different vegetation features is provided in Table 2.

In the field, features were drawn directly onto laminated aerial photographs. The broad scale features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet and combined with field notes and georeferenced photographs. From this information, habitat maps were produced showing the dominant estuary features, e.g. salt marsh, and its underlying substrate type.

Estuary boundaries for mapping purposes were based on the definition used in the New Zealand Estuary Trophic Index (ETI; Robertson et al. 2016a) and are defined as the area between the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt) and seaward to a straight line between the outer headlands where the angle between the head of the estuary and the two outer headlands is <150°. This is consistent with the New Zealand coastal hydrosystems boundaries (Hume et al. 2016) developed in support of NIWA's CLUES estuary model.

Assessment criteria, developed largely from previous broad scale mapping assessments, apply thresholds for helping to assess estuary condition. Additional details on specific broad scale measures are provided below.

Western side of Blueskin Bay looking toward the entrance

Lower intertidal flats near the entrance

2.2.1 Substrate classification and mapping

Salt Ecology has extended the NEMP approach to include substrate beneath vegetation to create a continuous substrate layer for the estuary. Furthermore, revisions of the NEMP substrate classifications are summarised in Appendix 1 and outlined in more detail in Stevens et al., (2020). Substrate classification is based on the dominant surface substrate features present; e.g. rock, boulder, cobble, gravel, sand, mud. Sand and mud substrates were divided into sub-categories based on sediment 'muddiness', assessed according to an expert field-based assessment of textural and firmness characteristics. In January 2021, 23 samples for sediment grainsize were collected in Blueskin Bay to validate field assessments of substrate type (Appendix 1). The area (horizontal extent) of mud-dominated sediment is used as a primary indicator of sediment mud impacts and in assessing susceptibility to nutrient enrichment impacts (trophic state).

Narrow band of cobble substrate on estuary margin

Firm sand substrate between sand dunes connected to the estuary

2.2.2 Sediment oxygenation

To assess the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment the apparent Redox Potential Discontinuity (aRPD) was assessed at all sediment grainsize locations collected from representative substrate types. The depth of the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour) was recorded. Sediments were considered to have poor oxygenation if the aRPD was consistently shallower than 10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments.

Example of distinct colour change with depth, brown oxygenated sediments are on the surface down to ~45mm

2.2.3 Macroalgae

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature.

The New Zealand Estuary Trophic Index (ETI) (Robertson et al. 2016b) has adopted the use of the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) for macroalgal assessment (Appendix 2). The OMBT is a 5-part multi-metric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which rates macroalgal condition within overall quality status threshold bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- *Percentage cover of opportunistic macroalgae:* The spatial extent and surface cover of algae present in intertidal soft sediment habitat in an estuary provides an early warning of potential eutrophication issues.
- *Macroalgal biomass:* Biomass provides a direct measure of macroalgal growth. Estimates of mean biomass are made within areas affected by macroalgal growth, as well across the total estuary intertidal area.

- *Extent of algal entrainment into the sediment matrix:* Macroalgae was defined as entrained when growing >30mm deep within sediments, which indicates that persistent macroalgal growths have established.

When present, the mean percent cover of discrete macroalgal patches was visually assessed using the 6-category percent cover rating scale presented in Fig. 3 as a guide. At spot locations in representative macroalgal patches, biomass and entrainment were recorded.

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

The integrated OMBT index provides a comprehensive measure of the combined influence of macroalgal growth and distribution in the estuary and is applied where macroalgal cover exceeds 5%.

Ulva sp. in the mid-estuary on the channel margin

Dense bed of *Gracilaria* in channel depressions north-west corner of Blueskin Bay

2.2.4 Seagrass

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 method, the mean percent cover of discrete seagrass patches was visually assessed using the 6-category percent cover rating scale presented in Fig. 3.

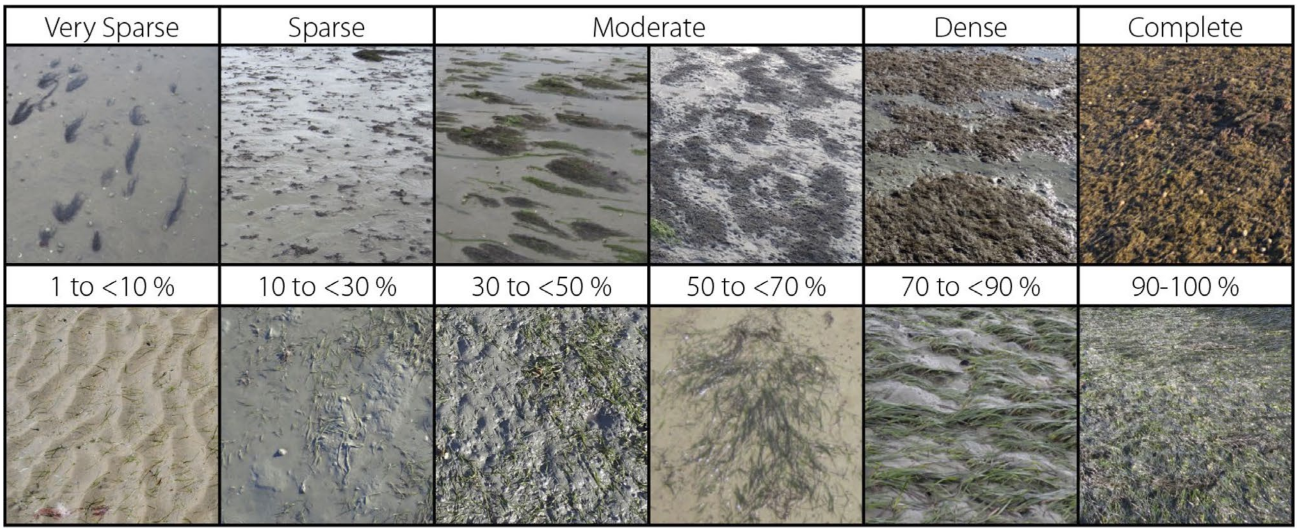


Fig. 3. Visual rating scale for percentage cover estimates for macroalgae and seagrass. Modified from FGDC (2012).

Mapping seagrass beds in the middle of the estuary

Salt marsh habitat, Blueskin Bay

2.2.5 Salt marsh

NEMP methods (Appendix 1) were 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). Two measures were used to assess salt marsh condition: i) intertidal extent (percent cover) and ii) current extent compared to estimated historical extent.

2.2.6 Terrestrial margin

Broad-scale NEMP methods were used to map and categorise the 200m terrestrial margin using the dominant land cover classification codes described in the Landcare Research Land Cover Data Base (LCDB) detailed in Appendix 1.

Table 2. Overview of the ecological significance of various vegetation types.

Habitat	Description
Terrestrial margin vegetation	A densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important food source and habitat for a variety of species and, in waterway riparian zones, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity.
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, acts as a buffer that protects against introduced grasses and weeds and provides an important habitat for a variety of species including fish and birds.
Seagrass	Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

2.3 DATA RECORDING AND QA/QC

Broad scale mapping is intended to provide a rapid overview of estuary condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial photos, 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 such as rushland, rockfields, dense seagrass, etc. 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 photographs, e.g. sparse seagrass beds, or where there is a transition between features that appear visually similar, e.g. sand, muddy sand, mud. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground truthed, but accuracy is unlikely to be better than ±20-50m for such features when relying on photographs alone.

After habitat features were digitised, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables.

During the field ground truthing, sediment grain size and macroalgal data were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP. Macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template.

Birds nesting in the salt marsh, Blueskin Bay

Salt marsh habitat, Blueskin Bay

Eastern margin of Blueskin Bay, firm sand and squat lobster washed up on the margins (red colouring)

2.4 ASSESSMENT OF ESTUARY CONDITION

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

The condition ratings used in the current report were derived primarily from the ETI (Robertson et al. 2016b) and subsequent revisions (Zeldis et al. 2017). The ETI provides screening guidance for assessing where an estuary is positioned on a eutrophication gradient. It includes site-specific thresholds for aRPD and mud content, generally using spot measures from within the most degraded 10% of the estuary. We adopted the ETI thresholds for present purposes, except for;

i. for % mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016);

ii. for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012);

iii. < and ≥ values were applied to CSR and NSR criteria in the ETI.

iv. High Enrichment Conditions (HEC) are referred to alternatively as 'Gross Eutrophic Zones' (GEZs) in the ETI (Zeldis et al. 2017). For our purposes HECs are defined as mud-dominated sediments (≥50% mud content) with >50% macroalgal cover and with macroalgae entrained (growing >30mm deep) within the sediment. HECs can also be present in non-algal areas where sediments have an elevated organic content (>1% total organic carbon) combined with low sediment oxygenation (aRPD <10mm).

As many of the scoring categories in Table 3 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Table 3. Indicators used to assess results in the current report.

Indicator	Unit	Very good	Good	Fair	Poor
Broadscale Indicators					
Mud-dominated substrate[2]	% of intertidal area >50% mud	< 1	1 to 5	> 5 to 15	> 15
Macroalgae (OMBT)[1]	Ecological Quality Rating (EQR)	≥0.8 to 1.0	≥0.6 to <0.8	≥0.4 to <0.6	0.0 to <0.4
Seagrass[2]	% decrease from baseline	< 5	≥ 5 to 10	≥ 10 to 20	≥ 20
Salt marsh extent (current)[2]	% of intertidal area	> 20	> 10 to 20	> 5 to 10	0 to 5
Historical salt marsh extent[2]	% of historical remaining	≥ 80 to 100	≥ 60 to 80	≥ 40 to 60	< 40
200m terrestrial margin[2]	% densely vegetated	≥ 80 to 100	≥ 50 to 80	≥ 25 to 50	< 25
High Enrichment Conditions[1]	ha	< 0.5	≥ 0.5 to 5	≥ 5 to 20	≥ 20
High Enrichment Conditions[1]	% of estuary	< 1	≥ 1 to 5	≥ 5 to 10	≥ 10
Sedimentation rate[1]*	CSR:NSR ratio	1 to 1.1 xNSR	1.1 to 2	2 to 5	> 5
Sedimentation rate[3]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Sediment quality					
aRPD depth[1]	mm	≥ 50	20 to < 50	10 to ≤ 20	≤ 10

1. General indicator thresholds derived from a New Zealand Estuarine Tropic Index, with adjustments for aRPD as described in the main text. See text for further explanation of the origin or derivation of the different metrics.
2. Subjective indicator thresholds derived from previous broad scale mapping assessments.
3. Ratings derived or modified from Townsend and Lohrer (2015).

**CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling)*

3. RESULTS

3.1 BROADSCALE HABITAT MAPPING

3.1.1 Substrate

Table 4 and Fig. 4 show intertidal substrate was dominated by firm sand (395.4ha, 63.2%), mobile sand (40.8ha, 6.5%) and firm muddy sand (58.2ha, 9.3%). Gravel field was a prominent feature in the north-west of Blueskin Bay near Carey's Creek and the southern margin near Waitati River comprising 49.5ha; 7.9%, of the intertidal area. A reasonably common feature in the lower estuary were ecologically important zootic habitats comprising shell bank and cockle (*Austrovenus stutchburyi)* beds (30.8ha; 4.9%); see photos.

Only a relatively small area (25.2ha, 4.0%) was mud-dominated (>50% mud) (Fig. 4, Appendix 6). These areas were localised around freshwater inflows, salt marsh and backwaters such as the Orokonui Inlet to the south and the small embayment near Doctor's Point Reserve near the entrance.

Table 4. Summary of dominant intertidal substrate, Blueskin Bay January 2021.

Substrate Class	Feature	Ha	%
Artificial	Boulder field	0.7	0.1
	Cobble field	0.6	0.1
Bedrock	Rock field	0.3	0.0
Boulder/Cobble/ Gravel	Boulder field	0.2	0.0
	Cobble field	6.8	1.1
	Gravel field	49.5	7.9
Sand (0-10% mud)	Mobile sand	40.8	6.5
	Firm sand	395.4	63.2
	Soft sand	0.8	0.1
Muddy Sand (>10-25% mud)	Firm muddy sand	58.2	9.3
	Soft muddy sand	7.7	1.2
Muddy Sand (>25-50% mud)	Firm muddy sand	2.7	0.4
	Soft muddy sand	6.0	1.0
Sandy Mud (>50-90% mud)	Soft sandy mud	8.2	1.3
Mud (>90% mud)	Firm mud	0.6	0.1
	Soft mud	16.4	2.6
Zootic	Shell bank	4.6	0.7
	Cockle bed	26.2	4.2
Total		625.6	100.0

Firm sand substrate through most of the estuary

Mobile sands in the lower estuary

Gravel field north-western side of Blueskin Bay

Shell banks in the lower estuary

Cockles on the eastern side of Blueskin Bay

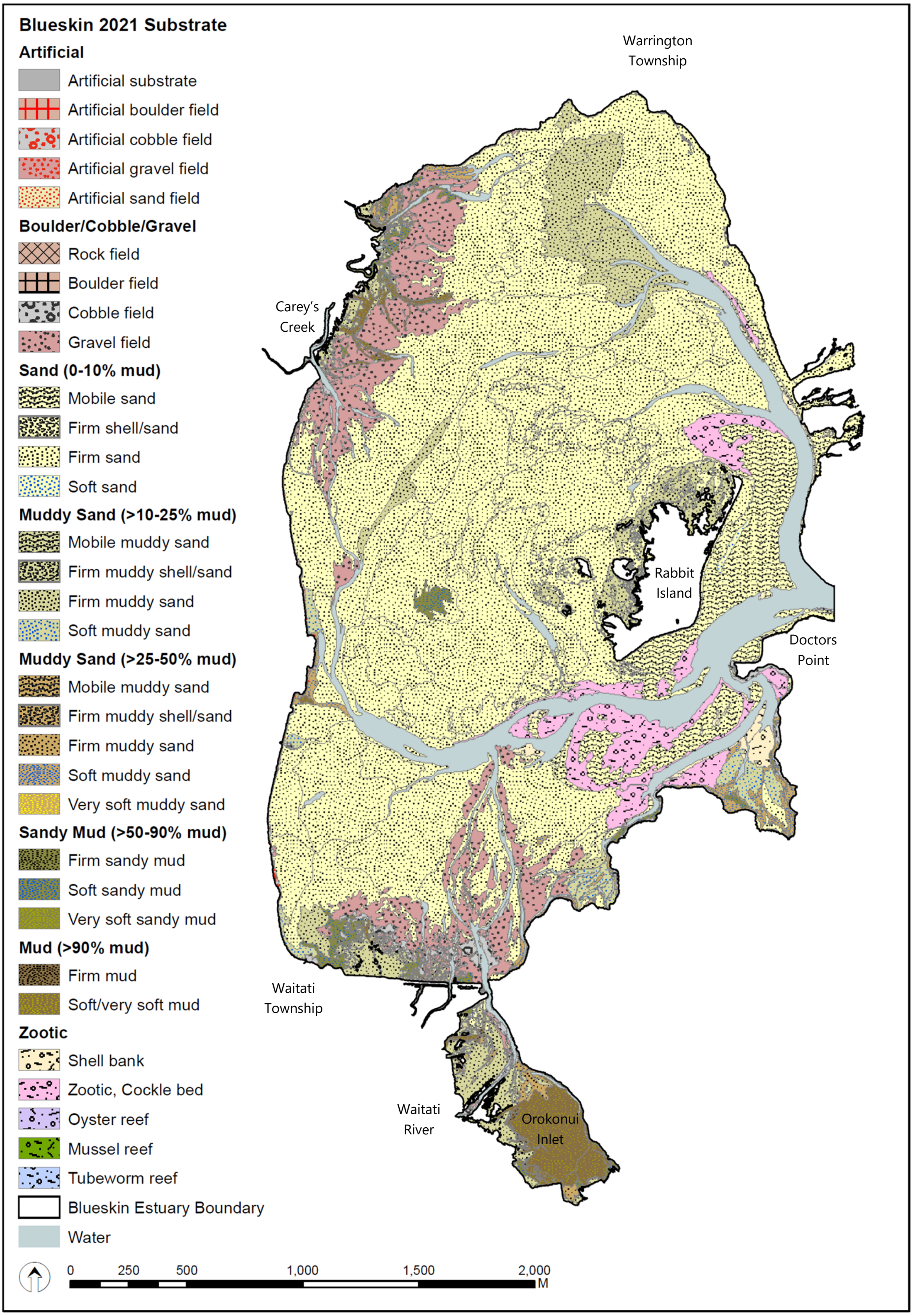


Fig. 4. Dominant substrate types in the intertidal zone, Blueskin Bay 2021.

3.1.2 Sediment oxygenation

Sediment oxygenation was measured within representative substrate types to assess the trophic status of the sediment. In general, enriched or muddy sediments have lower sediment oxygenation (or a shallower aRPD) than unenriched or sandy sediments.

In January 2021, as expected, spot measurements confirmed the shallowest aRPD depths occurred in sediments with high mud or organic contents, for example in northwest Blueskin Bay and Orokonui Inlet (see photos).

Shallow aRPD in mud-dominated sediments with high *Gracilaria sp*. cover, northwest Blueskin Bay

Soft muds in the Orokonui Inlet deposited on top of plant roots

There was also a large area of firm sands associated with shallow aRPD (<5mm), a condition rating of 'poor'. The area was located southwest of Rabbit Island and microalgae were visibly growing on the surface of the sediment.

Large areas of low oxygen conditions and microalgae growth are indicative of nutrient enrichment. When oxygen is close to the surface (see photos) adverse impacts on sediment dwelling organisms are likely which can have flow on effects for higher trophic organisms. The specific cause of the low oxygen sand flats is uncertain, however there is clearly an adequate supply of nutrients to fuel microalgal growth and deplete sediment oxygen.

Microalgae growing on firm sands and shallow aRPD, southwest of Rabbit Island

3.1.3 Macroalgae

Table 5 summarises the macroalgal percent cover classes for the estuary, with the mapped cover and biomass shown in Fig 5 and Fig 6, respectively.

Table 5. Summary of intertidal macroalgae cover, Blueskin Bay January 2021.

Percent Cover Category	ha	%
Trace (<1%)	269.8	43.1
Very sparse (1 to <10%)	213.6	34.1
Sparse (10 to <30%)	103.0	16.5
Low-Moderate (30 to <50%)	20.5	3.3
High-Moderate (50 to <70%)	9.0	1.4
Dense (70 to <90%)	3.7	0.6
Complete (>90%)	5.9	0.9
Total	625.6	100

Macroalgae cover was classified as trace (<1% cover), very sparse (1 to <10% cover) or sparse (10 to <30% cover) over 94% of the estuary. In these areas the dominant species present included the green seaweed *Ulva spp*. and red seaweed *Gracilaria chilensis* (recently renamed *Agarophyton chilense*).

Very sparse (top) to sparse (bottom) macroalgae cover

Areas of higher cover (30 to 90%) covered 5.3% of the intertidal area (Fig 5). Dense areas of macroalgal cover (>90% cover) represented only 0.9% of the intertidal area and were limited to the stream channel margins in the north-west corner of the estuary, in shallow depressions where water pooled on the tidal flats, and in a small patch within the seagrass beds in the middle of the central basin. The largest patch (4.3ha) was located on the channel bend toward the western side of Blueskin Bay, however this area was not associated with poor sediment condition.

Where macroalgae was present, low biomass (<100g/m^2) was recorded for 86% of the macroalgal patches, with high biomass (>500g/m^2) comprising just 2% of the intertidal area and ranging from 580g/m^2 to 3000g/m^2 (mean 1507g/m^2). The high biomass patches were associated with dense patches of *Ulva spp.* or entrained *Gracilaria*. Entrained *Gracilaria* was most common in the small channels toward the north-west corner, but scarce in the main body of the estuary with only a few small (<5m^2) patches recorded between Rabbit Island and the western estuary margin.

Mixed macroalgal species (top), dense patch of *Ulva spp.* in the seagrass beds (middle) and macroalgae on the channel margins (bottom)

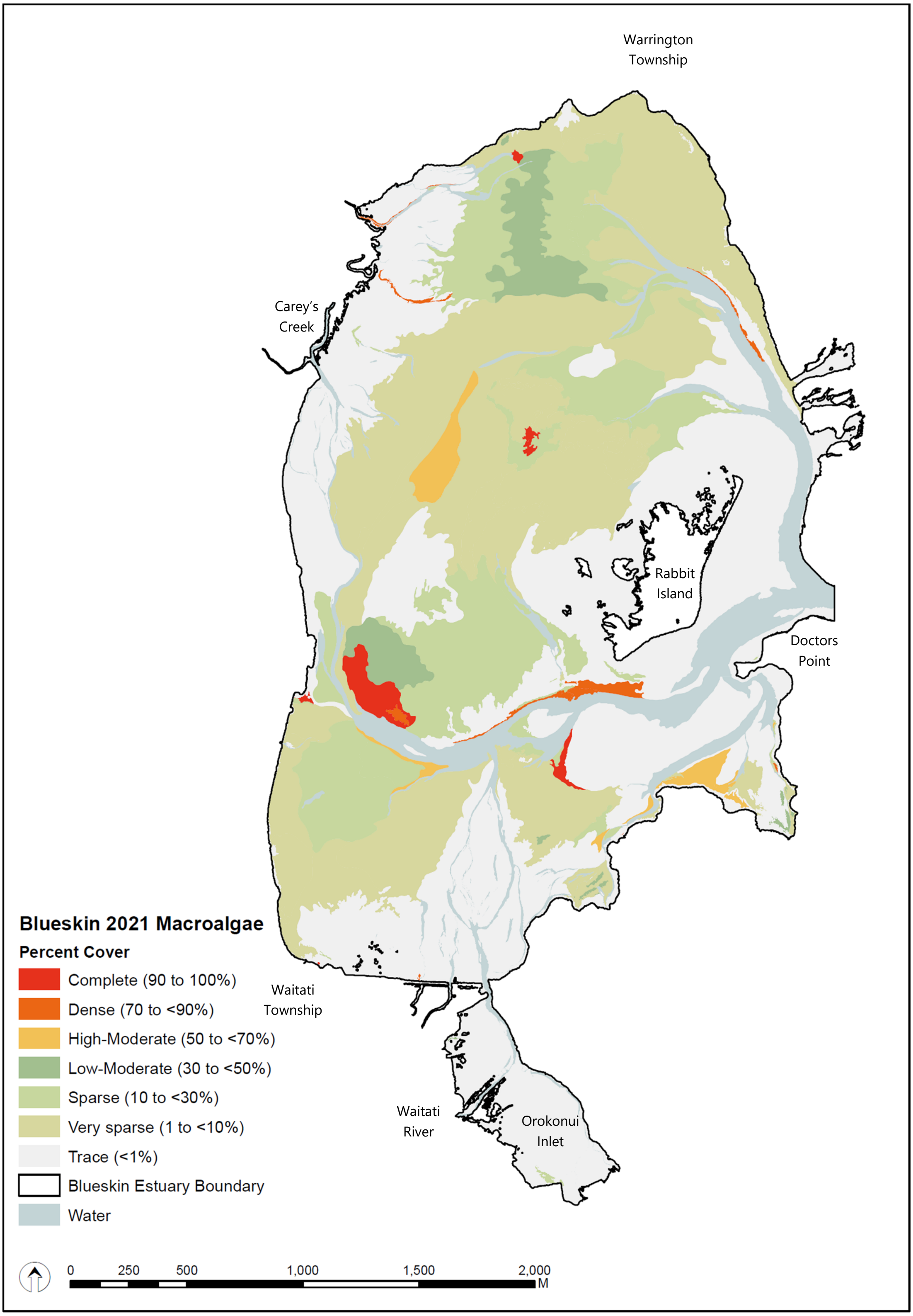


Fig 5. Distribution and percentage classes of macroalgae, Blueskin Bay 2021.

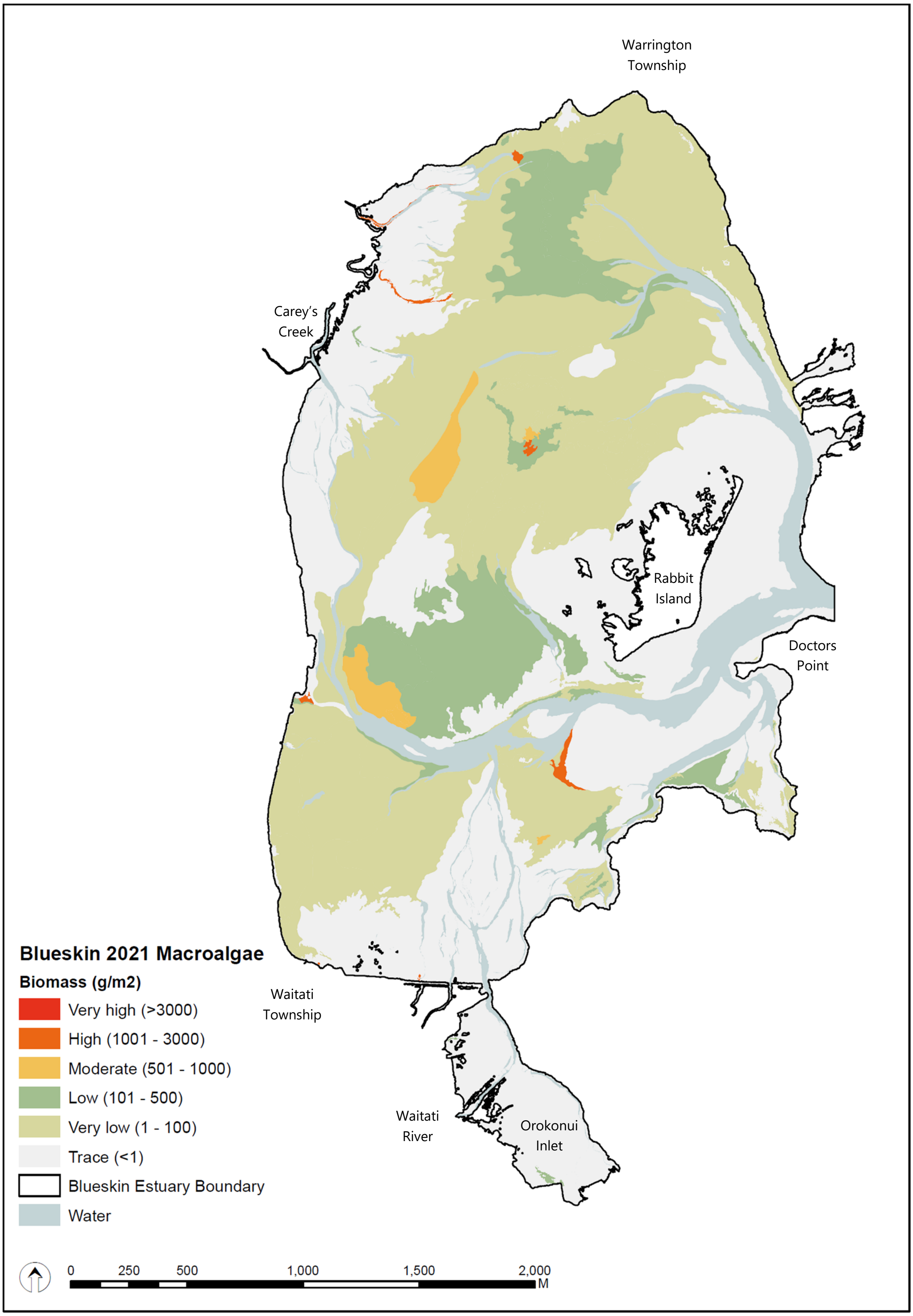


Fig 6. Biomass (wet weight g/m^2) classes of macroalgae, Blueskin Bay January 2021.

While *Ulva spp.* and *Gracilaria chilensis* were the dominant algae present, other species were also abundant including *Ceramium spp.* and *Tinocladia novae-zealandia*.

Sample of *Ceramium sp* collected in Blueskin Bay and *Tinocladia novae-zealandia* in situ, January 2021

The OMBT input metrics and overall EQR score for Blueskin Bay in January 2021 are shown in Table 6. The overall EQR was 0.711 which equates to a rating of 'good' according to the Table 3 criteria. The OMBT approach rates increased macroalgal prevalence, biomass and entrainment as undesirable because the tool is designed to track changes in systems degraded by nutrient enrichment that experience blooms of opportunistic species. The EQR score and rating reflect that a large proportion of the macroalgae recorded in Blueskin Bay was low cover and low biomass growths associated with clean firm sands, with only a small area associated with poor sediment conditions.

Sparse macroalgae (top) and dense cover (bottom) on clean firm sands

Table 6. Summary of OMBT metrics and calculation of overall macroalgal ecological quality rating (EQR) for Blueskin Bay January 2021.

Metric	Face Value	FEDS	Environmental Quality Status
% cover in AIH	8.1	0.738	Good
Biomass per m^2 AIH	62.7	0.875	High
Biomass per m^2 AA	110.1	0.780	Good
% entrained in AA	0.172	0.966	High
Worst of AA (ha) and AA (% of AIH)		0.196	Bad
AA (ha)	355.8	0.196	Bad
AA (% of AIH)	56.9	0.345	Poor
Survey EQR		0.711	Good

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

3.1.4 High enrichment conditions

High Enrichment Conditions (HECs) for the purposes of the current report comprise mud-dominated sediments (>50% mud content) with macroalgal cover >50% that is entrained (growing >30mm deep) within the sediment. These areas will displace sensitive estuarine animals and shellfish, and sediment anoxia can lead to the release of previously bound nutrients.

In Blueskin Bay, HEC areas were concentrated along the margins of small stream inputs on the northwest side of the estuary making up an area of 0.6ha or 0.1% of the intertidal area (Table 7 and Fig 7). There is clear deposition of fine sediments from the small stream inputs, likely exacerbated by salt marsh erosion along the channel margins. Established beds of entrained (*Gracilaria* are present (see photos). While the area of HEC is small compared to the size of the estuary, the presence of HECs indicate that parts of the estuary have exceeded their assimilative capacity. Further expansion of these areas can result in adverse ecological outcomes in the affected areas.

Established beds of *Gracilaria* on the channel margins with drift Ulva sp. on the surface (top and bottom)

Table 7. Summary of High Enrichment Condition (HEC) areas as a percentage of intertidal area, Blueskin Bay, January 2021.

	ha	%
High Enrichment Conditions (HEC)	0.6	0.1

HEC and eroding salt marsh on channel margins

Sediments in HEC areas are poorly oxygenated (shallow aRPD), black and sulfidic (rotten egg smell) when disturbed

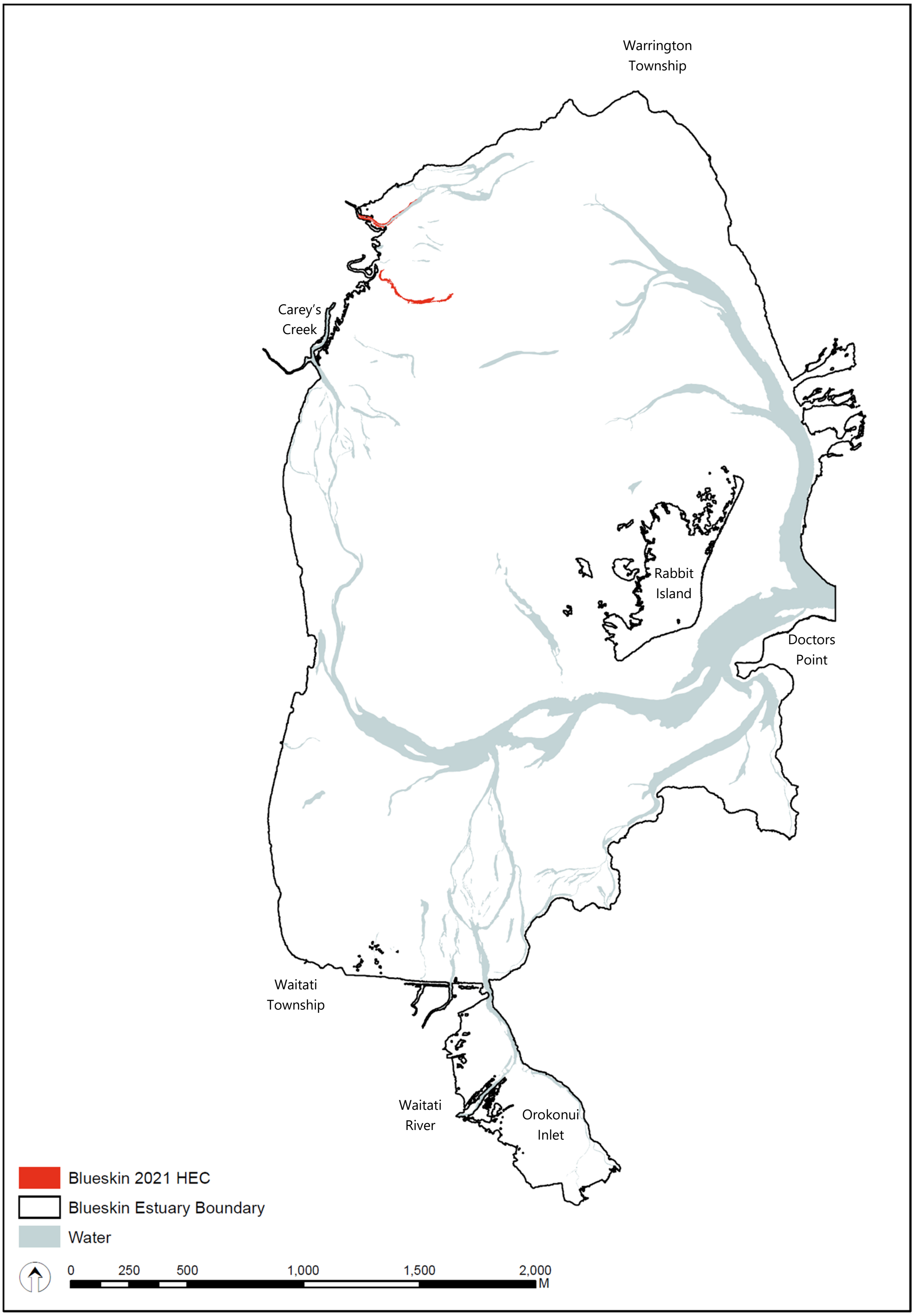


Fig 7. Areas of High Enrichment Conditions (HEC), Blueskin Bay January 2021.

3.1.5 Seagrass

Table 8 summarises the seagrass percent cover for Blueskin Bay in January 2021, with mapped seagrass cover presented in Fig 8.

Table 8. Summary of intertidal seagrass cover, Blueskin Bay January 2021.

Percent Cover Category	ha	%
Trace (<1%)	592.2	94.7
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	0.6	0.1
Low-Moderate (30 to <50%)	6.5	1.0
High-Moderate (50 to <70%)	0.1	0.0
Dense (70 to <90%)	26.0	4.1
Complete (>90%)	0.3	0.0
Total	625.6	100

Seagrass made up 33ha; 5.2%, of the intertidal area. The largest area was located in the middle of the estuary northwest of Rabbit Island. Dense (70 to <90% cover) made up 26.0ha; 4.1%, of the intertidal area. While there were some patches of drift algae covering seagrass, particularly around the margins, the beds appeared healthy overall. Historical imagery indicates seagrass beds have been in approximately in the same location since at least 1956 (Imagery source Retrolens). A small patch of seagrass remains in the north-east corner of the estuary that appeared to have diminished from its historical extent. Vehicle tracks were evident in this area (see photo).

Seagrass, Blueskin Bay January 2021

Seagrass beds looking toward Rabbit Island (top) and north (bottom), Blueskin Bay

Drift *Ulva spp*. and other macroalgae deposited on surface of seagrass

Motorbike tracks through the seagrass beds

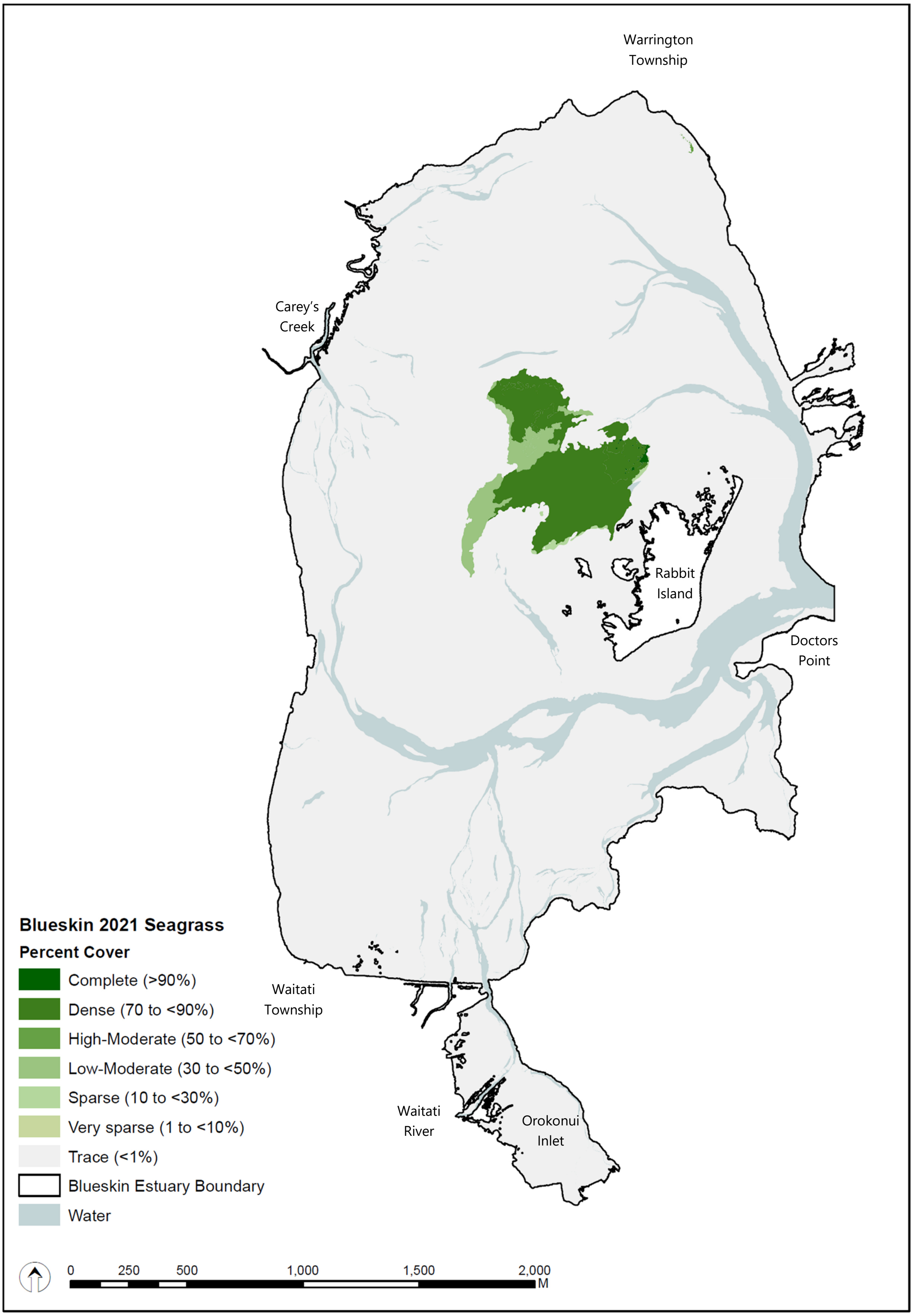


Fig 8. Distribution and percentage cover classes of seagrass, Blueskin Bay January 2021.

3.1.6 Salt marsh

Table 9 summarises intertidal salt marsh cover with the mapped distribution for January 2021 in Fig 9. Dominant and subdominant species are recorded in Appendix 8.

Table 9. Summary of salt marsh area (ha and %) in Blueskin Bay, January 2021.

Subclass	Ha	%
Estuarine Shrub	0.8	2.4
Tussockland	0.02	0.1
Sedgeland	0.04	0.1
Grassland	13.6	38.3
Rushland	1.8	5.0
Herbfield	19.2	54.1
Total	35.4	100

The area of salt marsh recorded in Blueskin Bay in January 2021 was 35.4ha representing 5.7% of the intertidal area (Table 9). The most extensive areas of salt marsh were located north of Carey's Creek, Rabbit Island, Orokonui Inlet and the outflow of Waitati River.

Herbfield made up the largest area of salt marsh, 19.2ha or 54.1% of the salt marsh area recorded. The dominant herbfield species *Sarcocornia quinqueflora* (Glasswort; see photos) and sub-dominant species were *Selliera radicans* (Remuremu), *Samolus repens* (Primrose) and *Suaeda novaezelandiae* (Sea blite).

Sarcocornia quinqueflora (glasswort; top left), *Selliera radicans* (Remuremu; top right), *Suaeda novaezelandiae* (Sea blite; bottom left) and *Samolus repens* (Primrose; bottom right)

The introduced salt-tolerant grass species *Festuca arundinacea* (Tall fescue) was widespread in saltmarsh areas comprising 38.3%; 13.6ha, and being particularly prominent in Orokonui Inlet.

Orokonui Inlet, tall fescue *(Festuca arundinacea)* growing in the upper tidal range above glasswort *(Sarcocornia quinqueflora)*

Tall fescue *(Festuca arundinacea)* near Waitati River outflow

Rushland was only found in the upper intertidal range and represented a small area (1.8ha) It comprised a mix of *Apodasmia similis* (Jointed wirerush), *Ficinia (Isolepis) nodosa* (Knobby clubrush) and *Juncus gerardii* (Salt marsh rush). The largest areas of rushland were localised to sheltered parts of the estuary in Orokonui Inlet and north of Rabbit Island. Sedgeland, tussockland and estuarine scrub were limited to remnant patches.

Jointed wirerush (*Apodasmia similis*) in Orokonui Inlet

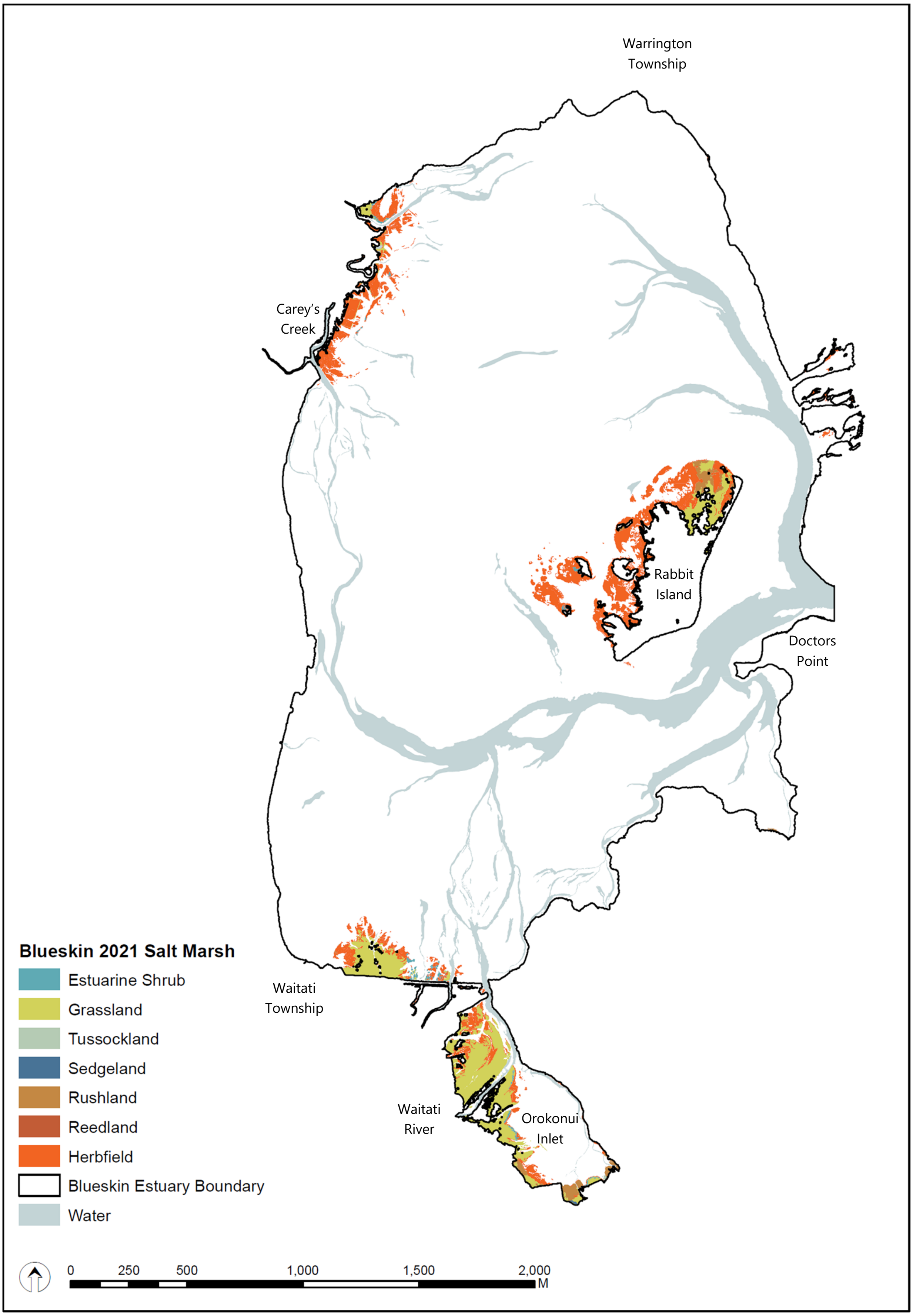


Fig 9. Map of salt marsh habitat, Blueskin Bay January 2021.

Salt marsh on Rabbit Island

Historically salt marsh was likely much more extensive in Blueskin Bay; however, modification of the estuary has limited its habitat, particularly along the western margin where artificial rock wall has been established to protect rail and roading infrastructure. The remaining salt marsh is under threat. North of Carey's Creek and the outflow of Waitati River showed signs of erosion, potentially influenced by scouring in higher freshwater flows or wind driven wave action. Areas of salt marsh adjacent to private land were fenced for an alternate land use. These areas where salt marsh remains, although currently degraded, would be suitable areas to focus protection and restoration efforts.

Salt marsh and estuary margin in 1956 (left; image source Retrolens) and 2021 (right; image source Google Earth) in the northwest of Blueskin Bay. Images show reclamation for roading infrastructure and pasture.

Eroding salt marsh north of Carey's Creek (top) and the outflow of Waitati River (bottom)

Remnant salt marsh on Western margin

Fencing through salt marsh habitat Orokonui Inlet (top) and north of Carey's Creek (bottom)

3.1.7 Terrestrial margin

The results of the 200m terrestrial margin mapping are presented in Table 10 and Fig. 10. Most of the 200m terrestrial margin has been modified and comprises the settlements at Warrington and Waitati (20.2%), and extensive areas of low producing grassland (33.8%).

Although it comprises a small area overall (4.4%), transport infrastructure is a prominent feature on the western margin and has a large relative impact with artificial rock walls disconnecting historic salt marsh and interrupting natural drainage connected to the estuary.

Remanent patches of broadleaved indigenous hardwoods are scattered around the margin (21.4%) mixed with exotic forest (7.3%). A sand dune system is located north of the estuary entrance along the spit, predominantly comprised of marram grass (*Ammophila arenaria*). On occasion seawater overtops the dune and directly enters the estuary (see photo and Fig. 10).

Table 10. Summary of 200m terrestrial margin land cover, Blueskin Bay 2021.

LCDB Class	Ha	%
1 Built-up Area (settlement)	69.6	20.2
2 Urban Parkland/Open Space	6.7	2.0
5 Transport Infrastructure	15.2	4.4
10 Sand and Gravel	23.3	6.8
20 Lake or Pond	3.3	1.0
21 River	0.4	0.1
33 Orchard Vineyard/ Perennial Crops	0.4	0.1
41 Low Producing Grassland	116.5	33.8
45 Herbaceous Freshwater Vegetation	0.4	0.1
46 Herbaceous Saline Vegetation	0.01	0.0
47 Flaxland	0.3	0.1
50 Fernland	0.1	0.0
51 Gorse and/or Broom	9.5	2.7
52 Manuka and/or Kanuka	0.01	0.0
54 Broadleaved Indigenous Hardwoods	73.7	21.4
56 Mixed Exotic Shrubland	0.1	0.0
69 Indigenous Forest	0.01	0.0
71 Exotic Forest	25.2	7.3
Grand Total	344.8	100
Total dense vegetated margin (LCDB classes 45-71)	109.3	31.7

Artificial rock walls for rail infrastructure on the western margins

Mixed indigenous and exotic forest

Sand dunes on the spit north of the estuary entrance, the depression in the dunes connects the estuary to the sea on occasion

As noted in Section 1.1, the upper catchment (Fig. 2) is densely vegetated (62%) and the mid to lower catchment dominated by high producing pasture (28%; Table 1). Most catchment nutrient and sediment inputs to the estuary likely originate in the lower catchment where yields from the land uses present are relatively high and land disturbance is more prominent.

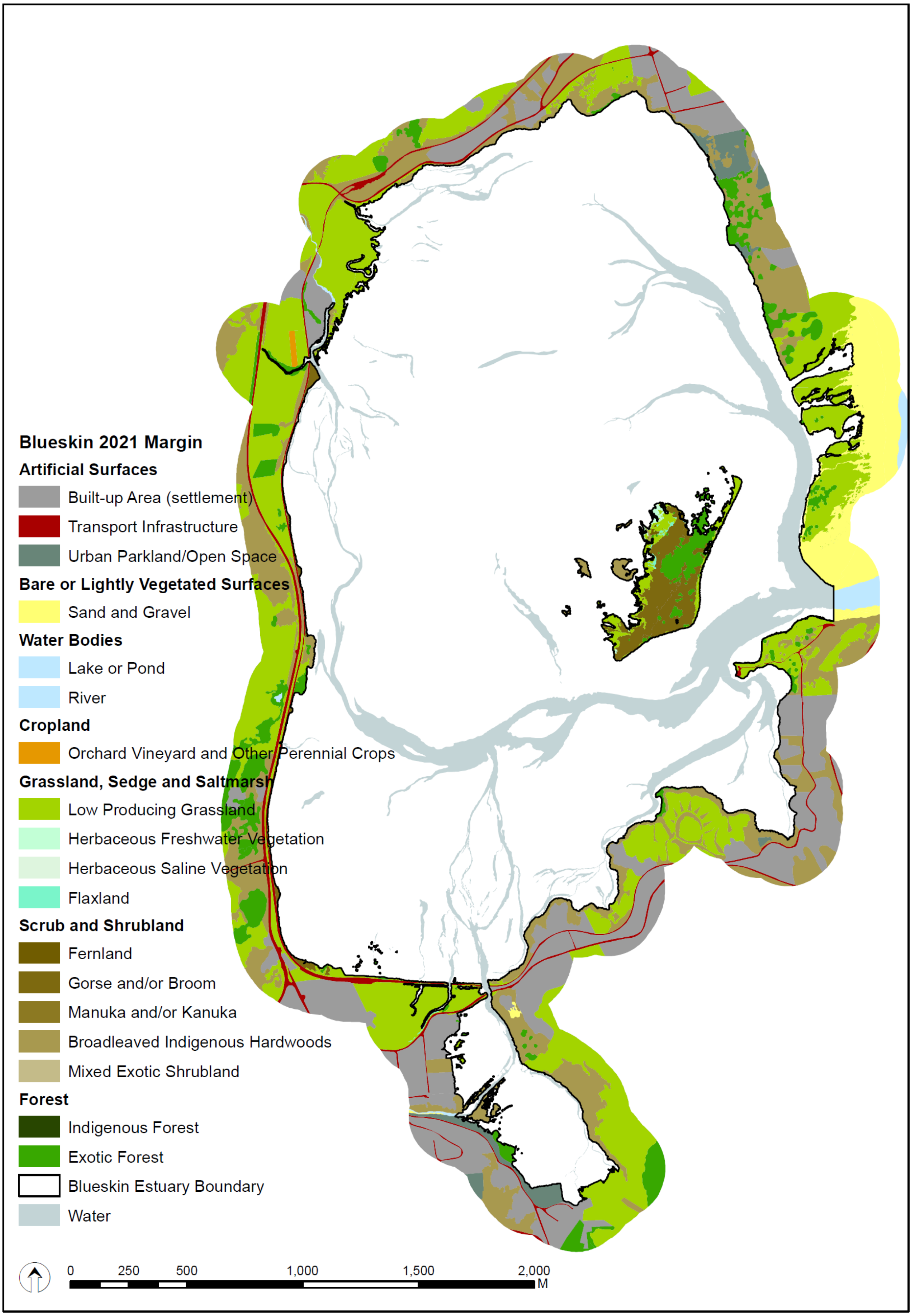


Fig. 10. Map of 200m terrestrial margin land cover, Blueskin Bay (LCDB5 2017/18).

4. KEY FINDINGS

4.1 BROADSCALE HABITAT MAPPING

The dominant features assessed as part of broad scale habitat mapping of Blueskin Bay carried out between 12th to 15th January 2021 are summarised in Table 11. Key broad scale indicator results and ratings are presented in Table 12 and additional supporting data used to assess estuary condition are presented in Table 13.

Table 11. Summary of dominant broad scale features as a percentage of total estuary or margin area, Blueskin Bay 2021.

a. Area summary	ha	% Estuary
Intertidal area	625.6	91.0
Subtidal area	62.2	9.0
Total estuary area	687.8	100

b. Key substrate features	ha	% Estuary
Mud-enriched sediment (25 to <50%)	8.7	1.3
Mud-dominated sediment (≥50%)	25.2	3.7

c. Key habitat features	ha	% Estuary
Salt marsh	35.4	5.2
Seagrass (≥50% cover)	26.3	3.8
Macroalgal beds (≥50% cover)	18.7	2.7

d. Terrestrial margin (200m)	ha	% Margin
200m densely vegetated margin	109.3	31.7
Total area of terrestrial margin	344.8	-

Overall Blueskin Bay is in good condition and supports a variety of habitat types (salt marsh, seagrass and shell) and associated biological communities. With regard to preliminary rating criteria for assessing estuary health, the extent of salt marsh and the percentage of densely vegetated 200m terrestrial margin were rated 'fair'. The area of mud dominated sediments was rated 'good' and other eutrophic indicators (macroalgae and HEC) were rated 'good' to 'very good' (Table 12). The good condition of the estuary reflects low catchment nutrient and sediment loads (Table 13) and almost complete flushing on each tidal cycle (O'Connell-Milne et al. 2020).

Shellbanks in the lower estuary (top) and seagrass in the middle of the estuary (bottom)

Table 12. Summary of key broad scale indicator results and ratings.

Broadscale Indicators	Unit	Value	2021
Mud-dominated substrate	% of intertidal area >50% mud	4.0	Good
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	0.71	Good
Seagrass	% decrease from baseline	-	2021 baseline established
Salt marsh extent (current)	% of intertidal area	5.7	Fair
Historical salt marsh extent	% of historical remaining	50*	Fair
200m terrestrial margin	% densely vegetated	31.7	Fair
High Enrichment Conditions	ha	0.6	Good
High Enrichment Conditions	% of estuary	0.1	Very Good
Sedimentation rate*	CSR:NSR ratio	2.5	Fair
Sedimentation rate*	mm/yr	0.5	Good

Dash represents no data. Colour bandings are reported in Table 3. OMBT = Opportunistic Macroalgal Blooming Tool. *Estimated Value

Seagrass (*Zostera muelleri*) is an important habitat in estuaries because it is a food source and habitat for fish, birds and macroinvertebrates. Seagrass can also influence water quality by trapping fine sediments, stablising the substrate and filtering nutrients from the water column. Seagrass was a prominent feature in Blueskin Bay and historic imagery indicates the main beds in the middle of the estuary have been reasonably stable since, at least, 1956. Likely reasons for the extensive seagrass presence are relatively low catchment sediment and nutrient inputs to the estuary, sand-dominated sediments and extensive flushing with clean seawater (maintaining high water clarity), and protection of the beds from wave action and strong currents by Rabbit Island. Healthy and stable seagrass beds are a common feature in estuaries in good condition.

While only small in area, there were some signs of localised eutrophication observed in the estuary in January 2021. This comprised a small area of HEC located in the northwest and a patch of microalgae and low sediment oxygenation was present on the sandflats in the middle of the estuary. The presence of such conditions indicates localised nutrient inputs are sufficient to cause sediment degradation and organic enrichment and should be monitored to ensure potential sources are appropriately managed and eutrophic conditions do not worsen or expand.

Mud-dominated sediments only made up a small proportion of the intertidal area (3.7%; Fig. 4, Appendix 6) and were localised around freshwater inflows, within salt marsh and in backwaters such as the Orokonui Inlet to the south and the small embayment near Doctor's Point Reserve near the entrance. In general, these muddy areas had relatively poor sediment oxygenation.

NIWA's national estuary sediment load estimator (Hicks et al., 2019) was used to predict sediment inputs and retention, and calculate a net deposition rate for the estuary. The estuary is predicted to be highly efficient at trapping sediment (97% retention) and if all of the retained sediment was spread evenly throughout the estuary it would result in an overall average of ~0.5mm/y of estuary infilling (Table 13), a condition rating of 'Good' (Table 3).

Based on the relative difference in estimated yields from an undisturbed catchment, and assuming a further 50% attenuation from the historical presence of wetlands, the current sedimentation rate (CSR) is estimated to be 2.5 times the natural sedimentation rate (NSR). The condition rating for the CSR:NSR ratio is 'fair' (Table 3). These sedimentation rate results, and the widespread presence of sand-dominated sediments in the estuary, indicate fine sediment issues are currently not a significant concern in the estuary.

Mapping the eastern side of Blueskin Bay

Table 13. Supporting data used to assess estuary ecological condition.

Supporting Condition Measure	Value
Mean freshwater flow (m^3/s)[1]	0.8
Catchment Area (Ha)[1]	9277
Catchment nitrogen load (TN/yr)[2]	25.5
Catchment phosphorus load (TP/yr)[2]	4.0
Catchment sediment load (KT/yr)[1]	4.9
Estimated N areal load in estuary (mg/m^2/d)[2]	10
Estimated P areal load in estuary (mg/m^2/d)[2]	2
CSR:NSR ratio[1]	1.3
CSR:NSR with 50% natural wetland attenuation	2.5
Trap efficiency (sediment retained in estuary)[1]	97%
Estimated rate of sed. trapped in estuary (mm/yr)[1]	0.5

[1]Hicks et al. 2019.
[2]CLUES version 10.3, Run date: May 2021

The most significant issues identified in Blueskin Bay were the historical loss of salt marsh habitat and modification in the 200m terrestrial margin. Modification of the estuary margin for roading and rail infrastructure, in addition to drainage of salt marsh for pasture, have disrupted the natural connectivity between the land and the estuary. These changes have created barriers which will limit the capacity of estuarine species, particularly salt marsh, to respond and adapt to predicted sea level rise, inevitably leading to further losses in future. Salt marsh provide important ecosystem services by trapping sediment and stablising estuary margins, filtering nutrients and providing habitat and nesting areas for birds and other organisms. There is significant potential for salt marsh protection and restoration in Blueskin Bay (e.g. replanting salt marsh, improving tidal flushing and removing barriers to salt marsh expansion).

5. RECOMMENDATIONS

Overall Blueskin Bay represents an estuary in good health, with high value seagrass and cockle beds present. This is attributable to a combination of small freshwater inflows, high tidal flushing, and catchment sediment and nutrient loads that the estuary is currently able to assimilate.

However, on top of historic losses, threats to current salt marsh habitat are a cause for concern. Furthermore, localised areas of eutrophication close to freshwater inflows should be explored to identify potential nutrient sources and ensure they are appropriately managed so eutrophic conditions do not worsen or expand. Based on the findings it is recommended that ORC consider the following:

1. Repeat the broad scale habitat mapping 5 yearly to track long term changes in estuary condition.
2. Protect and enhance existing salt marsh to prevent further losses and consider restoration in areas of suitable habitat.
3. Review historic imagery to assess changes in important habitats over time (e.g. seagrass and salt marsh).
4. Include Blueskin Bay in the ORC limit setting programme and establish limits for catchment sediment and nutrient inputs that will protect the estuary from degradation.

Mapping the eastern margin near the estuary entrance

Blueskin Bay seagrass beds in the center of the estuary

Blueskin Bay salt marsh habitat

Sea lion roaming around the eastern margin of the estuary

Entrance of Waitati River to the estuary, remnant patch of saltmarsh

6. REFERENCES CITED

Brownstein G, Wilson JB, Buritt DJ. 2013. Waterlogging tolerance on a New Zealand saltmarsh, Journal of Experimental Marine Biology and Ecology 446, 202–208.

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

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.

Kainamu AA. 2010. The fishery trend and feeding capacity of the New Zealand Littleneck Clam, Austrovenus stutchburyi, in a southern New Zealand inlet. A thesis submitted for the degree of Masters of Science (Marine Science) At the University of Otago, Dunedin New Zealand.

Leduc D, Probert PK, Frew RD, Hurd CL. 2006. Macroinvertebrate diet in intertidal seagrass and sandflat communities: a study using C, N, and S stable isotopes, New Zealand Journal of Marine and Freshwater Research 40, 615-629

Moore M. 2015. Appendix 3: Dunedin City Coastal Section Natural Landscape Units and Natural Features identified for assessment In: Coastal Environment of Otago Natural Character and Outstanding Natural Features and Landscapes Assessment Clutha District Section Report. Prepared for Otago Regional Council. p77.

O'Connell-Milne SA, Wing SR, Suanda SH, Udy JA, Durante LM, Salmond NH, Wing LC. 2020. Interactions between bivalve filter feeding and oceanographic forcing drive the fluxes of organic matter and nutrients at an estuarine–coastal interface, Marine Ecology Progress Series, 655, 29-42.

Otis M, Schallenberg M. 2020. Nitrogen load estimates to Blueskin Bay from sewage disposal, Report prepared for Otago Regional Council by Southern Lakes Lab, Report number 2020/01.

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

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

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

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

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

Stevens LM, Scott-Simmonds T, Forrest BM. 2020. Broad Scale Intertidal Habitat Mapping of Freshwater Estuary. Salt Ecology Report 051, prepared for Environment Southland, October 2020. 45p.

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

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

Zhang M. 2018. The relative importance of pelagic and benthic primary production for Austrovenus stutchburyi in Blueskin Bay in the South Island, New Zealand. A thesis submitted for the degree of Masters of Science (Marine Science) University of Otago Dunedin, New Zealand.

APPENDICES

Appendix 1. Broadscale Habitat Classification Definitions

Estuary vegetation was classified using an interpretation of the Atkinson (1985) system described in the NEMP (Robertson et al. 2002) with minor modifications as listed.

Revised substrate classes were developed by Salt Ecology to more accurately classify fine unconsolidated substrate.

Terrestrial margin vegetation was classified using the field codes included in the Landcare Research Land Cover Database (LCDB5) - see following page.

VEGETATION (mapped separately to the substrates they overlie and ordered where commonly found from the upper to lower tidal range).

Estuarine shrubland: Cover of estuarine shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh (density at breast height).

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

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

Grassland[1]: Grass cover (excluding tussock-grasses) is 20-100% and exceeds that of any other growth form or bare ground.

Introduced weeds[1]: Introduced weed cover is 20-100% and exceeds that of any other growth form or bare ground.

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

Lichenfield: Lichen cover is 20-100% and exceeds that of any other growth form or bare ground.

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

Rushland: Rush cover (excluding tussock-rushes) is 20-100% and exceeds that of any other growth form or bare ground. A tall grass-like, often hollow-stemmed plant. Includes some species of *Juncus* and all species of *Apodasmia (Leptocarpus)*.

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

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

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

Note NEMP classes of Forest and Scrub are considered terrestrial and have been included in the terrestrial Land Cover Data Base (LCDB) classifications.

[1] Additions to the NEMP classification.

SUBSTRATE (physical and zoogenic habitat)

Sediment texture is subjectively classified as: firm if you sink 0-2 cm, soft if you sink 2-5cm, very soft if you sink >5cm, or mobile - characterised by a rippled surface layer.

Artificial substrate: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates. Commonly sub-grouped into artificial: substrates (seawalls, bunds etc), boulder, cobble, gravel, or sand.

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

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

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

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

Sand: Granular beach sand with a low mud content 0-10%. No conspicuous fines evident when sediment is disturbed.

Sand/Shell: Granular beach sand and shell with a low mud content 0-10%. No conspicuous fines evident.

Muddy sand (Moderate mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >10-25%). Granular when rubbed between the fingers, but with a smoother consistency than sand with a low mud fraction. Generally firm to walk on.

Muddy sand (HIgh mud content): Sand/mud mixture dominated by sand, but has an elevated mud fraction (i.e. >25-50%). Granular when rubbed between the fingers, but with a much smoother consistency than muddy sand with a moderate mud fraction. Often soft to walk on.

Sandy mud (Very high mud content): Mud/sand mixture dominated by mud (i.e. >50%-90% mud). Sediment rubbed between the fingers is primarily smooth/silken but retains a granular component. Sediments generally very soft and only firm if dried out or another component, e.g. gravel, prevents sinking.

Mud (>90% mud content): Mud dominated substrate (i.e. >90% mud). Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out or another component, e.g. gravel, prevents sinking.

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

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

Shell bank: Area that is dominated by dead shells

Table of modified NEMP substrate classes and list of Landcare Land Cover Database (LCDB5) classes.

Consolidated substrate			Code
Bedrock		Rock field "solid bedrock"	RF
Coarse Unconsolidated Substrate (>2mm)			
Boulder/ Cobble/ Gravel	>256mm to 4.096m	Boulder field "bigger than your head"	BF
	64 to <256mm	Cobble field "hand to head sized"	CF
	2 to <64mm	Gravel field "smaller than palm of hand"	GF
	2 to <64mm	Shell "smaller than palm of hand"	Shel
Fine Unconsolidated Substrate (<2mm)			
Sand (S)	Low mud (0-10%)	Firm shell/sand	fSS
		Mobile sand	mS
		Firm sand	fS
		Soft sand	sS
Muddy Sand (MS)	Moderate mud (>10-25%)	Firm muddy shell/sand	fSS10
		Mobile muddy sand	mMS10
		Firm muddy sand	fMS10
		Soft muddy sand	sMS10
	High mud (>25-50%)	Firm muddy shell/sand	fSS25
		Mobile muddy sand	mMS25
		Firm muddy sand	fMS25
		Soft muddy sand	sMS25
Sandy Mud (SM)	Very high mud (>50-90%)	Firm sandy mud	fSM
		Soft sandy mud	sSM
		Very soft sandy mud	vsSM
Mud (M)	Mud (>90%)	Firm mud	fM90
		Soft or very soft mud	sM90
Zootic (living)			
		Cocklebed	CKLE
		Mussel reef	MUSS
		Oyster reef	OYST
		Sabellid field	TUBE
Artifical Substrate			
		Substrate (brg, bund, ramp, walk, wall, whf)	aS
		Boulder field	aBF
		Cobble field	aCF
		Gravel field	aGF
		Sand field	aSF

Artificial Surfaces
1 Built-up Area (settlement)
2 Urban ParklandOpen Space
5 Transport Infrastructure
6 Surface Mines and Dumps

Bare or Lightly Vegetated Surfaces
10 Sand and Gravel
12 Landslide
14 Permanent Snow and Ice
15 Alpine Grass/Herbfield
16 Gravel and Rock

Water Bodies
20 Lake or Pond
21 River

Cropland
30 Short-rotation Cropland
33 Orchard Vineyard & Other Perennial Crops

Grassland, Sedge and Saltmarsh
40 High Producing Exotic Grassland
41 Low Producing Grassland
43 Tall-Tussock Grassland
44 Depleted Grassland
45 Herbaceous Freshwater Vegetation
46 Herbaceous Saline Vegetation

Scrub and Shrubland
47 Flaxland
50 Fernland
51 Gorse and/or Broom
52 Manuka and/or Kanuka
54 Broadleaved Indigenous Hardwoods
55 Sub Alpine Shrubland
56 Mixed Exotic Shrubland
58 Matagouri or Grey Scrub

Forest
64 Forest - Harvested
68 Deciduous Hardwoods
69 Indigenous Forest
71 Exotic Forest

Appendix 2. Opportunistic Macroalgal Blooming Tool

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

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

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

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

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

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

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

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded. For quality assurance of the percentage cover estimates, two independent readings should be within ±5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

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

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

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

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

Timing

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

Suitable Locations

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

Derivation of Threshold Values

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A1).

Reference Thresholds

A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning. The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g m^{-2} wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.

Class Thresholds for Percent Cover

High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.

Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).

Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).

Class Thresholds for Biomass

Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 g.m^{-2} wet weight was an acceptable level above the reference level of <100 g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500 g.m^{-2} represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 g.m^{-2} but less than 1,000 g.m^{-2} would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).

Thresholds for Entrained Algae

Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously

Table A1. The final face value thresholds and metrics for levels of the ecological quality status.

ECOLOGICAL QUALITY RATING (EQR)	High	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)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^2) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^2) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

EQR calculation

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

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

The EQR calculation process is as follows:

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

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

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

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

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

Table A2 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range. Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.

The final EQR score is calculated as the average of equidistant metric scores.

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

Users have a choice to either use default (European) thresholds or define thresholds specific to local conditions. Plew et al. (2020) describe how OMBT biomass thresholds were lowered for use in New Zealand based on unpublished data from >25 shallow well-flushed intertidal New Zealand estuaries (Robertson et al. 2016b) and the results from similar estuaries in California. Sutula et al. (2014) reported that in eight Californian estuaries, a macroalgal biomass of 1450g/m^2 wet weight, total organic carbon of 1.1% and sediment total nitrogen of 0.1%, were thresholds associated with anoxic conditions near the surface (aRPD <10mm). Green et al. (2014) reported significant and rapid negative effects on benthic invertebrate abundance and species richness at macroalgal abundances as low as 840-930 g/m^2 wet weight in two Californian estuaries. McLaughlan et al. (2013) reviewed Californian biomass thresholds and found the elimination of surface deposit feeders in the range of 700-800g/m^2 wet weight. As the Californian results were consistent with New Zealand findings, the latter thresholds were used to lower the OMBT good/moderate threshold from ≤500 to ≤200 g/m^2, the moderate/poor threshold from ≤1000 to ≤500, and the poor/bad threshold from >3000 to >1450 g/m^2. These thresholds (Table A3) are considered to provide an early warning of nutrient related impacts in New Zealand prior to the establishment of adverse enrichment conditions that are likely difficult to reverse.

Table A2. Values for the normalisation and re-scaling of face values to EQR metric.

Metric	Quality status	Face value ranges			Equidistant class range values		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.99	≥0.2	<0.4	0.2
	Bad	100	>75	24.99	0	<0.2	0.2
Average Biomass of AIH (g m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.9	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.9	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g m^{-2})	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.9	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.9	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.99	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.99	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.9	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.99	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.99	≥0.2	<0.4	0.2
	Bad	100	>75	27.99	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.99	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.99	≥0.6	<0.4	0.2
	Bad	100	>50	49.99	1	<0.6	0.2

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

Table A3. The final face value thresholds and metrics for levels of the ecological quality status applied in New Zealand. Note, the face values and normalisation scores in Table A2 are updated to reflect these values in the online UK WFD spreadsheet calculator used to derive EQR scores.

ECOLOGICAL QUALITY RATING (EQR)	High	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)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass ($g.m^2$) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass ($g.m^2$) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

REFERENCES

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

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

Green, L., Sutula, M. and Fong, P. 2014. How much is too much? Identifying benchmarks of adverse effects of macroalgae on the macrofauna in intertidal flats. Ecological Applications 24(2): 300-314.

Hull, S.C., 1987. Macroalgal mats and species abundance: a field experiment. Estuar. Coast. Shelf Sci. 25, 519-532.

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

McLaughlin, K., Sutula, M., Busse, L., Anderson, S., Crooks, J., Dagit, R., Gibson, D., Johnston, K. and Stratton, L. 2013. A regional survey of the extent and magnitude of eutrophication in Mediterranean estuaries of Southern California, USA. Estuaries and Coasts. dx.doi.org/10.1007/s12237-013-96708

Raffaelli, D., Hull, S., Milne, H., 1989. Long-term changes in nutrients, weedmats and shore birds in an estuarine system. Cah. Biol. Mar. 30, 259–270.

Robertson, B.M., Stevens, L.M., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., 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.

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

Sutula, M., Green, L., Cicchetti, G., Detenbeck, N. and Fong, P. 2014. Thresholds of Adverse Effects of Macroalgal Abundance and Sediment Organic Matter on Benthic Habitat Quality in Estuarine Intertidal Flats. Estuaries and Coasts. doi:10.1007/s12237-014-9796-3.

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

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

Appendix 3. Information supporting ratings in the report

Sediment Mud Content

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more sticky and cohesive, and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon, and sediment bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations and, on intertidal flats of estuaries, can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

Apparent Redox Potential Discontinuity (aRPD)

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

The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species. The tendency for sediments to become anoxic is much greater if the sediments are muddy. Anoxic sediments contain toxic sulphides and support very little aquatic life. As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, becomes released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (greater than 3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to less than 1cm (Jørgensen & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

Opportunistic Macroalgae

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

Seagrass

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

REFERENCES

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

Nelson, Walter G. (ed.) 2009. Seagrasses and Protective Criteria: A Review and Assessment of Research Status. Office of Research and Development, National Health and Environmental Effects Research Laboratory, EPA/600/R-09/050.

Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016a, b. NZ Estuary Trophic Index. Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data (47p). Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State (68p). Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420.

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

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

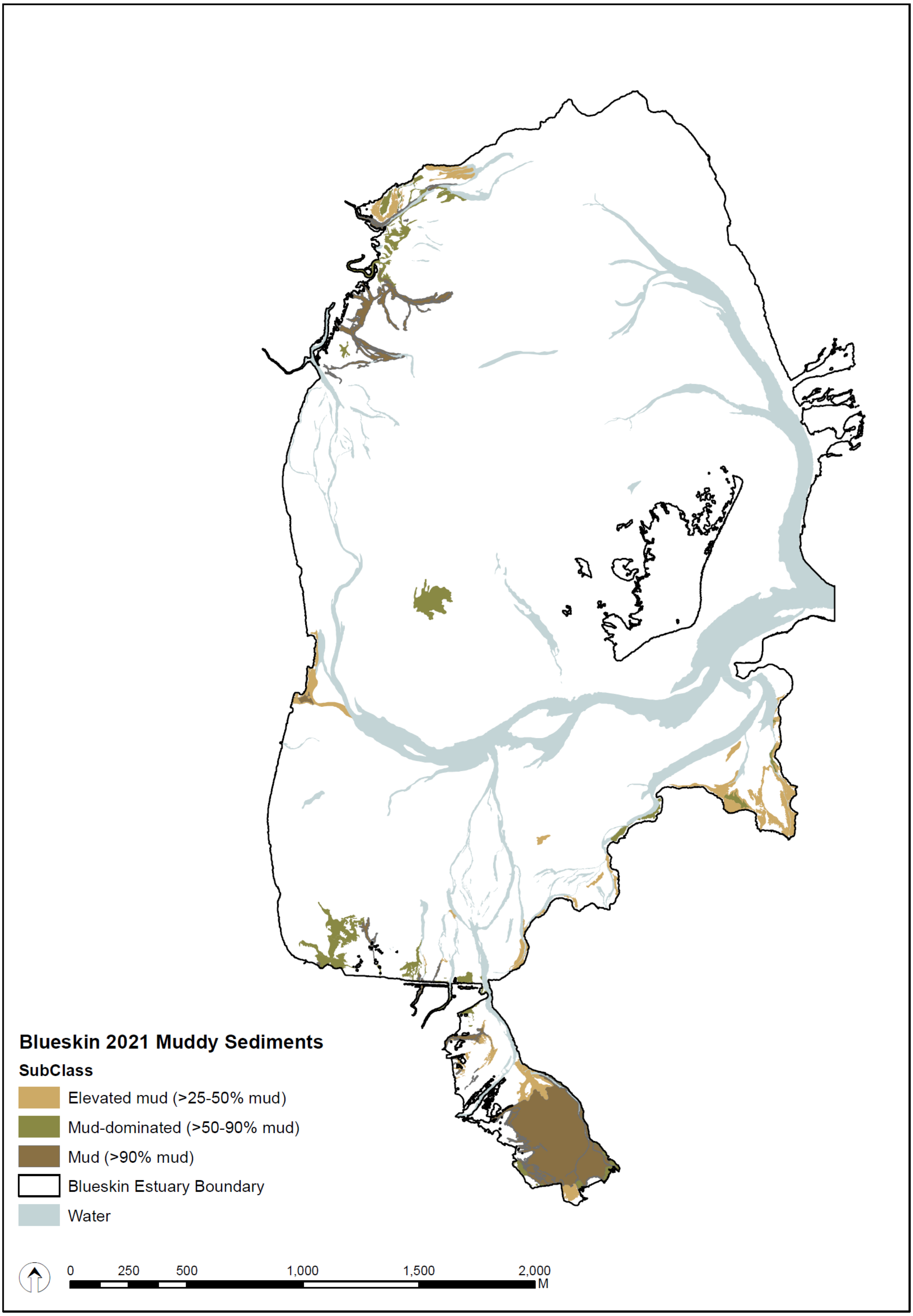
Appendix 4: Macroalgae biomass sites

Appendix 5: Substrate validation

Source	NZTM_E	NZTM_N	Field code	Subjective % mud	% mud	% sand	% gravel
Blue-Otag - FSA	1411514	4933310	fs	≤10	5	94	< 0.1
Blue-Otag - FSB	1411222	4932096	fs	≤10	6	93	2
Blue-Otag - S1	1411614	4931511	sSM	>50 to 90	45	47	8
Blue-Otag - S2	1411427	4931997	fs	≤10	5	95	< 0.1
Blue-Otag - S3	1411258	4399414	fs	≤10	6	94	0.2
Blue-Otag - S4	1412123	4934953	fMS10	>10 to 25	9	90	2
Blue-Otag - S5	1411353	4934538	sM90	>90	79	20	2
Blue-Otag - S6	1411427	4931997	sSM	>50 to 90	38	51	11
Blue-Otag - S7	1412149	4932209	fs	≤10	3	96	0.9
Blue-Otag - S8	1412251	4931693	sMS25	>25 to 50	24	72	3
Blue-Otag - S9	1411723	4931305	vsSM	>50 to 90	39	61	0.4
Blue-Otag - S10	1411240	4931458	sM90	>90	67	26	7
Blue-Otag - S11	1411029	4932680	sMS25	>25 to 50	26	69	6
Blue-Otag - S12	1413046	4932484	sMS10	>10 to 25	16	78	7

Note, >70% of sites measured were within ±5% mud of the subjective mud classification, which is considered very good given the heterogeneity of the sediment substrate within each area. However, four sites were >10% different to the subjective mud classification. These were for sediments subjectively classified in the >50 to 90% mud and >90% mud categories, but which had measured values below this. This can occur where muds have been deposited over sands or gravels. As the grain size sample is collected by scraping the top ~2cm of the sediment surface it can include coarser substrate below a mud-dominated surface layer reducing the overall mud content resulting in it being lower than that apparent at the surface, and on which the mapping classification is based. Photos at the sample sites and the wider area have been reassessed to confirm the classification of substrate type where the validation samples were >10% mud (see example photos below).

Appendix 6. Mud-dominated sediments Blueskin Bay, January 2021



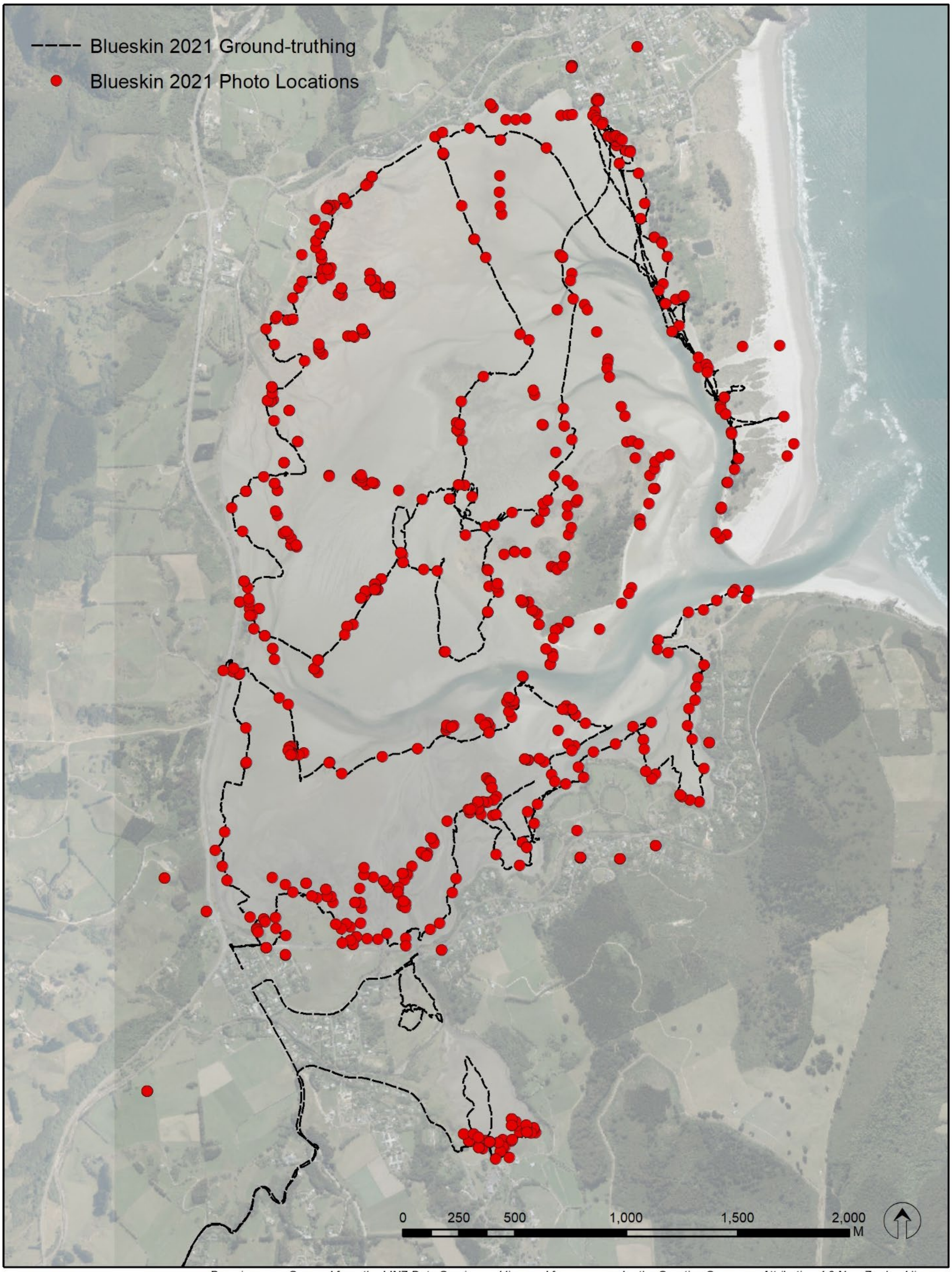
Appendix 7: Grainsize method from RJ Hill Laboratories

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
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	1-4
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	1-4
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	1-4
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-4

Appendix 8. Salt marsh species recorded in Blueskin Bay, 2021

Substrate Class	Dominant species	Subdominant species 1	Subdominant species 2	Ha	%
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood	*Apodasmia similis* (Jointed wirerush)		0.1	0.3
	Plagianthus divaricatus (Salt marsh ribbonwood	*Cortaderia richardii* (Toetoe)		0.0	0.1
	Plagianthus divaricatus (Salt marsh ribbonwood	*Festuca arundinacea* (Tall fescue)		0.1	0.3
	Plagianthus divaricatus (Salt marsh ribbonwood	*Ficinia (Isolepis) nodosa* (Knobby clubrush)		0.1	0.4
	Plagianthus divaricatus (Salt marsh ribbonwood			0.5	1.3
Tussockland	*Puccinella stricta* (Salt grass)			0.0	0.1
Sedgeland	*Cyperus ustulatus* (Giant umbrella sedge)			0.0	0.1
	Schoenoplectus pungens (Three square)			0.0	0.0
Grassland	*Festuca arundinacea* (Tall fescue)	*Ammophila arenaria* (Marram grass)		0.0	0.1
	Festuca arundinacea (Tall fescue)	*Ficinia (Isolepis) nodosa* (Knobby clubrush)	*Phormium tenax* (New Zealand flax)	2.2	6.2
	Festuca arundinacea (Tall fescue)			11.2	31.6
	Festuca arundinacea (Tall fescue)	*Plagianthus divaricatus* (Salt marsh ribbonwood		0.1	0.2
	Festuca arundinacea (Tall fescue)	*Samolus repens* (Primrose)		0.1	0.2
	Festuca arundinacea (Tall fescue)	*Sarcocornia quinqueflora* (Glasswort)		0.0	0.0
Rushland	*Apodasmia similis* (Jointed wirerush)			0.4	1.3
	Apodasmia similis (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood	*Festuca arundinacea* (Tall fescue)	0.4	1.0
	Ficinia (Isolepis) nodosa (Knobby clubrush)	*Festuca arundinacea* (Tall fescue)	*Plagianthus divaricatus* (Salt marsh ribbonwood	0.6	1.6
	Ficinia (Isolepis) nodosa (Knobby clubrush)			0.3	0.8
	Ficinia (Isolepis) nodosa (Knobby clubrush)	*Plagianthus divaricatus* (Salt marsh ribbonwood		0.1	0.2
	Juncus gerardii (Salt marsh rush)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	0.0	0.1
Herbfield	*Cotula coronopifolia* (Bachelor's button)	*Isolepis cernua* (Slender clubrush)		0.4	1.0
	Cotula coronopifolia (Bachelor's button)			0.0	0.1
	Samolus repens (Primrose)			0.2	0.5
	Samolus repens (Primrose)	*Sarcocornia quinqueflora* (Glasswort)		0.3	0.8
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)		0.1	0.2
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	0.0	0.1
	Sarcocornia quinqueflora (Glasswort)			1.0	2.7
	Sarcocornia quinqueflora (Glasswort)	*Samolus repens* (Primrose)	*Leptinella dioica*	0.1	0.2
	Sarcocornia quinqueflora (Glasswort)	*Samolus repens* (Primrose)		1.4	4.0
	Sarcocornia quinqueflora (Glasswort)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	2.7	7.5
	Sarcocornia quinqueflora (Glasswort)	*Selliera radicans* (Remuremu)	*Apium prostratum* (Native celery)	0.1	0.3
	Sarcocornia quinqueflora (Glasswort)	*Selliera radicans* (Remuremu)		1.0	2.9
	Sarcocornia quinqueflora (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	1.2	3.5
	Sarcocornia quinqueflora (Glasswort)	*Selliera radicans* (Remuremu)	*Suaeda novaezelandiae* (Sea blite)	4.9	13.7
	Sarcocornia quinqueflora (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Cotula coronopifolia* (Bachelor's button)	0.7	1.9
	Sarcocornia quinqueflora (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Ficinia (Isolepis) nodosa* (Knobby clubrush)	0.1	0.4
	Sarcocornia quinqueflora (Glasswort)	*Suaeda novaezelandiae* (Sea blite)		0.0	0.1
	Sarcocornia quinqueflora (Glasswort)	*Suaeda novaezelandiae* (Sea blite)	*Selliera radicans* (Remuremu)	0.0	0.1
	Selliera radicans (Remuremu)	*Isolepis cernua* (Slender clubrush)		0.0	0.1
	Selliera radicans (Remuremu)			0.0	0.1
	Selliera radicans (Remuremu)	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	2.6	7.4
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)		0.8	2.2
	Selliera radicans (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	*Samolus repens* (Primrose)	1.6	4.5
			Total	35.4	100.0

Appendix 9. Ground truthing in Blueskin Bay, January 2021



Base imagery: Sourced from the LINZ Data Service and licensed for re-use under the Creative Commons Attribution 4.0 New Zealand licence

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