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ECOLOGICAL ASSESSMENT & REPORTING SERVICES

Broughton and Ohinetaha Bays

Broad Scale Habitat Mapping and Ecological Assessment

For Marlborough District Council

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REPORT INFORMATION & QUALITY CONTROL

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Contents

List of Appendices

List of Tables

List of Figures

Executive Summary

Robertson Environmental Limited has been engaged by Marlborough District Council (MDC) to undertake the baseline broad scale habitat mapping of Broughton and Ohinetaha Bays, both small sized, shallow intertidal dominated (SIDE) type estuaries, which are situated respectively within the wider Kenepuru Sound and inner Pelorus Sound/Te Hoiere complex.

The purpose of the assessment was to characterise each estuary's current ecological condition in relation to several key coastal issues (i.e. eutrophication, sedimentation, and habitat modification), and compare the findings with relevant national standards (NZ Estuary Trophic Index, NZ ETI), to provide recommendations regarding future monitoring and management priorities in the estuaries. The survery was undertaken in February 2020, and the results, risk indicator ratings, overall estuary condition, and monitoring recommendations are summarised below.

As summarised in the below table, the 2020 assessment identified the following, with NZ ETI-based risk indicator ratings included:

- Intertidal flats dominated the estuaries, with limited subtidal habitat;
- Seagrass beds characterised only a relatively small intertidal area (<2% of intertidal) and were largely confined to the mid-upper intertidal reaches;
- Saltmarsh areas were also relatively small, comprising <5% of the intertidal area, and were dominated by rushland and herbfield species;
- Soft muddy habitat was uncommon in Broughton Bay (4% of the intertidal area), but was widespread and often associated with poorly oxygenated sediments in Ohinetaha Bay (80% of the intertidal area). Areas of firm muddy sand, firm sand, gravel, cobble, boulder and bedrock were also featured;
- Sediment mud content measured within soft mud habitat was high (41.7-93.9%);
- No opportunistic macroalgal growth or gross eutrophic zones were present; and,
- Dense buffering vegetation bordered the majority of the 200 m terrestrial margin and was dominated by a mix of native and exotic scrub and forest.

Estuary Issue	Indicator	Risk Indicator	
		Broughton Bay	Ohinetaha Bay
Sedimentation	Soft mud (% cover)	Moderate	Very High
Eutrophication	Macroalgal Growth (OMBT Index)	Minimal	Minimal
	Gross Eutrophic Zones (ha)	Minimal	Minimal
	Sediment Oxygenation (ha)	Minimal	Very High
Habitat Modification	Seagrass Change (since baseline)*	Moderate	Moderate
	Saltmarsh (% of intertidal area)	Moderate	Moderate
	200 m Vegetated Terrestrial Margin	Minimal	Minimal
Overall NZ ETI Rating**		**Moderate**	**Moderate**

*interim rating applied in the absence of a multi-year baseline.**refer Appendix F for details.

Based on the combined results from the February 2020 survey, the estuaries are considered to be in a moderate state in relation to broad scale ecological features. Eutrophication issues are not presently affecting either estuary and both supported small areas of saltmarsh and seagrass habitat which remain in relatively good condition. Most underlying sediments appeared to have low levels of organic enrichment, but there are sediment muddiness/poor oxygenation issues evident throughout the intertidal estuary at Ohinetaha Bay. The NZ ETI (Tool 2) scores for Broughton Bay (0.30, Band B – Moderate) and Ohinetaha Bay (0.45, Band B – Moderate) acknowledge the absence of eutrophication symptoms from both estuaries and the sediment muddiness/poor oxygenation problem in Ohinetaha Bay.

On the basis of these findings, the following recommendations for ongoing monitoring for the Broughton and Ohinetaha Bays estuaries are proposed by Robertson Environmental Limited for consideration by MDC:

Broad scale monitoring

- To characterise any issues of change in habitat (e.g. soft mud extent, saltmarsh or seagrass area), it is recommended that broad scale habitat mapping be undertaken at both estuaries at 10 yearly intervals (next scheduled for consideration in 2030), unless obvious changes are observed in the interim.

Fine scale monitoring

- **Broughton Bay** – Given the large extent of native forest cover in the catchment surrounding the estuary, and the absence of significant impacts within it, we recommended that consideration be given to establishing a long-term fine scale monitoring site in Broughton Bay as a reference location against which results from other monitoring in the Marlborough Sounds can be compared. This would enable inferences to be made about the potential significance of changes within catchments subjected to higher inputs of sediment and nutrients, or habitat loss. Such information will help support management actions relating to sediment and nutrient inputs that may be considered by MDC.
- **Ohinetaha Bay** – Although the estuary is expressing a muddiness/poor oxygenation issue, intensive fine scale monitoring is not considered to be necessary in this instance. Instead it is recommended that outputs from ongoing monitoring of several established intertidal sites within nearby Havelock Estuary (refer Robertson 2019b), also a SIDE type estuary affected by muddiness, be used as a proxy for fine scale conditions in Ohinetaha Bay estuary. This is on the basis that the two systems are essentially physically connected at the head of the Pelorus Sound and more than likely are subjected to the same source(s) of often highly elevated inputs of sediment and to a lesser extent nutrients from surrounding catchments (principally Kaituna and Pelorus), and therefore are likely to reflect a similar ecological condition in relation to those inputs over time.
- Because of the potential for increased sediment inputs, particularly in the case of Ohinetaha, it is recommended that a series of sediment plates be deployed (as per Hunt 2019) within both Ohinetaha and Broughton Bays estuaries, the latter acting as a reference site. Sediment accrual and sediment grain size should be measured annually.

1 Introduction

1.1 Project Brief

The Marlborough District Council (MDC) coastal monitoring strategy (Tiernan 2012) identifies priorities for long-term coastal and estuarine monitoring in the region including broad scale habitat mapping and fine scale monitoring of intertidal sediments in key estuaries. As part of this work, MDC recently engaged Robertson Environmental Limited to map the broad scale intertidal habitat features of Broughton and Ohinetaha Bay estuaries, which are located respectively within the upper tidal reaches of the Kenepuru Sound and Mahau Sound, Marlborough (Figure 1.1). The purpose of the work was to provide MDC with baseline information on each estuary's ecological condition for state of the environment (SoE) monitoring purposes and to help support planning and resource management decision-making. The following report describes the methods and results of field sampling undertaken on 10th-12th February 2020.

1.2 Background

Estuary monitoring in NZ generally comprises three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) to address major issues identified in NZ estuaries (refer Appendix A). The tiered approach includes:

i. Ecological Vulnerability Assessment (EVA) of estuaries to major coastal issues and the design of prioritised and targeted monitoring programmes. This has been partially completed within the MDC coastal monitoring strategy (Tiernan 2012), and in reports documenting ecologically significant marine sites in Marlborough (e.g. Davidson et al. 2011). The specific vulnerability of Broughton and Ohinetaha Bay estuaries to key coastal issues has not yet been specifically assessed;

ii. Broad Scale Habitat Mapping (NEMP approach). This component documents the key biophysical features and habitats within the estuary, enables changes to these habitats to be assessed over time, and is used to define fine scale monitoring needs and management priorities.

iii. Fine Scale Monitoring (NEMP approach). This component monitors physical, chemical and biological indicators within estuary sediments and provides more detailed information on estuary condition.

This report focuses on detailed broad scale habitat mapping undertaken in February 2020 to assess the current state of the estuaries and uses a range of established broad scale indicators to assess ecological condition. Key indicators are described in Table 2.1 and Appendix A and include mapping and assessment of:

- Substrata types (e.g. mud, sand, gravel);
- Sediment oxygenation;
- Macroalgal beds (i.e. *Ulva* spp., *Gracilaria* spp.);
- Seagrass (i.e. *Zostera muelleri*);
- Gross Eutrophic Zones (GEZs - i.e. macroalgal-dominated, organically enriched/poorly oxygenated benthic environment);
- Saltmarsh vegetation; and,
- 200 m terrestrial margin surrounding the estuary.

Assessment of results uses a suite of indicator ratings developed for nationally standardised estuarine assessment (Table 2.1), many of which are included in the NZ Estuary Trophic Index (NZ ETI) (Robertson et al. 2016a,b and recent extensions in Plew et al. 2020). The NZ ETI is designed to enable the consistent assessment of estuary state in relation to nutrient over-enrichment (eutrophication), and also includes assessment criteria for sediment muddiness (sedimentation).

1.3 Report Structure

The current report presents a brief introduction to Broughton and Ohinetaha Bay estuaries (Section 1.4), the sampling methods, monitoring indicators and assessment criteria used (Section 2), and results and discussion of the field sampling (Section 3). To help the reader interpret the findings, results are related to relevant condition and/or risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 4 with conclusions in Section 5), and to guide monitoring recommendations (Section 6).

1.4 Site Details

Broughton and Ohinetaha Bay estuaries are small (~13-54 ha, respectively), shallow, intertidal dominated (SIDE; NZ ETI classification in Robertson et al. 2016a) type estuaries. They are situated within the upper tidal reaches of Broughton Bay (Kenepuru Sound) and Ohinetaha Bay (Mahau Sound), both long, deep, subtidally dominated estuary (DSDE) systems associated to the wider Pelorus Sound complex (Figure 1.1). The estuaries are macrotidal (>1.8 m spring tidal range), have one opening, one main basin, and no poorly flushed tidal arms. Freshwater inflows are relatively small and can dry up in summer, but respond quickly to catchment rainfall and flows can quickly increase causing the stream channels that cross the estuary deltas to be relatively mobile, particularly in areas characterised by coarse grained sediments.

Like much of the Marlborough Sounds, the Pelorus/Kenepuru Sound complex is a drowned valley system characterised by steep hillsides that slope directly to narrow rocky shorelines. Intertidal estuarine flats are largely confined to the upper tidal reaches of the elongate and narrow arms where sediment deposition from catchment erosion contributes to the natural build up of river and stream deltas. The extent and nature of the intertidal estuarine deltas is determined largely by the combined influences of underlying geology, the size and steepness of the catchment, and the volume of freshwater flowing to the coast. The type of land cover also has a strong influence on substrata composition, particularly as rates of sediment erosion (and subsequent deposition at the coast) are increased where land cover is disturbed either through natural events such as landslides or fires, or more commonly through human activities such as land clearance for farming or forestry. The drainage of wetland areas (which are very effective at trapping terrestrial sediments) can also significantly increase the delivery of fine sediment to coastal areas.

The catchments surrounding the estuarine areas are relatively steep with erodbile geology, but are relatively small (179-357 ha) and dominated by mixed native forest/scrub vegetation (66-85%) and to a lesser extent high producing pasture (17-25%) (refer table below – source New Zealand Land Cover Database version five, LCDBv5). A small part of each estuary's margin is directly bordered by developed rural land and roads.

Summary of catchment land cover, Broughton and Ohinetaha Bay Estuary, 2020.

Class (LCDBv5)	Broughton		Ohinetaha	
	Area (ha)	Percentage	Area (ha)	Percentage
Herbaceous Freshwater Vegetation	-	-	2	1%
Indigenous Forest	-	-	3	1%
Exotic Forest	18	10%	5	1%
Indigenous Hardwoods	53	30%	89	25%
Manuka and/or Kanuka	64	36%	196	55%
High Producing Grassland	44	25%	62	17%
Low Producing Grassland	-	-	-	-
Built-up Area	-	-	-	-
Total Catchment	**179**	**100%**	**357**	**100%**
Catchment Densely vegetated	**135**	**75%**	**295**	**83%**

Figure 1.1. Location of Ohinetaha and Broughton Bay estuaries within Mahau and Kenepuru Sound, respectively. Mapped intertidal extents also shown (green areas in inset maps).

The estuarine deltas are relatively small and dominated by either a combination of firm muddy sand, cobble and gravel (Broughton Bay) or soft muddy (Ohinetaha Bay) sediments, and both naturally support only small areas of saltmarsh and seagrass habitat.

In terms of sedimentation impacts, fine sediment deposited in intertidal areas of relatively small, well flushed SIDE estuaries situated at the head of DSDE type estuaries is generally re-suspended by localised tidal and wave action and settles in the deeper waters of the subtidal zone - the predominant area of fine sediment deposition in the Marlborough Sounds (see Handley et al. 2017). While this certainly describes the general lack of muddiness at Broughton Bay, it does not explain the predominance of muddy habitat within Ohinetaha Bay. The latter is most likely related to the proximity of Ohinetaha Bay to the main Pelorus Sound Reach where suspended sediment loads are often highly elevated (particularly following periods of high rainfall within surrounding catchments), some of which will be exported to and settle within adjacent estuaries, promoting a mud-dominated benthic environment. The cloudy waters and muddy bed can lead to the loss of high value seagrass from intertidal and shallow subtidal areas, and reduced phytoplankton production, seabed life and fish communities.

The ratio of the estimated current suspended sediment load (CSSL) compared to the estimated natural state sediment load (NSSL) of 2.7 in Ohinetaha Bay and 3.0 in Broughton Bay, an NZ ETI susceptibility rating of moderate, indicating that the current sedimentation rate is likely to exceed the natural state sedimentation rate and therefore may contribute to sedimentation issues in the estuaries, despite the relatively high forest/scrub cover in the catchments. Ohinetaha Bay is considered to be more vulnerable to increased sediment inputs from several adjacent catchments, including those surrounding the Havelock Estuary where sediment muddiness appears to be an ongoing issue (Robertson 2019a).

The estuaries each have relatively low nutrient loads (estimated catchment N areal loading of <20 mg N m^{-2} d^{-1} which is well below the proposed guideline for SIDE estuaries of ~100 mg N m^{-2} d^{-1}, Robertson et al. 2016; Robertson & Savage under review). Consequently, both estuaries currently have low susceptibility to eutrophication.

The results of this survey coupled with future monitoring will help determine the extent to which the estuaries are affected by major estuary issues (Appendix A), both in the short- and long-term.

2 Sampling Methodology

2.1 Broad Scale Habitat Mapping and GIS Analyses

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrata: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland, etc). It follows the NEMP approach originally described for use in NZ estuaries by Robertson et al. (2002) with a combination of detailed ground-truthing of aerial photography, and GIS-based digital mapping from photography to record the primary habitat features present. Appendix C lists the definitions used to classify substrata and saltmarsh vegetation. Very simply, the method involves:

- Obtaining aerial photos of the estuary for recording dominant habitat features;
- Carrying out field identification and mapping (i.e. ground-truthing using laminated aerial photos); and,
- Digitising ground-truthed features evident on aerial photographs into GIS layers (e.g. ArcMap).

The georeferenced spatial habitat maps provide a robust baseline of key indicators that are used with risk indicators (Table 2.1) to assess estuary condition in response to common stressors, and assess future change.

While the transitional estuarine waters of Ohinetaha and Broughton Bays estuaries extend well into Pelorus/Kenepuru Sound, the extent mapped in the present study applied an arbitrary seaward boundary based on the methods of Robertson et al. (2002). The mapped extent (Figure 1.1) includes the intertidal margins of the upper estuary, as well as the deltas present at the lower estuary. For the current study, orthorectified colour aerial photos (~3-5 cm per pixel resolution) flown in January 2020 were provided by MDC, laminated (scale of 1:3,000), and used by an experienced scientist who walked the areas in February 2020 to ground-truth the spatial extent of dominant vegetation and substrata types (see Appendix C). From representative broad scale substrata types, several grain size samples were analysed to validate substrata classifications (Appendix D and G). When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Appendix D). Notes on sampling, resolution and accuracy are presented in Appendix D, and representative field photos are presented in Appendix H.

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

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

Where macroalgal cover exceeded 5% of the Available Intertidal Habitat (AIH), a modified Opportunistic Macroalgal Blooming Tool (OMBT) is used to rate macroalgal condition (WFD-UKTAG 2014). The OMBT is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands (i.e. bad/low, poor, good, moderate, high). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution.

Broad scale habitat features were digitised into ArcMap 10.5, and combined with field notes and georeferenced photos to produce habitat maps showing the dominant cover of: substrata, macroalgae (e.g. *Ulva* spp., *Gracilaria* spp.), seagrass, saltmarsh vegetation, and the 200 m wide terrestrial margin vegetation/landuse. These results are summarised in Section 3, with supporting GIS files (supplied as a separate electronic output) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions.

Table 2.1. Summary of NZ ETI condition and risk indicator ratings used in the present report.

NZ ETI Condition Bands and Risk Indicator Ratings (indicate risk of adverse ecological impacts)					
Broad and Fine Scale Indicators	NZ ETI Condition Rating*	Minimal (Band A)	Moderate (Band B)	High (Band C)	Very High (Band D)
	Risk Rating	Minimal	Moderate	High	Very High
Sediment Oxygenation (aRPD <0.5 cm or RP @ 3 cm <-150 mV)*		<0.5 ha or <1%	0.5-5 ha or 1-5%	6-20 ha or >5-10%	>20 ha or >10%
Macroalgal Ecological Quality Rating (OMBT)*		≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	0.0 - <0.4
Seagrass (% change from baseline)		<5% decrease		5-10% decrease	>10-20% decrease
Gross Eutrophic Zones (ha or % of intertidal area)		<0.5 ha or <1%	0.5-5 ha or 1-5%	6-20 ha or >5-10%	>20 ha or >10%
Soft mud (% of unvegetated intertidal substrata)*		<1%	1-5%	>5-15%	>15%
Sediment Mud Content (% mud)*		<5%	5-10%	>10-25%	>25%
Apparent Redox Potential Discontinuity (aRPD)**		>2 cm (Good or Very Good)		0.5-2 cm	<0.5 cm
Saltmarsh Extent (% of intertidal area)		>20%	>10-20%	>5-10%	0-5%
Saltmarsh Extent (% remaining from estimated natural state)		>80-100%	>60-80%	>40-60%	<40%
Vegetated 200 m Terrestrial Margin		>80-100%	>50-80%	>25-50%	<25%
Percent Change from Monitored Baseline		<5%	5-10%	>10-20%	>20%
NZ ETI score*		**0 - 0.25**	**0.25 - 0.50**	**0.50 - 0.75**	**0.75 - 1.0**

* NZ ETI (Robertson et al. 2016b, Plew et al. 2020), ** Hargrave et al. (2008), Keeley et al. (2012) - Refer to Appendix B for further information.

3 Results and Discussion

3.1 Broad Scale Habitat Mapping Summary

The 2020 broad scale habitat survey of Ohinetaha and Broughton Bays estuaries ground-truthed and mapped all intertidal substrata and vegetation including the dominant land cover of the terrestrial (200 m) margin, with the five dominant estuary features summarised in Table 3.1 and shown in Figures 3.1-3.12. This report does not include any mapping or description of subtidal habitat associated with the estuaries.

Estuarine habitat was characterised by extensive unvegetated intertidal flats (>75% of estuary). Saltmarsh (3.0-4.6% of intertidal area) was located predominantly at the head of each estuary where valley floors meet the sea. Small areas of intertidal seagrass were also present (~1% of intertidal area), and no dense (>50% cover) opportunistic macroalgae was observed. The mapping also showed that 71-80% of the 200 m wide terrestrial margin was densely vegetated, and mixed native and exotic forest/scrub cover in the surrounding catchments was relatively high (75-83%).

- In the following sections, various factors related to each of these habitats (e.g. area of soft mud) are used to apply risk ratings (Table 2.1) to assess key estuary issues of sedimentation, eutrophication, and habitat modification; and,
- In addition, the supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuaries. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

Table 3.1. Summary of dominant broad scale features in Broughton and Ohinetaha Bay estuaries, 2020.

Dominant Estuary Feature		Broughton			Ohinetaha		
		Area (ha)	% of Inter-tidal	% of Estu-ary	Area (ha)	% of Inter-tidal	% of Estu-ary
1.	Intertidal flats (excluding saltmarsh)	10.0	96%	78.8%	47.0	97%	89.0%
2.	Macroalgal beds (>50% cover) [included in 1. above]	0	0%	0%	0	0%	0%
3.	Seagrass (>20% cover) [included in 1. above]	0.1	1.1%	0.9%	0.5	1.1%	1.0%
4.	Intertidal saltmarsh	0.5	4.4%	3.5%	1.4	2.9%	2.6%
5.	Subtidal waters	2.4	-	18.6%	5.0	-	9.4%
	Total Estuary	**12.9 ha**	**100%**	**100%**	**53.4 ha**	**100%**	**100%**

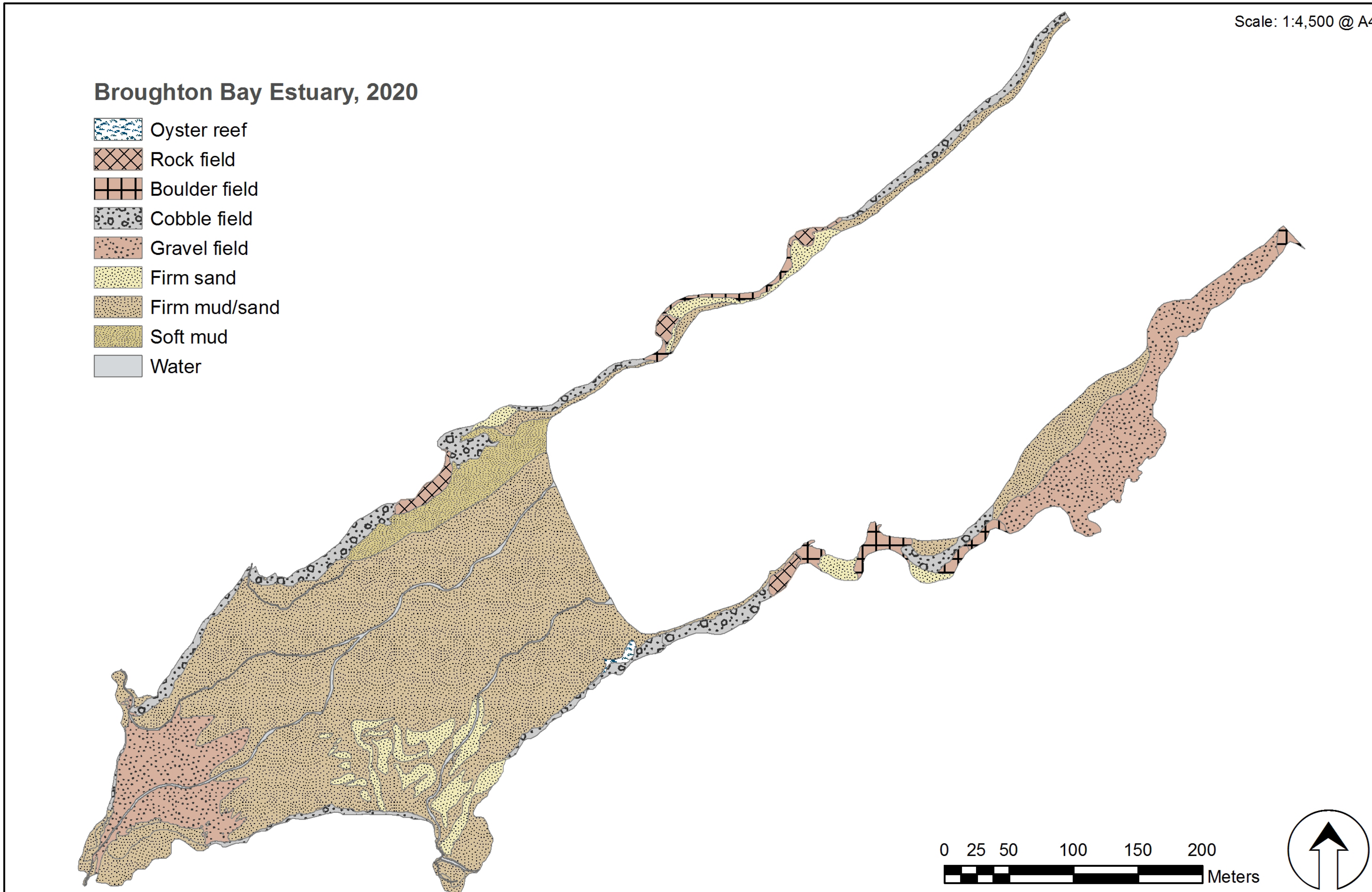


Figure 3.1. Intertidal substrata (including saltmarsh area), Broughton Bay Estuary, February 2020.

3.2 Intertidal Substrata (including saltmarsh)

Results (summarised in Table 3.2 and Figures 3.1 and 3.2) show the dominant intertidal substrata was firm mud sand (65%) in Broughton Bay and very soft mud (60%) and soft mud (20%) in Ohinetaha Bay. Whereas the former firm mud sands appeared well oxygenated (aRPD >3 cm), the latter muddy substrata (present throughout the intertidal zone - Figure 3.2) were generally poorly oxygenated (aRPD <1 cm). Soft muds were also evident in the shallow subtidal zone of both estuaries with regular tidal and wave action likely to mobilise a proportion of the fine material from the intertidal zone and deposit it in the subtidal zone where it settles and is retained.

Table 3.2. Summary of dominant intertidal substrata, Broughton and Ohinetaha Bays estuaries, 2020.

Dominant Substrata	Broughton		Ohinetaha	
	Area (ha)	Percentage	Area (ha)	Percentage
Boulder field	-	-	0.3	1%
Cobble field	0.8	8%	1.6	3%
Gravel field	1.7	16%	3.6	7%
Shell bank	-	-	0.5	0.1%
Mobile sand	-	-	-	-
Firm sand	0.6	6%	0.8	2%
Firm mud/sand	6.9	65%	3.2	7%
Soft mud	0.4	4%	9.5	20%
Very soft mud	-	-	29.2	60%
Oyster reef	0.02	0.2%	0.01	0.03%
Total Intertidal	**10.5**	**100%**	**48.4**	**100%**

Despite their muddiness, these substrata often supported extensive beds of filter-feeding bivalve (in this case the common cockle, *Austrovenus stutchburyi*), with the greatest densities observed within the lower third of the tidal range at each estuary. Reasons for its dominance/persistence, and despite the elevated mud contents (i.e. cockles tolerate mud content up to 85% with an optimum range of 0-10%, but are sensitive to long-term exposure to high levels of mud; Robertson 2013), may include each site's relative proximity to the nearshore subtidal zone where access to food supply is enhanced (Thrush et al. 2003; Gibbs and Hewitt 2004). The beds were covered in muds they are hard to distinguish visually using aerial photography. Because of this they have been classified as soft or very soft mud. Raised and defined beds of dead cockle shells were classified as shell bank.

Other prominent habitats included cobble (3-8%) and gravel fields (7-16%) and firm sands (2-6%). Gravel, cobble and sand features were predominantly located in the lower reaches of the estuary and adjacent to channels which have a high degree of flushing from river and tidal flows. Rock and boulder features were relatively uncommon and generally confined to the upper tidal range in each estuary. Within vegetated areas, substrata among herbfields was predominantly cobble and gravel dominated, while that among rushland was mostly firm mud or muddy sand. Seagrass beds, present in both estuaries, were growing in sand and mud substratum, often located in small depressions among cobble/gravel beds.

Small beds of Pacific oyster (<1%) were noted in both estuaries, but were not extensive and appeared to be healthiest in the lower tidal reaches attached to rock substratum. Sabellid tube worm (*Spirobranchus cariniferus*), macroaglae (*Hormosira banksii*), and mussels were present within lower third of the tidal range at Broughton Bay, and most evident among rocks on the true left and right of the bay.

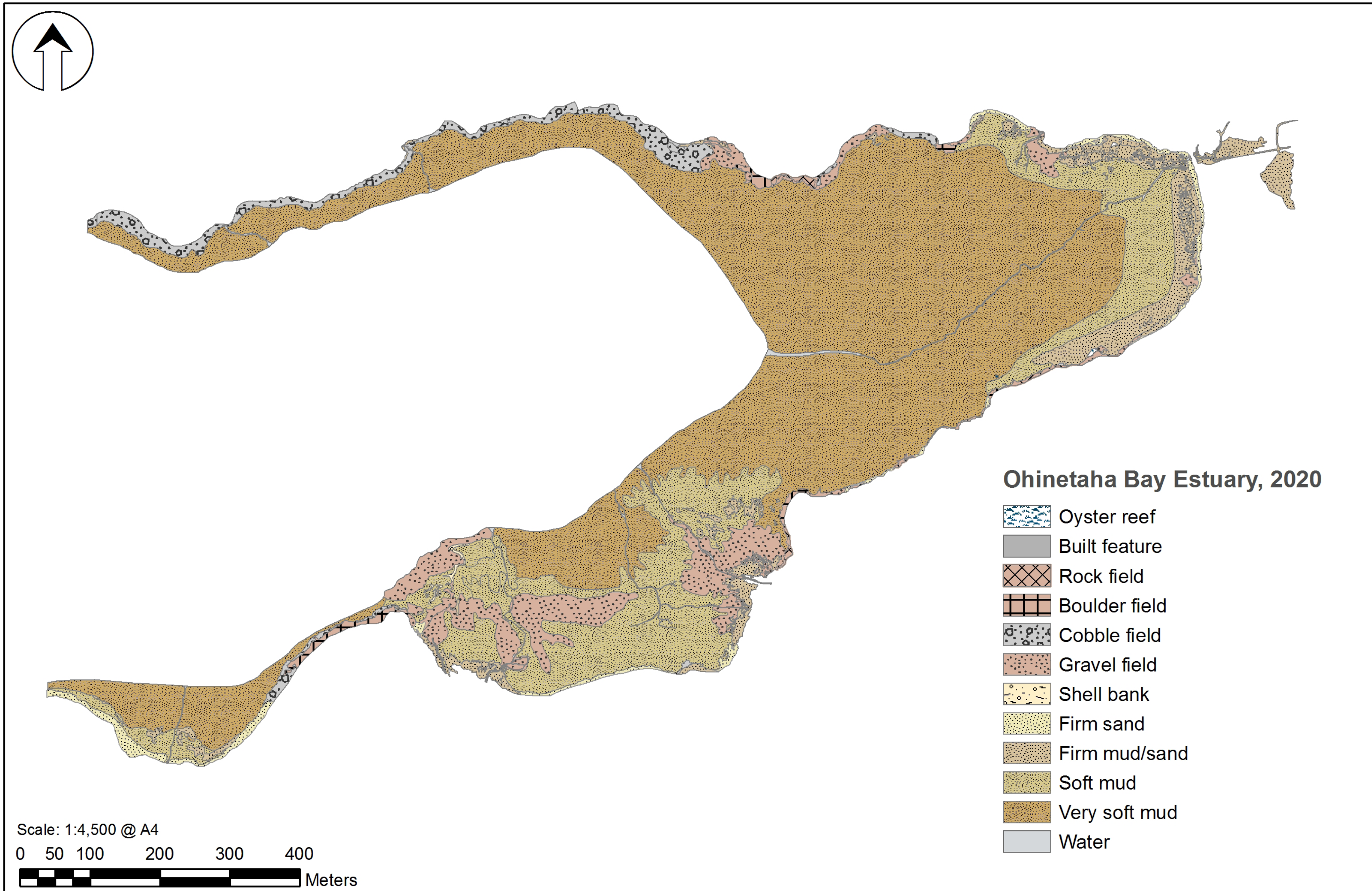


Figure 3.2. Intertidal substrata (including saltmarsh area), Ohinetaha Bay Estuary, February 2020.

3.3 Extent of Intertidal Soft Mud	Broughton	Ohinetaha
NZ ETI Condition Rating	Moderate	Very High
Risk Rating	Moderate	Very High

Adverse impacts are commonly encountered when estuaries receive excessive inputs of fine sediment (mud), often resulting in shallowing, elevated turbidity, nutrients, organic matter degradation by anoxic processes (e.g. sulphide production), increased contaminant concentrations (where fine muds provide a sink for catchment contaminants like heavy metals), and alterations to saltmarsh, seagrass, fish and invertebrate communities through declining sediment oxygenation, smothering, and compromisation of feeding habits (e.g. see Mannino and Montagna 1997; Rakocinski et al. 1997; Peeters et al. 2000; Norkko et al. 2002; Ellis et al. 2002; Thrush et al. 2003; Lohrer et al. 2004; Sakamaki and Nishimura 2009; Wehkamp and Fischer 2012; Robertson 2013).

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

i. Horizontal extent (area of soft mud): broad scale indicator (see rating in Table 2.1);

ii. Vertical buildup (sedimentation rate): measured using buried sediment plates or retrospectively through historical coring. Ratings are currently under development as part of national ANZECC guidelines; and,

iii. Sediment mud content: fine scale indicator of the degree of muddiness within sediments from representative habitat (recommended guideline is no increase from established baseline).

The area (horizontal extent) of intertidal soft/very soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Table 3.2 and Figures 3.1 and 3.2 shows that soft mud habitat in Ohinetaha Estuary was present throughout the intertidal flats and, to a lesser extent, the edges of smaller streams entering the estuary. This corresponds to a risk rating of very high, based on the large area of soft or very soft mud relative to the intertidal habitat area (38.7 ha, 80%). Soft mud coverage was much less extensive in Broughton Bay, with only a relatively small pocket (0.4 ha, 4% of intertidal area) confined to its lower intertidal reaches at the true left side of the estuary.

The most extensive areas of very soft mud in Ohinetaha Bay were in the central settling basin and seaward shorelines along the true left and right of the bay (Figure 3.2). This is thought to predominantly reflect a hydrodynamic boundary, with the settlement of fine sediments promoted in these areas by changes in freshwater flow velocities, combined with salinity driven flocculation.

Compared to other estuaries in the Marlborough Sounds (including Broughton Bay) and around NZ, the extent of soft mud in Ohinetaha Bay was very high (Figure 3.3), a likely reflection of the estuary's position at the head of the Pelorus Sound and thus exposure to often highly elevated sources of suspended sediment from other catchments (principally Kaituna and Pelorus), some of which will be exported to and settle within the estuary. Within soft mud and very soft mud habitat in both estuaries, the measured mud contents were 57.5-93.9%, which is well within the very high risk indicator rating band (>25%). Biological communities in these areas are likely to be adversely impacted.

Overall, soft muddiness appears to be a key ecological issue for Ohinetaha Bay Estuary, whereas Broughton Bay was much less affected, in 2020. Future conditions are unlikely to further deteriorate if land use in surrounding catchments, in particular those contributing to muddiness issues in Ohinetaha, is managed appropriately. Because of the potential for increased sediment inputs to occur in the future, it is recommended that a series of sediment plates be buried (as per Hunt 2019) in likely deposition areas within both Ohinetaha Bay and Broughton Bay, the latter acting as a reference site.

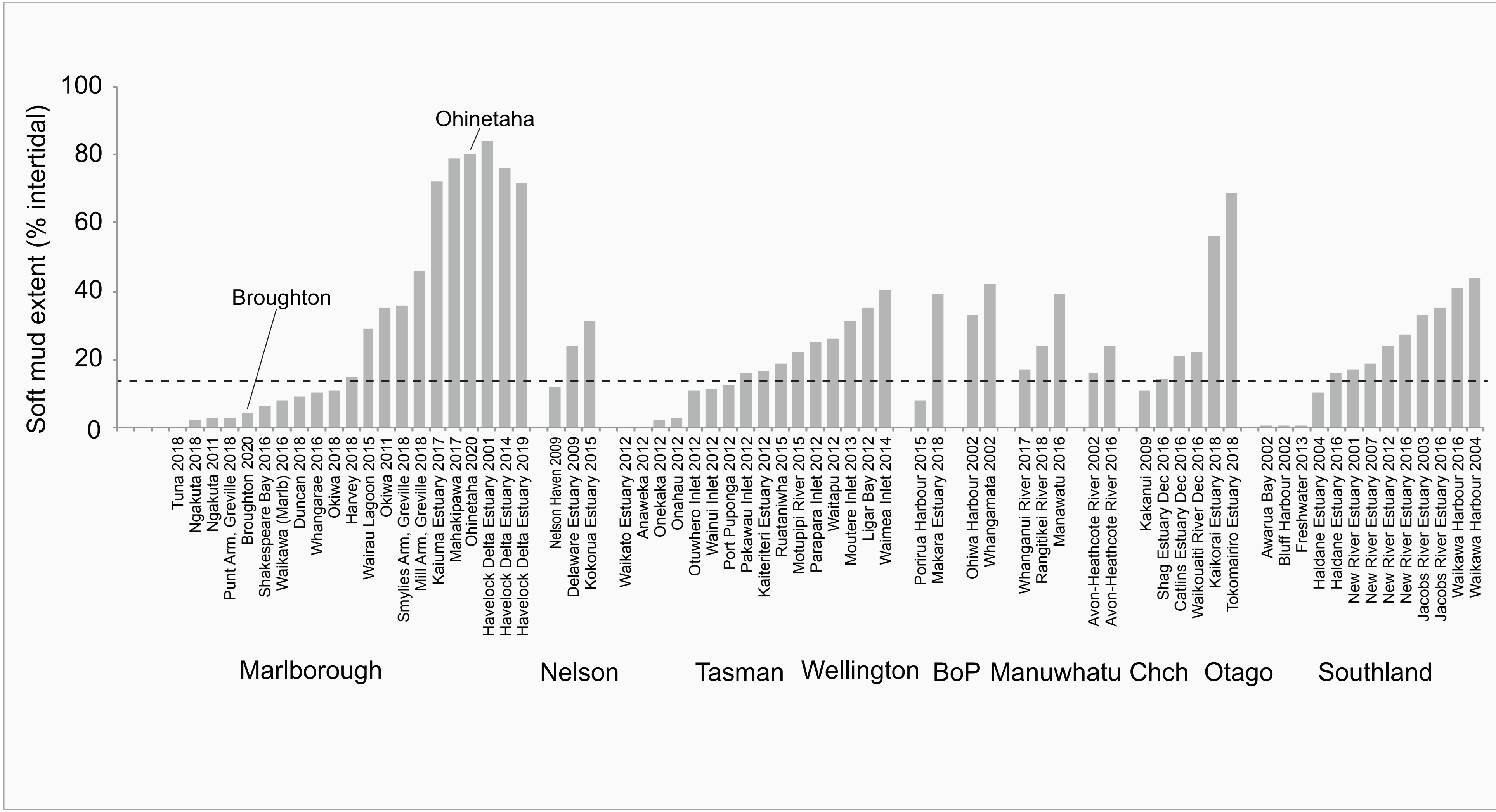


Figure 3.3. Percentage of intertidal estuary with soft mud habitat for various NZ tidal lagoon and delta estuaries (shallow, intertidal dominated, residence time <3 days - data from Robertson Environmental database). Dashed line represents high/very high risk threshold (Table 2.1).

3.4 Intertidal Opportunistic Macroalgae	Broughton	Ohinetaha
NZ ETI Condition Rating	Minimal	Minimal
Risk Rating	Minimal	Minimal

Opportunistic macroalgae are a primary indicator used to diagnose symptoms of estuary eutrophication. This is because they are highly effective at utilising excess nutrients (primarily nitrogen both from water column and sediment sources; Robertson 2018, Robertson and Savage 2018), enabling them to out-compete other seaweed and macrophyte species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Decaying macroalgae can also accumulate subtidally and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the consequent impacts.

Opportunistic macroalgal growth in Broughton and Ohinetaha Bay estuaries (Figures 3.4 and 3.5) was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH), and calculating an “Ecological Quality Rating” (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT) described in Appendix E. The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and relates to a quality status threshold band (i.e. bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change.

The overall opportunistic macroalgal EQR score for Broughton Bay and Ohinetaha Bay estuaries in February 2020 was 0.92 and 0.90 (see Appendix E for detailed results), a quality status of high and indicates that the estuaries overall are not expressing symptoms of eutrophication. The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change. These range from high to moderate, the overall high score reflecting the relatively low cover of benthic macroalgae within each system. The macroalgae present was dominated by green alga *Ulva* spp. and, to a much lesser extent, red alga *Gracilaria chilensis*. When present, these macroalgae tended to have a relatively low percent coverage (5-10%) and biomass (<20 g wet weight m^{-2}) and were most common on muds, and rocks in the upper estuary. Some drift (unattached) *Ulva* spp. was also observed at relatively low biomass along the high water mark of each estuary.

The threshold at which significant adverse impacts from excessive macroalgal growth become apparent has been determined from multiple studies in NZ and internationally to be >1450 g ww m^{-2} (e.g. Robertson et al. 2016b, Robertson 2018). It is clear from the present results that this threshold is not being exceeded in Broughton and Ohinetaha Bay estuaries.

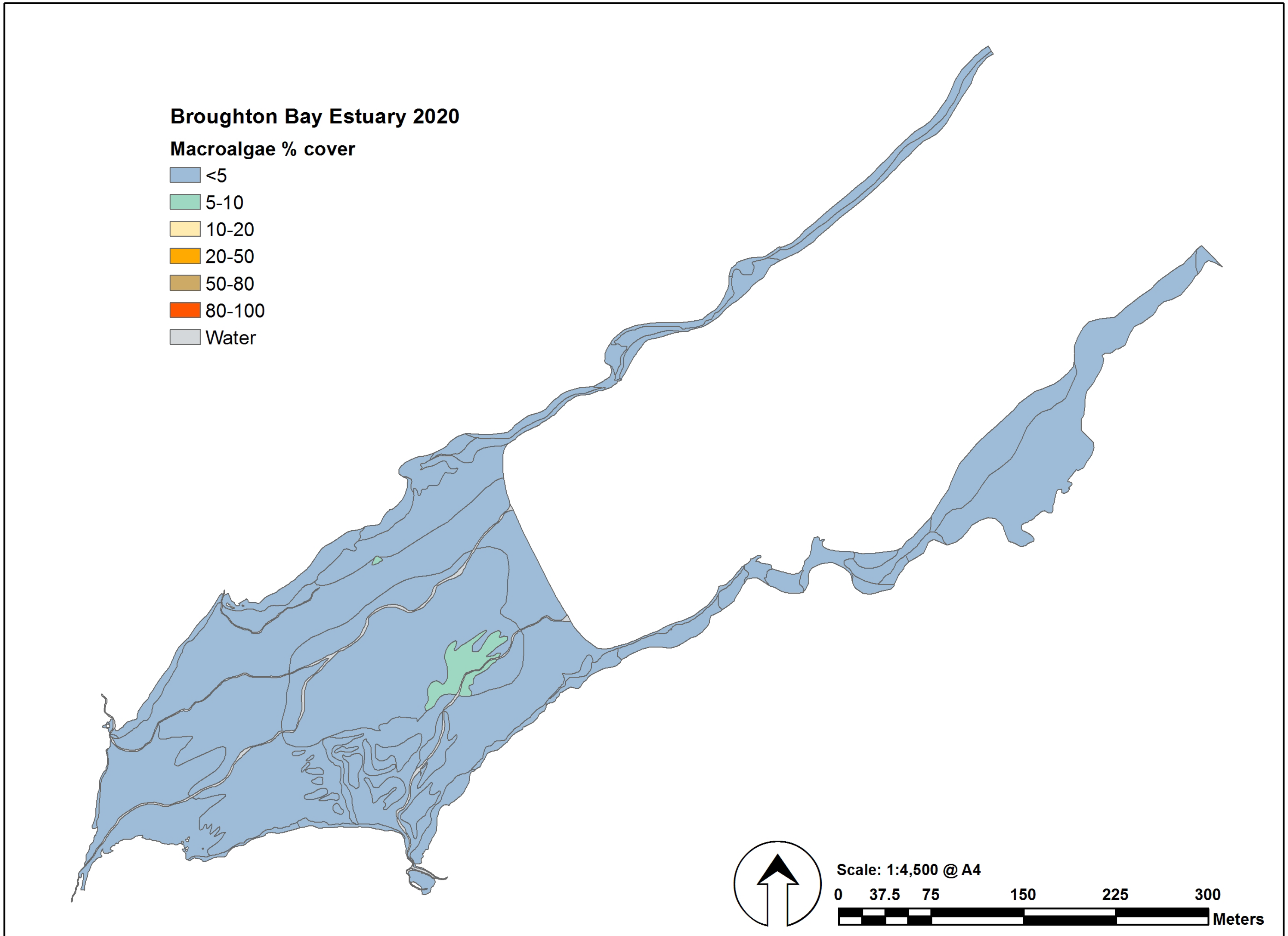


Figure 3.4. Extent and location of intertidal benthic macroalgae (percentage cover), Broughton Bay Estuary, February 2020.

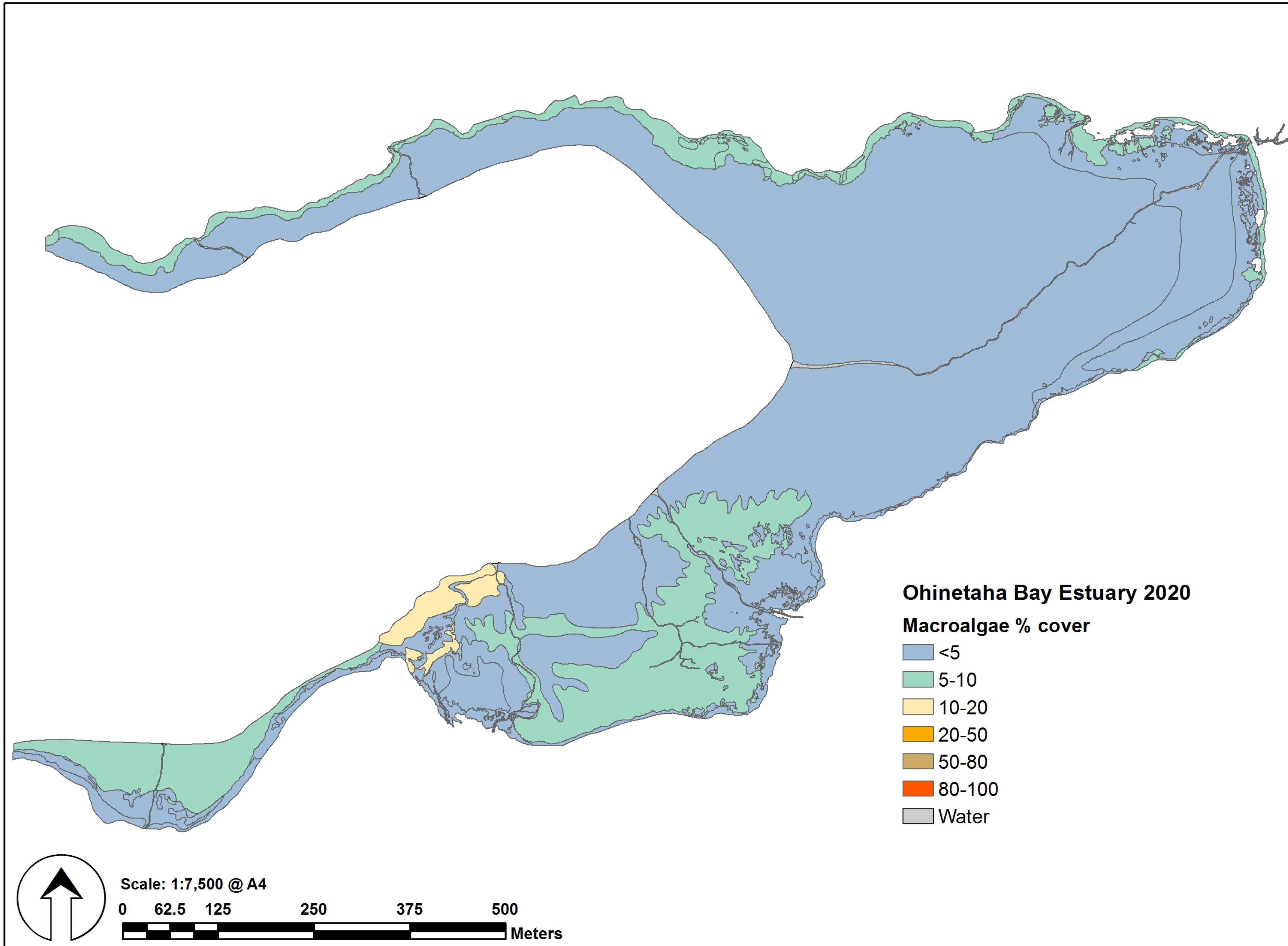
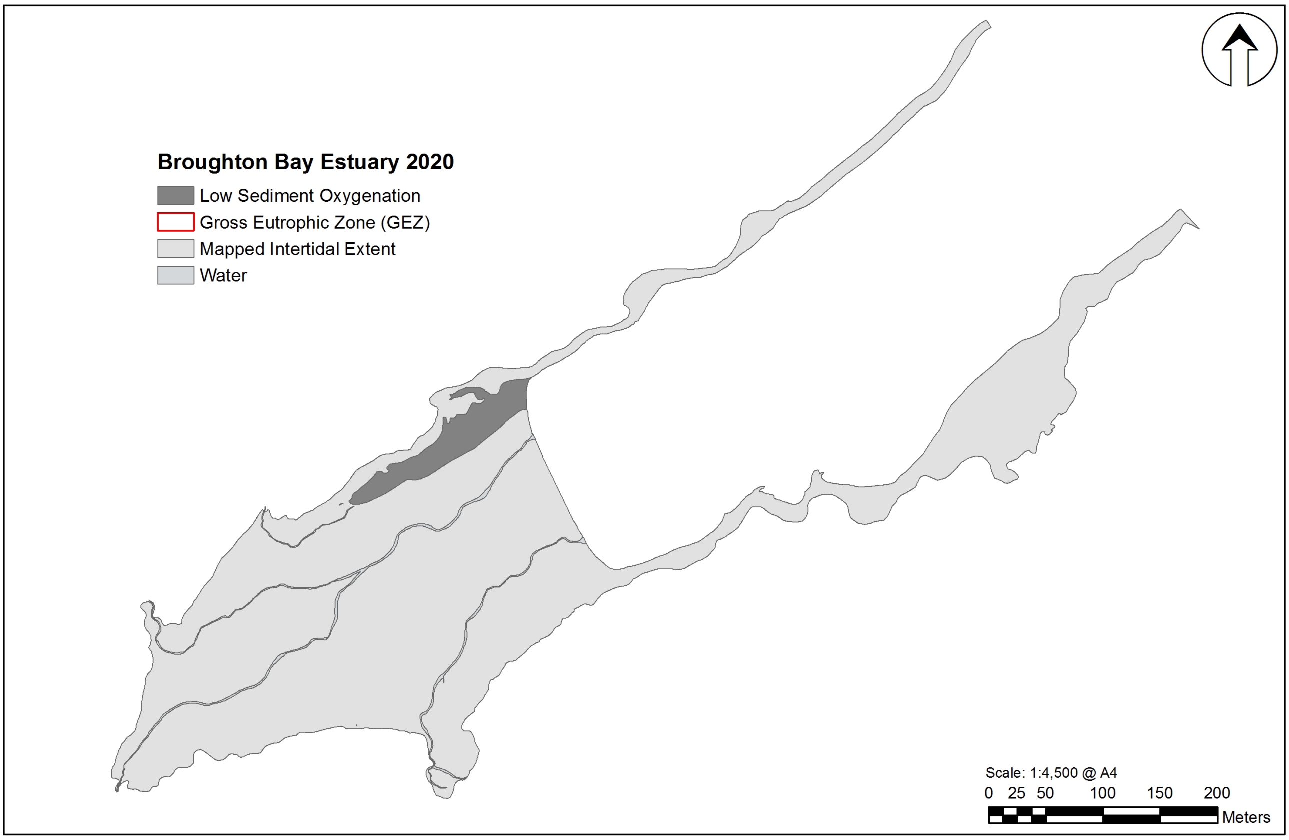


Figure 3.4. Extent and location of intertidal benthic macroalgae (percentage cover), Ohinetaha Bay Estuary, February 2020.



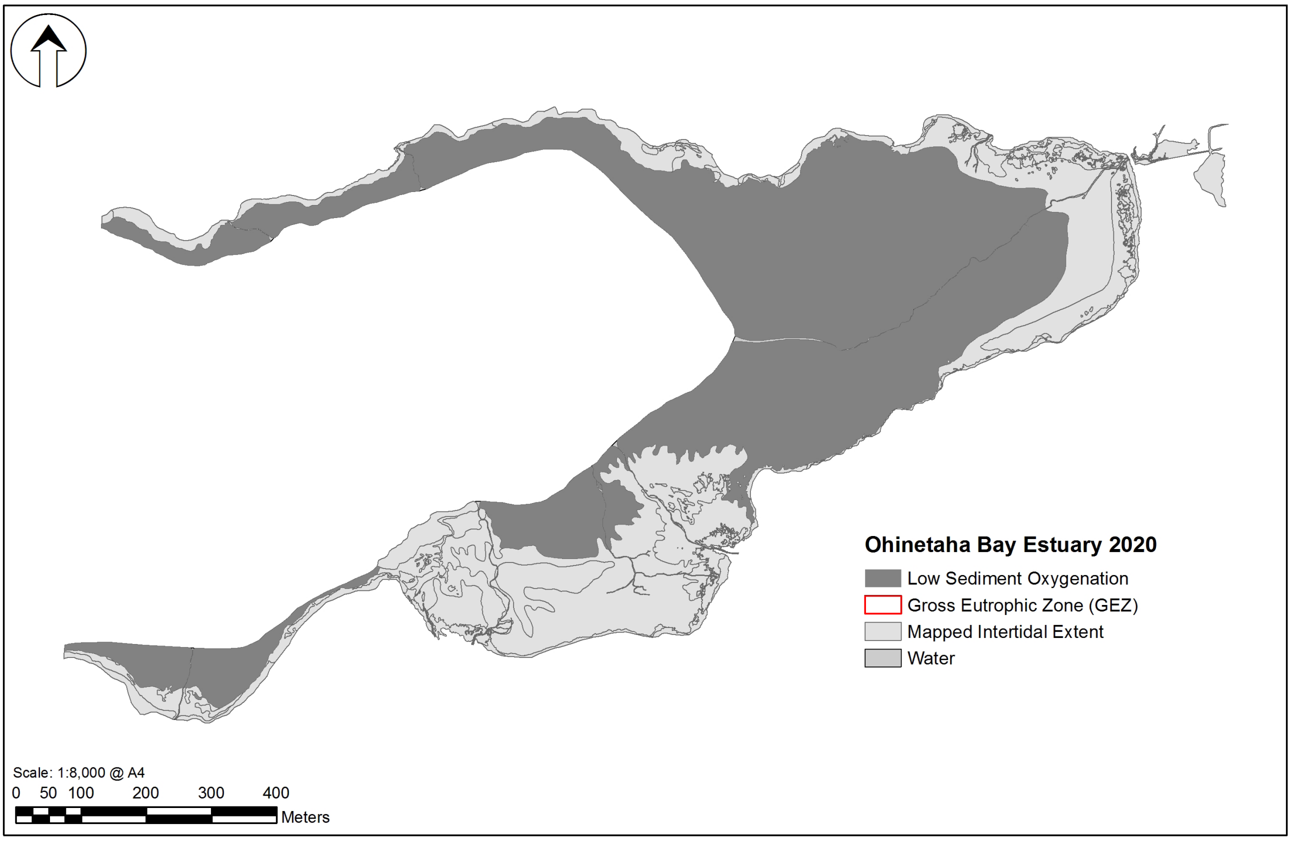


Figure 3.6. Indicating areas with low sediment oxygenation and an absence of Gross Eutrophic Zone (GEZ), Broughton and Ohintehaha Bay Estuary, February 2020.

3.5 Gross Eutrophic Conditions	Broughton	Ohinetaha
NZ ETI Condition Rating	Minimal	Minimal
Risk Rating	Minimal	Minimal

When sediments are characterised by a combination of high mud content, a shallow RPD, elevated nutrient and organic concentrations, and high macroalgal growth (>50% cover), they represent gross eutrophic conditions (Robertson et al. 2016b). These conditions will kill or displace most estuarine animals and shellfish, and also release nutrients previously bound in the sediments. In extreme cases sediment condition may deteriorate to such an extent that macroalgae can no longer survive, although this has yet to be formally validated in the case of NZ estuaries. Released nutrients will predominantly be in the form of ammonia, which is much more readily available to fuel macroalgal growth (Robertson and Savage 2018), supporting a cycle of increasing habitat deterioration that is likely to be difficult to reverse. Gross eutrophic conditions should not occur in short residence time tidal lagoon estuaries, with their presence providing a clear signal that the assimilative capacity of the estuary for nutrients is being exceeded.

Gross eutrophic conditions were also absent from Broughton and Ohinetaha Bay estuaries in February 2020 (Figure 3.6), confirming that the estuaries remain in a functional (healthy) trophic state and that their assimilative capacity for nutrients is currently not being exceeded. Nevertheless, studies on other NZ SIDE type estuaries indicate that mud-dominated systems are more susceptible to rapid degradation caused by eutrophication stress, therefore ongoing monitoring of associated potential changes in trophic status within both Ohinetaha Bay and Broughton Bay should be considered (the latter acting as a reference site).

3.6 Sediment Oxygenation	Broughton	Ohinetaha
NZ ETI Condition Rating	Minimal	Very High
Risk Rating	Minimal	Very High

The primary indicators used to assess sediment oxygenation are apparent Redox Potential Discontinuity (aRPD) depth and Redox Potential (RP mV) measured at 3 cm. These indicators were measured at representative sites throughout the dominant sand and mud substrata types, including vegetated intertidal areas. From these measurements, broad boundaries have been drawn of estuary zones where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected (Figure 3.6). Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

These results show that for Ohinetaha Bay there is a large part (29.2 ha, 60%) of the total intertidal area identified as having depleted sediment oxygen (i.e. aRPD <0.5 cm or RP@3 cm<-150 mV), a NZ ETI rating of poor. This was largely confined to very soft muds located throughout the main settlement basin and narrower nearshore regions along the true left and right of the bay.

Sediments did appear to be slightly more well oxygenated among relatively extensive areas of soft mud habitat in Ohinetaha Bay where the presence of cockles, which are very effective bioturbators of sediment, act to facilitate oxygen exchange with underlying sediments. Furthermore, sediments in the soft mud-dominated areas of Ohinetaha appeared to have a relatively low level of organic enrichment (i.e. no surface anoxia or strong hydrogen sulphide odours indicating anaerobic degradation was occurring).

Elsewhere, and including the vast majority of Broughton Bay, estuarine sediments were well to moderately well oxygenated, with the aRPD depth at 2-5 cm and the RP above -150 mV at 3 cm in most sand dominated sediments in the lower estuary reaches and among seagrass/saltmarsh where oxygen exchange through plant roots contributed to good but variable sediment oxygenation.

3.7 Intertidal Seagrass Habitat	Broughton	Ohinetaha
NZ ETI Condition Rating	Moderate	Moderate
Risk Rating[1]	Moderate	Moderate

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

Table 3.3 and Figure 3.7 and 3.8 summarise the results of the 2020 survey of the available seagrass habitat (mapped intertidal estuary area minus saltmarsh) in Broughton and Onihetaha Bay as follows:

- Seagrass beds were supported in the estuaries, although in both cases the vast majority of the intertidal estuary area (>98%) had no seagrass growing;
- When present, seagrass beds ranged in cover from 10% to 80% but were most common at moderate (10-40% cover) densities;
- Patches were generally highly localised and confined to the upper margins nearby to well flushed estuary channels where access to light and nutrients for growth is maximised;
- Beds were also evident nestled within depressions in cobble and gravel habitat and growing in sand and muddy sand; and,
- Seagrass within estuary deposition zones and lower estuary zones was scarce and, if present, appeared highly stressed, most likely due to a combination of excessive muddiness and/or poor water clarity (limiting light for photosynthesis/growth) during periods of tidal submersion.

In the absence of any comprehensive rating system for seagrass extent within NZ estuaries, which can be highly variable in the extent of seagrass that they support (Robertson 2018), changes from a documented baseline currently represent the most reliable method for monitoring seagrass extent and assessing change. The current study has provided baseline maps of seagrass extent for this purpose. Based on the relatively localised extent of seagrass beds in each estuary, the absence of macroalgae growing on beds, and no obvious evidence of seagrass wasting disease, an interim condition/risk rating of moderate has been applied to both estuaries.

[1] Interim rating applied in the absence of a suitable multi-year baseline.

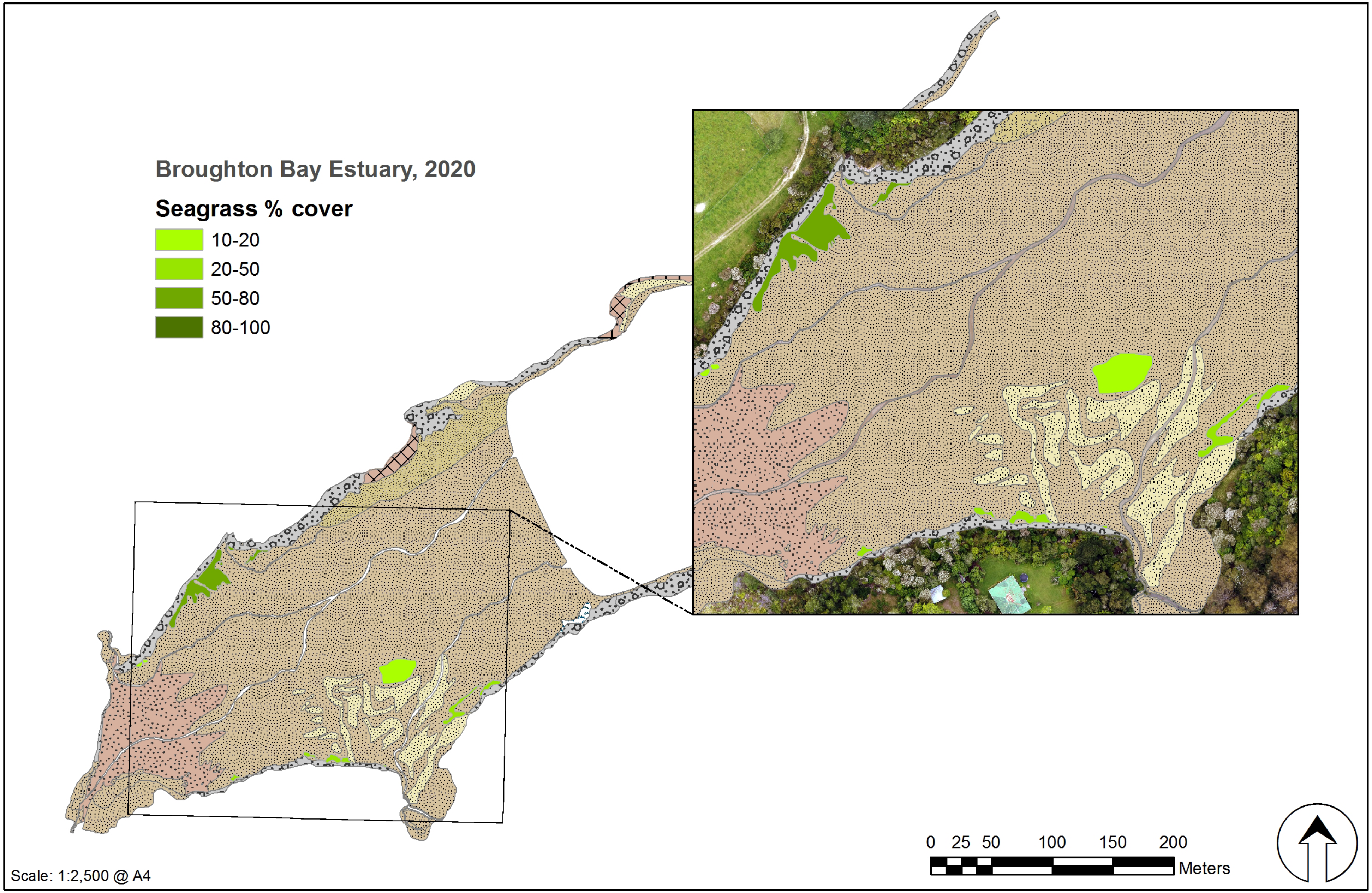


Figure 3.7. Extent of intertidal seagrass habitat (percentage cover), Broughton Bay Estuary, February 2020.

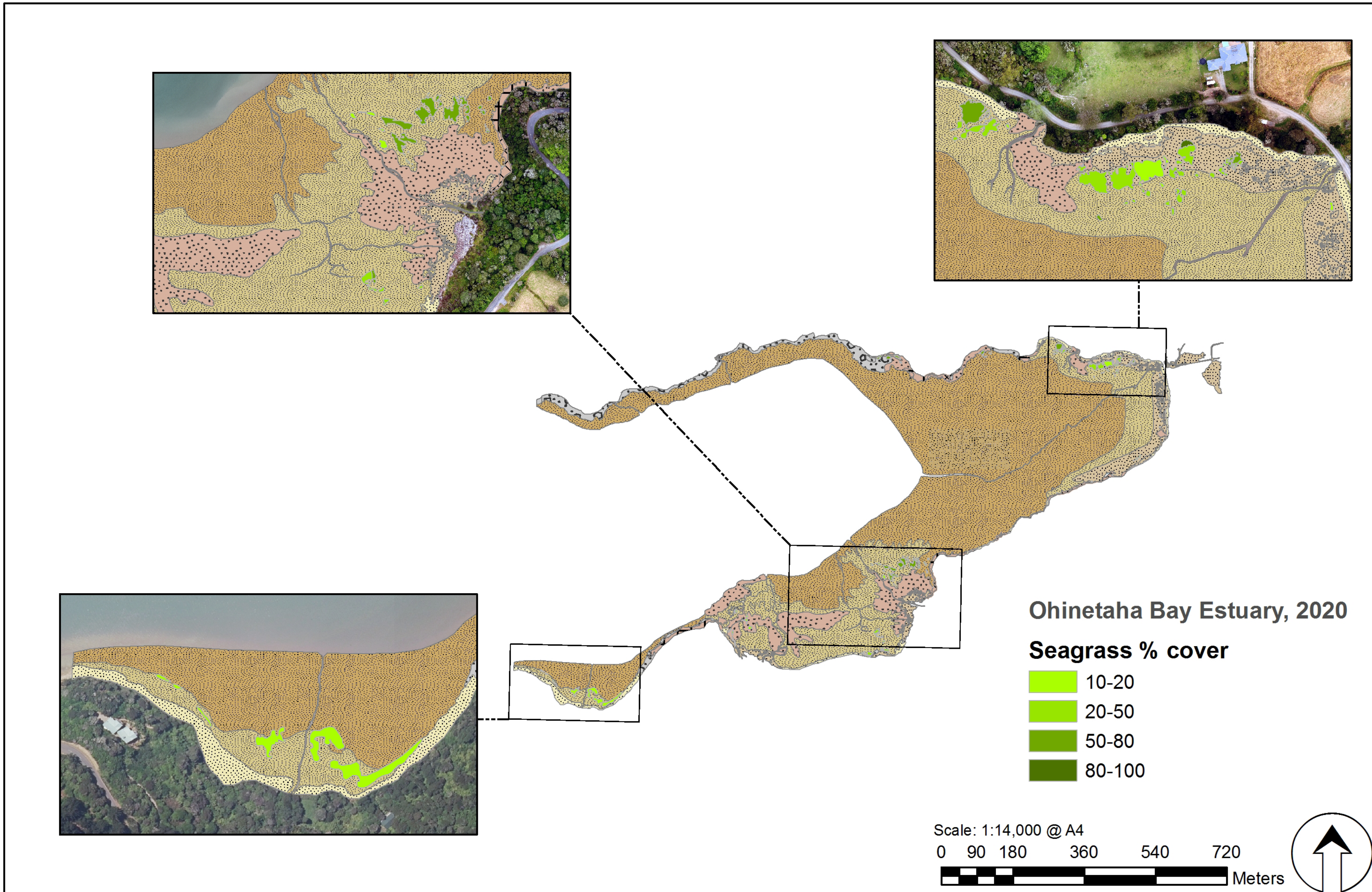


Figure 3.8. Extent of intertidal seagrass habitat (percentage cover), Ohinetaha Bay Estuary, February 2020.

Table 3.3. Summary of seagrass (*Z. muelleri*) cover, Broughton and Ohinetaha Bay Estuary, February 2020.

Seagrass Habitat	Broughton		Ohinetaha	
Percentage Cover	**Area (ha)**	**% intertidal**	**Area (ha)**	**% intertidal**
0 (unvegetated intertidal)	8.9	98.3%	47.4	98.9%
1-5%	0	0%	0	0%
5-10%	0	0%	0	0%
10-20%	0.05	0.5%	0.18	0.4%
20-50%	0.04	0.4%	0.15	0.3%
50-80%	0.08	0.9%	0.18	0.4%
>80%	0	0%	0.01	0.01%
Overall Seagrass Habitat	**0.17 ha**	**1.7%**	**0.52 ha**	**1.1%**

3.8 Intertidal Saltmarsh	Broughton	Ohinetaha
NZ ETI Condition Rating	Very High	Very High
Risk Rating	Moderate	Moderate

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

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 3.4 and Figures 3.9 and 3.10 summarise the 2020 results. Saltmarsh areas were relatively small (0.46-1.41 ha) and confined to <5% of the intertidal area, an NZ ETI condition rating of very high. Saltmarsh, most prominent in the upper estuary margins as either narrow strips or isolated beds along the edges, was dominated in both estuaries by rushland (60.9-83.6%), predominantly searush often mixed with jointed wirerush and ribbonwood. Herbfields were less prominent (2.6-8.0%) and featured primrose and remuremu, sometimes mixed with slender clubrush and glasswort, located in small beds bordering rushland in the upper estuary. There were also areas of sedgeland (0.2% in Broughton and 8.4% in Ohinetaha, comprising mainly three-square) often associated with rushland species at the head of each estuary. Neither estuary supported saltmarsh habitat dominated by tussockland or grassland species.

Comparably low saltmarsh cover has been recorded in other SIDE type estuaries located in the Marlborough Sounds, including those where catchment and indeed saltmarsh vegetation are considered to be relatively unmodified (e.g. Duncan, Harvey and Tuna Bay estuaries; Stevens 2019). The principle reason for the lack of saltmarsh is that available saltmarsh habitat (i.e. high water to supratidal area) is typically very narrow in such small SIDE type estuaries, hence they do not naturally support extensive saltmarsh.

A supporting measure for saltmarsh is estimated loss compared to expected natural state cover. While assumptions need to be made regarding likely historical extent, the current saltmarsh extent appears to be relatively unmodified other than small losses from upper estuary areas historically drained and converted to pasture. It is estimated that <20% of saltmarsh has been lost from the estuaries, a supporting risk rating of minimal. The combined overall risk rating was assessed as moderate recognising that saltmarsh, although relatively small in area, remains a significant ecological feature within each estuary.

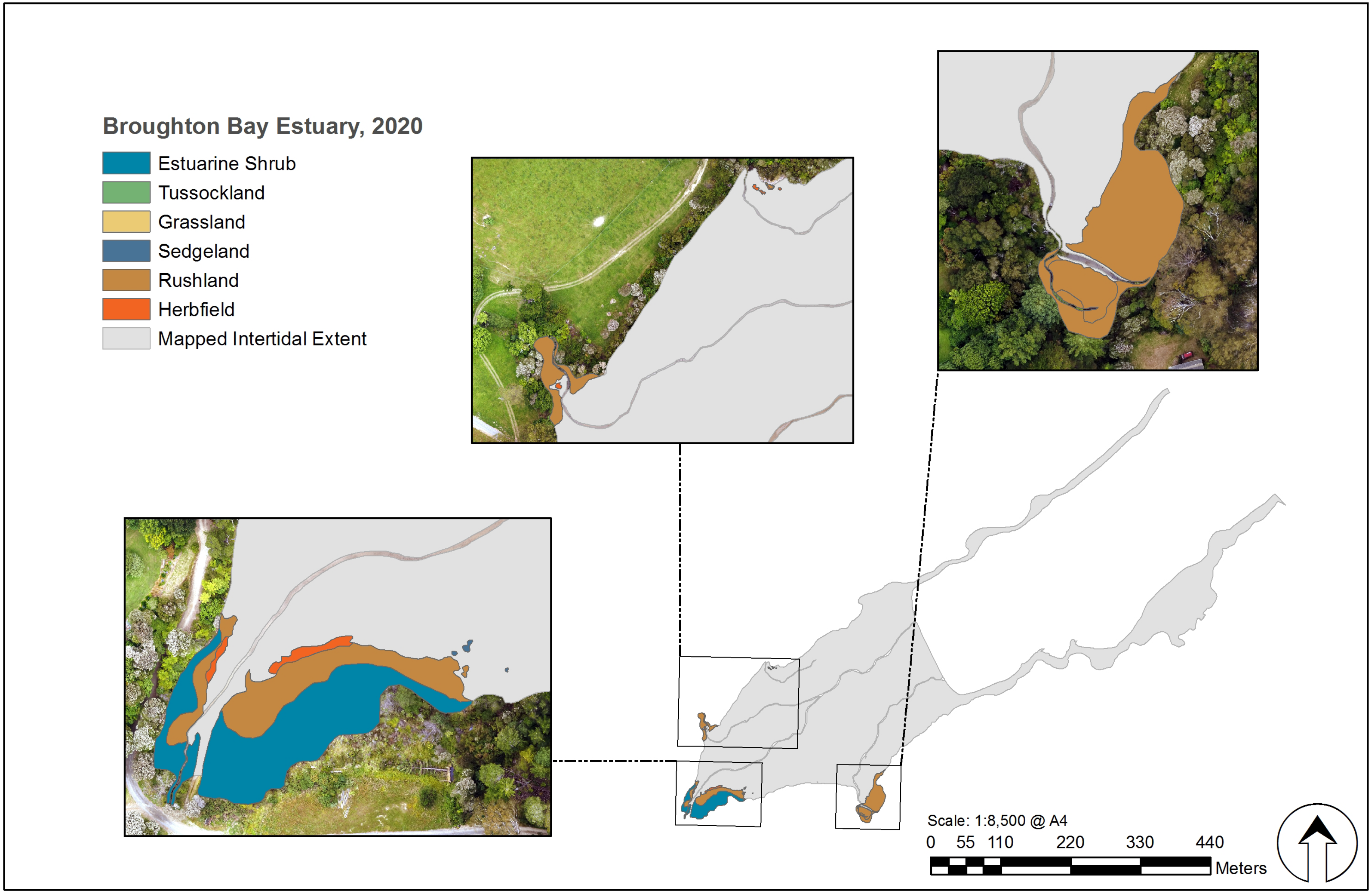


Figure 3.9. Location and extent of dominant saltmarsh cover, Broughton Bay Estuary, 2020.

Table 3.4. Summary of dominant saltmarsh cover, Broughton and Ohinetaha Bay Estuary, 2020.

Class	Dominant Species	Primary sub-dominant species	Broughton		Ohinetaha	
			Area (ha)	% Salt-marsh	Area (ha)	% Salt-marsh
Estuarine Shrub			0.17	36.3%		0.0%
	Plagianthus divaricaus (Saltmarsh ribbonwood)	*Apodesmia* (*Leptocarpus*) *similis* (Jointed wirerush)	0.17			
Sedgeland			0.001	0.2%	0.1	8.4%
	Schoenoplectus pungens (Three-square)	*Juncus kraussii* (Searush)	0.001		0.1	
	Schoenoplectus pungens (Three-square)				0.02	
Rushland			0.3	60.9%	1.18	83.6%
	Juncus kraussii (Searush)	*Schoenoplectus pungens* (Three-square)	0.02			
	Apodesmia (*Leptocarpus*) *similis* (Jointed wirerush)	*Juncus kraussii* (Searush)	0.04			
	Juncus kraussii (Searush)		0.02		0.29	
	Juncus kraussii (Searush)	*Apodesmia* (*Leptocarpus*) *similis* (Jointed wirerush)	0.20		0.03	
	Juncus kraussii (Searush)	*Plagianthus divaricaus* (Saltmarsh ribbonwood)			0.43	
	Juncus kraussii (Searush)	*Samolus repens* (Prim-rose)			0.43	
Herbfield			0.012	2.6%	0.11	8.0%
	Samolus repens (Prim-rose)	*Selliera radicans* (Remuremu)	0.003		0.11	
	Samolus repens (Prim-rose)	*Juncus kraussii* (Searush)	0.001			
	Samolus repens (Prim-rose)		0.009		0.0001	
	Isolepis cernua				0.005	
	Sarcocornia quinqueflora (Glasswort)				0.001	
		Total	**0.46 ha**	**100%**	**1.41 ha**	**100%**

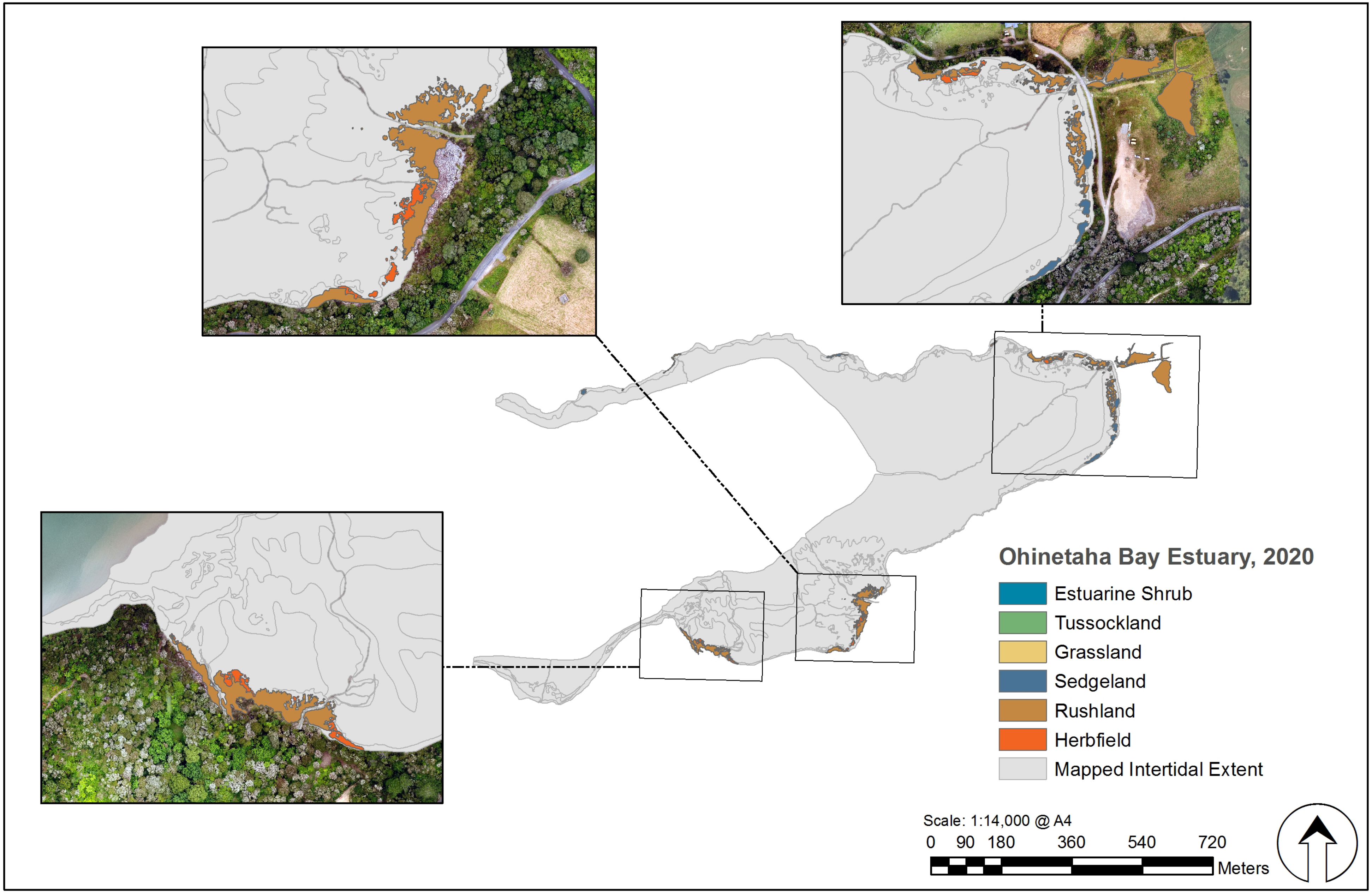


Figure 3.10. Location and extent of dominant saltmarsh cover, Ohinetaha Bay Estuary, 2020.

3.9 Terrestrial Margin (200 m)	Broughton	Ohinetaha
NZ ETI Condition Rating	Minimal	Minimal
Risk Rating	Minimal	Minimal

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade to help moderate stream temperature fluctuations, and contributes to estuary biodiversity. The results of the 200 m terrestrial margin mapping of the estuaries, presented in Table 3.5 and Figure 3.11 and 3.12, showed:

- Dense buffering vegetation bordered the majority of each estuary's margin (71-80%) and was dominated by mix of native and exotic scrub and forest;
- Small areas of plantation forestry (1-3%) were present;
- The remaining 200 m wide terrestrial margin buffer featured grassland, predominantly as high productivity pasture (14-26%) growing around the upper estuary river areas on flood plain and also hillsides; and,
- Small areas of residential (1%) and road (3-5%) infrastructure were present throughout the 200 m margin.

The ecological value of the margin areas is significantly enhanced by the adjoining stands of terrestrial native forest on the steep hillsides flanking the seaward edges of each estuary. This particularly helps to buffer the estuary against sediment inputs from local sources and introduced weeds, and supports regionally rare ecological connectivity between the estuary and surrounding natural habitats.

The greatest area of margin modification is in the valley floors where land has been cleared and converted largely to pasture. Historically these areas most likely would have supported lowland wetlands which apart from their high ecological value, are also very effective at assimilating catchment derived nutrient and sediment inputs. Consequently, there is likely to be an increased delivery of sediment and nutrients to the estuaries compared to natural state conditions, however, this is expected to be small given the dominance of native scrub/forest cover in the wider catchments (Figure 3.13). Indigenous vegetation includes manuka, kanuka, broadleaf hardwoods and sub alpine shrubland.

Overall, a risk rating of minimal has been applied based on the high proportion (71-80%) of the 200 m terrestrial margin of the estuaries having a densely vegetated cover, with the majority comprising high value (regenerating) native species.

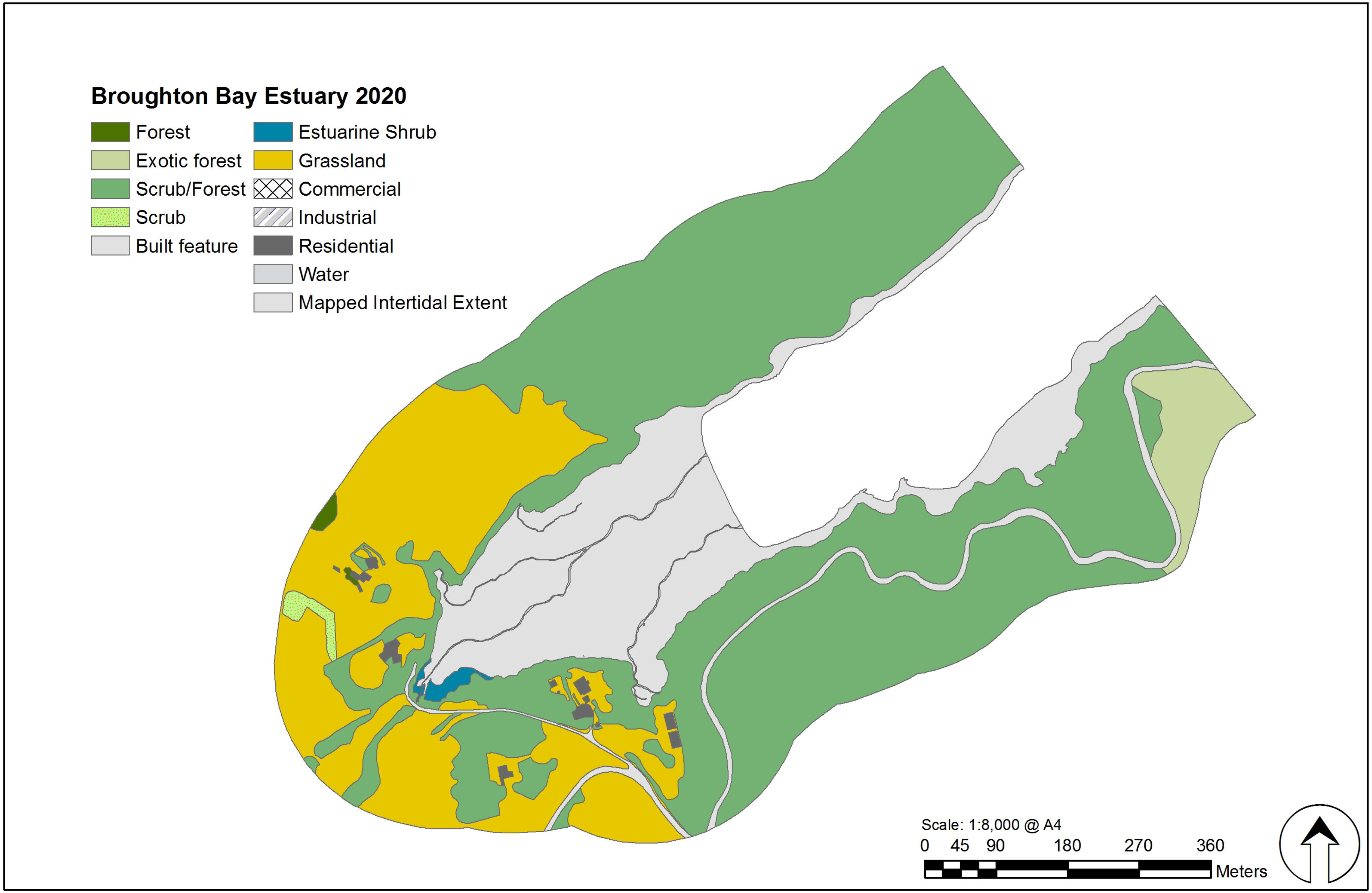


Figure 3.11. 200 m Terrestrial Margin - Dominant Land Cover, Broughton Bay Estuary, 2020.

Table 3.5. Summary of 200 m terrestrial margin land cover, Broughton and Ohinetaha Bay Estuary, 2020.

Class	Dominant Cover	Broughton		Ohinetaha	
		Area (ha)	Percent-age	Area (ha)	Percent-age
Exotic Forest	*Pinus radiata* (Pine tree)	1.6	3%	0.4	1%
Scrub/Forest	Mixed native and exotic	31.3	67%	63.4	79%
Scrub	Mixed native and exotic	0.2	0%	0.5	1%
Estuarine Shrub	*Plagianthus divaricatus* (Saltmarsh ribbonwood)	0.2	0.4%	0.4	0%
Pasture		12.1	26%	11.6	14%
Unmanaged Grass-land		-	-	-	-
Roads		1.3	3%	3.6	5%
Commercial		-	-	-	-
Industrial		-	-	-	-
Residential		0.2	1%	0.6	1%
	Total 200 m margin	**46.9 ha**	**100%**	**80.5 ha**	**100%**
	200 m Densely vegetated	**33.3 ha**	**71%**	**64.7 ha**	**80%**

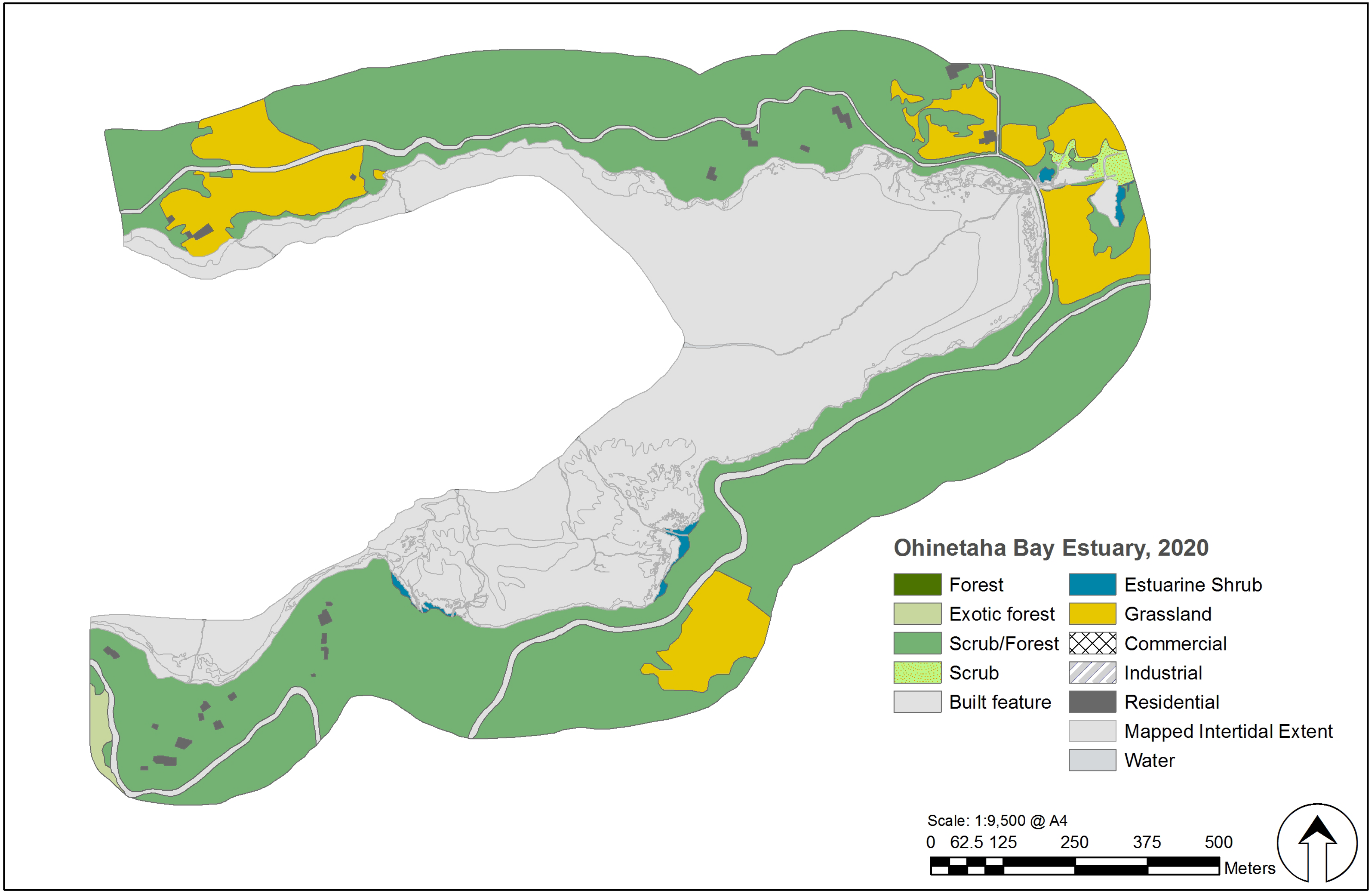


Figure 3.12. 200 m Terrestrial Margin - Dominant Land Cover, Ohinetaha Bay Estuary, 2020.

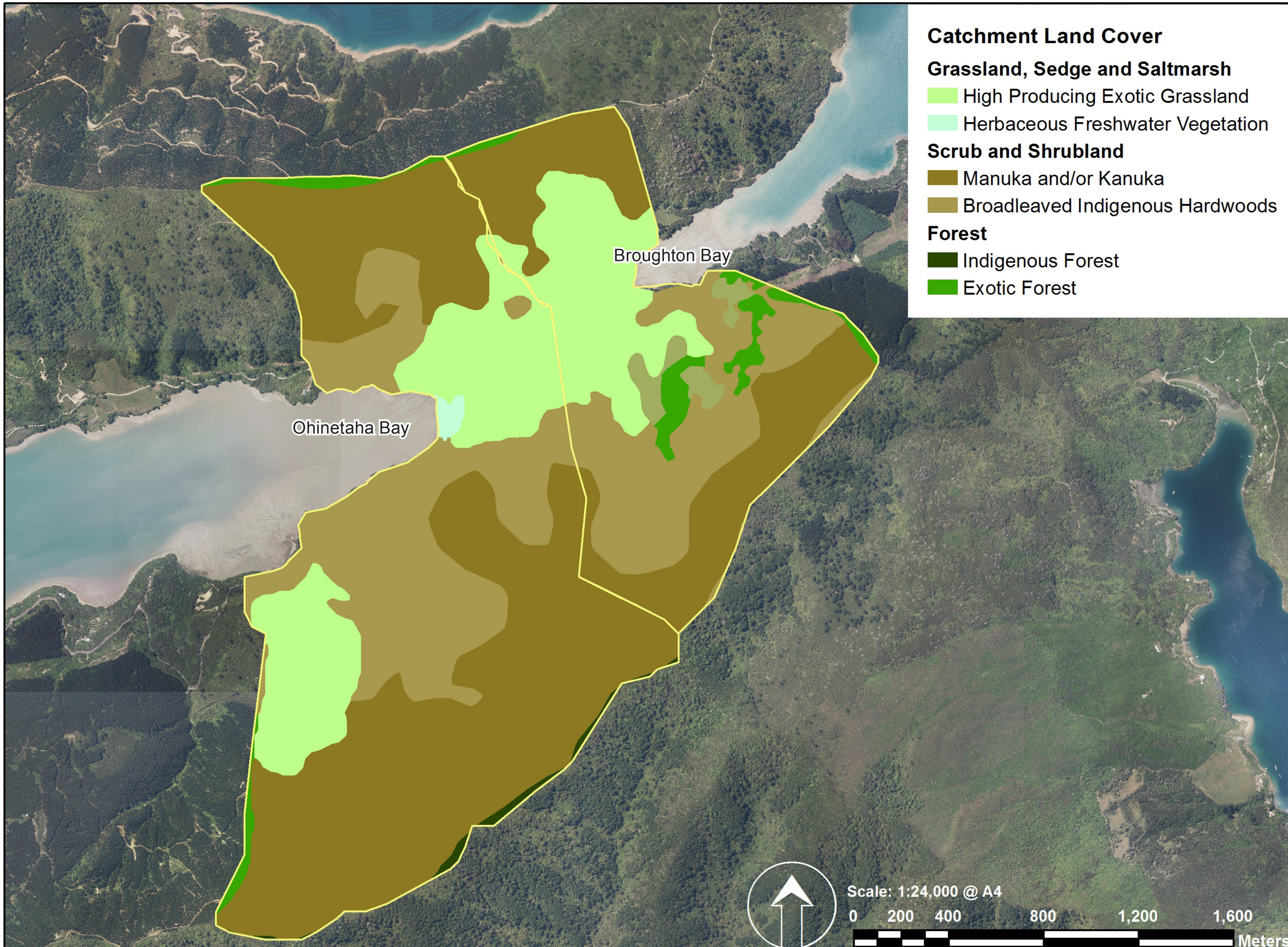


Figure 3.13. Summary of Catchment Land Cover (LCDBv5), Broughton and Ohinetaha Bays.

4 Summary

Habitat mapping undertaken in February 2020, combined with risk indicator ratings, in relation to the key estuary issues (i.e. sedimentation, eutrophication and habitat modification) have been used to assess the overall condition of Broughton and Ohinetaha Bay estuaries (Table 4.1).

Sedimentation (Muddiness)

Sedimentation within estuaries is a natural process but excessive sedimentation can lead to poor ecological health. Soft or very soft muds covered 0.4 ha (4%) and 38.7 ha (80%) of the intertidal area in Broughton Bay and Ohinetaha Bay, a respective risk indicator rating of moderate and very high. When present, soft muds were concentrated in the central estuary where mud settlement is facilitated by a combination of unfavorable tidal flow, salinity driven flocculation and the cohesive (mud attracting) nature of existing mudflats.

To inform the broad scale recommendations, the current state/natural state sediment load (CSSL/NSSL) ratio and the mean annual rate of sediment deposition have been estimated. The CSSL/NSSL ratio is estimated as 2.7 in Ohinetaha Bay and 3.0 in Broughton Bay, an NZ ETI susceptibility rating of moderate (see Appendix F for details), indicating that the current sedimentation rate is likely to exceed the natural state sedimentation rate and therefore may contribute to the observed sedimentation issue in the estuaries. However, when compared to Broughton Bay, muddiness issues in Ohinetaha Bay are expected to be driven by (and therefore further exacerbated through) intermittent delivery and retention of fine sediments from adjacent sources (i.e. Pelorus and Kaituna catchments), given the estuary's exposure to those sources via the main Pelorus Sound Reach coupled with unfavorable tidal flows and limited flushing potential.

Associated with the presence of very soft muds in Ohinetaha Bay, 29.2 ha (60%) of the intertidal area (excluding saltmarsh) had sediment oxygenation depleted to a level where adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, a risk rating of very high.

Table 4.1. Summary of broad scale risk indicator ratings and overall NZ ETI (Tool 2) Rating for Broughton and Ohinetaha Bay Estuary, 2020.

Estuary Issue	Indicator	Risk Indicator	
		Broughton Bay	Ohinetaha Bay
Sedimentation	Soft mud (% cover)	Moderate	Very High
Eutrophication	Macroalgal Growth (OMBT Index)	Minimal	Minimal
	Gross Eutrophic Zones (ha)	Minimal	Minimal
	Sediment Oxygenation (ha)	Minimal	Very High
Habitat Modification	Seagrass Change (since baseline)*	Moderate	Moderate
	Saltmarsh (% of intertidal area)	Moderate	Moderate
	200 m Vegetated Terrestrial Margin	Minimal	Minimal
	Overall NZ ETI Rating**	**Moderate**	**Moderate**

*interim rating applied in the absence of a suitable baseline dataset. **refer Appendix F for details.

Eutrophication (Nutrient Over-Enrichment)

Key broad scale indicators used to assess eutrophic expression in the estuary are primary productivity through macroalgal growth, and supporting indicators of sediment muddiness, oxygenation, and the presence of gross eutrophic zones (a combined presence of dense algal growth, muds and poor sediment oxygenation).

With no significant opportunistic macroalgal growth, the Opportunistic Macroalgal Blooming Tool EQR score was 0.92 (Broughton) and 0.90 (Ohinetaha), a risk indicator rating of minimal. This rating is supported in the total catchment-derived nitrogen areal load that was estimated as <20 mg N m^{-2} d^{-1}, which is well below the 100 mg N m^{-2} d^{-1} threshold where advanced eutrophic symptoms commonly occur in open-mouthed SIDE type estuaries in NZ (Robertson et al. 2016a; Robertson and Savage under review).

Overall, such results indicate that nutrient inputs to the estuaries are presently not sufficient to fuel nuisance algal growths that often degrade underlying sediment conditions, and that both estuaries remain in a relatively functional (healthy) trophic state.

Habitat Modification

Saltmarsh areas were relatively small (0.46-1.41 ha) and confined to <5% of the intertidal area. It is estimated that <20% of saltmarsh has been lost from the estuaries, with a combined overall risk rating was assessed as moderate recognising that saltmarsh, although relatively small in area, remains a significant ecological feature within each estuary.

The 200 m terrestrial margins remained relatively intact, supporting a densely vegetated buffer of native and exotic scrub and forest (71-80%), with 14-26% in pasture or grassland and 4-6% developed (residential/road), a risk indicator of minimal.

Seagrass beds populated only a relatively small intertidal area (0.17-0.52 ha, <2%) and were largely confined to upper estuary reaches. Given the absence of macroalgae growing on beds, and no obvious evidence of seagrass wasting disease, an interim condition/risk rating of moderate has been applied to both estuaries.

5 Conclusions

Based on the combined results from the February 2020 survey, the estuaries are considered to be in a good (Broughton) and moderate (Ohinetaha) state in relation to broad scale ecological features. Eutrophication issues are not presently affecting either estuary and both supported small areas of saltmarsh and seagrass habitat which remain in good condition. Most underlying sediments appeared to have low levels of organic enrichment, but there are sediment muddiness/poor oxygenation issues evident throughout the intertidal estuary at Ohinetaha Bay. The NZ Estuary Trophic Index (NZ ETI) score has been calculated using available broad scale indicators (details summarised in Appendix F). The NZ ETI (Tool 2) scores for Broughton Bay (0.30, Band B – Moderate) and Ohinetaha Bay (0.45, Band B – Moderate) acknowledge the absence of eutrophication symptoms from both estuaries and the sediment muddiness/poor oxygenation problem in Ohinetaha Bay.

6 Recommendations

Broughton and Ohinetaha Bays estuaries have been identified by MDC as a priority for inclusion within a coastal and estuarine monitoring programme being undertaken throughout the region. In order to assess ongoing long-term trends in the condition of estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth or high sedimentation rates), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the inaugural broad scale mapping component of the long-term programme. The following recommendations for ongoing monitoring for the Broughton and Ohinetaha Bay estuaries are proposed by Robertson Environmental Limited for consideration by MDC:

Broad scale monitoring

- To characterise any issues of change in habitat (e.g. soft mud extent, saltmarsh or seagrass area), it is recommended that broad scale habitat mapping be undertaken at both estuaries at 10 yearly intervals (next scheduled for consideration in 2030), unless obvious changes are observed in the interim.

Fine scale monitoring

- **Broughton Bay** – Given the large extent of native forest cover in the catchment surrounding the estuary, and the absence of significant impacts within it, we recommended that consideration be given to establishing a long-term fine scale monitoring site in Broughton Bay as a reference location against which results from other monitoring in the Marlborough Sounds can be compared. This would enable inferences to be made about the potential significance of changes within catchments subjected to higher inputs of sediment and nutrients, or habitat loss. Such information will help support management actions relating to sediment and nutrient inputs that may be considered by MDC.
- **Ohinetaha Bay** – Although the estuary is expressing a muddiness/poor oxygenation issue, intensive fine scale monitoring is not considered to be necessary in this instance. Instead it is recommended that outputs from ongoing monitoring of several established intertidal sites within nearby Havelock Estuary (refer Robertson 2019b), also a SIDE type estuary affected by muddiness, be used as a proxy for fine scale conditions in Ohinetaha Bay estuary. This is on the basis that the two systems are essentially physically connected at the head of the Pelorus Sound and more than likely are subjected to the same source of often highly elevated inputs of sediment and to a lesser extent nutrients from surrounding catchments (principally Kaituna and Pelorus), and therefore are likely to reflect a similar ecological condition in relation to those inputs over time.
- Because of the potential for increased sediment inputs, particularly in the case of Ohinetaha, it is recommended that a series of sediment plates be deployed (as per Hunt 2019) within both Ohinetaha and Broughton Bays estuaries, the latter acting as a reference site. Sediment accrual and sediment grain size should be measured annually.

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8 Limitations

This document does not include any assessment or consideration of ecological conditions within the subtidal environment of Broughton and Ohinetaha Bays estuaries, and grain size and sediment oxygenation (aRPD and RP mV) sampling was carried out at a site-specific scale only. Regarding the latter, from a technical perspective, the benthic environment outside of areas sampled may present substantial uncertainty. It is a heterogeneous, complex environment, in which small surface features or changes in geologic conditions can have substantial impacts on associated physicochemical conditions and biology. This assessment has been carried out in line with the project brief received by Robertson Environmental Limited on the 8th of November 2019.

Robertson Environmental Limited's professional opinions are based on its professional judgement, experience, and training. These opinions are also based upon data derived from the monitoring and analysis described in this document, with the support of relevant national standards (e.g. NZ ETI; Robertson et al. 2016a,b, Plew et al. 2020). It is possible that additional testing and analyses might produce different results and/or different opinions. Should additional information become available, this report should be updated accordingly. Robertson Environmental Limited has relied upon information provided by the Client to inform parts of this document, some of which has not been fully verified by Robertson Environmental Limited. This document may be transmitted, reproduced or disseminated only in its entirety.

Appendix A:

Major Issues facing NZ Estuaries

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva, and Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Indicator(s)	Method
Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
Phytoplankton (water column)	Chlorophyll a concentration (water column).
Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Sedimentary changes influence the ecology of estuaries. Because they are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were most likely dominated by sandy sediments and had low sedimentation rates (e.g. <1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, NZ's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007a, 2010b, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

- habitat loss such as the infilling of saltmarsh and tidal flats;
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows;
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients;
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders;
- making the water unappealing to swimmers.

Recommended Indicators	Method
Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
Seagrass Area/Biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Mud Content	Grain size - estimates the % mud content of sediment.
Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

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

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

Toxic Contamination has become an issue in the last 60 years, as NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Indicators	Method
Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring. Note disease risk indicators on the Marlborough coast are assessed separately in MDC's recreational water quality monitoring programme.
Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Appendix B:

Support Information (Table 2.1)

The estuary monitoring approach used by Robertson Environmental Ltd has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change; Appendix A), and to assess changes in the long-term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water and/or sediment quality.

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

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

Supporting notes explaining the use and justifications for each rating indicator are presented below. The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing. See Robertson et al. (2016a, 2016b) and Robertson (2018) for further information supporting these ratings.

Soft Mud Percent Cover: Soft mud (>25% mud content) has been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are a sink for sediments, the presence of large areas of soft mud is likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, its presence indicates where changes in land management may be needed. If an estuary is suspected of being an outlier (e.g. has >25% mud content but substrata remains firm to walk on), it is recommended that the initial broad scale assessment be followed by particle grain size analyses of relevant areas to determine the extent of the estuary with sediment mud contents >25%.

Sedimentation Mud Content*:* Below mud contents of 20-30% sediments are relatively incohesive and firm to walk on. Above this, they become sticky and cohesive and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon concentrations, which typically increase with mud content, as do the concentrations of sediment bound nutrients and heavy metals. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, and on intertidal flats of estuaries can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready resuspension of fine muds, impacting on seagrass, birds, fish and aesthetic values.

apparent Redox Potential Discontinuity (aRPD): aRPD depth, the transition between oxygenated sediments near the surface and deeper anoxic sediments, is a primary estuary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Knowing if the aRPD is close to the surface is important for two main reasons:

1. As the aRPD layer gets close to the surface, a "tipping point" is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and to worsen sediment conditions;
2. Anoxic sediments contain toxic sulphides and support very little aquatic life.

In sandy porous sediments, the aRPD layer is usually relatively deep (>3 cm) 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 <1 cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

Opportunistic Macroalgae: The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic 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 Section 3.4 and Appendix E), with results combined with those of other indicators to determine overall condition.

Seagrass: Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent is likely to indicate an increase in these types of pressures. Thresholds used to assess this indicator are derived from the changes from a measured baseline, with results combined with those of other indicators to determine overall condition.

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

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

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

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Appendix C:

Broad Scale Habitat Classifications

Vegetation was classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the two first letters of their Latin genus and species names e.g. marram grass, *Ammophila arenaria*, was coded as Amar. An indication of dominance is provided by the use of ( ) to distinguish subdominant species e.g. Amar(Caed) indicates that marram grass was dominant over ice plant (*Carpobrotus edulis*). The use of ( ) is not always based on percentage cover, but the subjective observation of which vegetation is the dominant or subdominant species within the patch. A measure of vegetation height can be derived from its structural class (e.g. rushland, scrub, forest).

Vegetation (mapped separately to the substrata they overlie):

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10 cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.

Treeland: Cover of trees in the canopy is 20-80%. Trees are woody plants >10 cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.

Scrub: Cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.

Shrubland: Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.

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

Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly *Spinifex*, *Pingao* or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.

Grassland: Vegetation in which the cover of grass (excluding tussock-grasses) in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground.

Sedgeland: Vegetation in which the cover of sedges (excluding tussock-sedges and reed-forming sedges) in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it's probably a grass or a reed, if the stem is clearly triangular, it's a sedge. Sedges include many species of *Carex, Uncinia*, and *Scirpus*.

Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Leptocarpus*.

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

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

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

Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and where lichen cover exceeds that of any other growth form or bare ground.

Introduced weeds: Vegetation in which the cover of introduced weeds in the canopy is 20-100% and in which the weed cover exceeds that of any other growth form or bare ground.

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

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

Substrata (physical and biogenic habitat):

Artificial structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

Cliff: A steep face of land which exceeds the area covered by any one class of plant growth-form. Cliffs are named from the dominant substrata type when unvegetated or the leading plant species when plant cover is ≥1%.

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

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

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

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

Mobile sand: Granular beach sand characterised by a rippled surface layer from strong tidal or wind-generated currents. Often forms bars and beaches.

Firm or soft sand: Sand flats may be mud-like in appearance but are granular when rubbed between the fingers and no conspicuous fines are evident when sediment is disturbed e.g. a mud content <1%. Classified as firm sand if an adult sinks <2 cm or soft sand if an adult sinks >2 cm.

Firm muddy sand: A sand/mud mixture dominated by sand with a moderate mud fraction (e.g. 1-10%), the mud fraction conspicuous only when sediment is mixed in water. The sediment appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm sandy mud, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers.

Firm sandy mud: A sand/mud mixture dominated by sand with an elevated mud fraction (e.g. 10-25%), the mud fraction visually conspicuous when walking on it. The surface appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers, but with a smoother consistency than firm muddy sand.

Firm or soft mud: A mixture of mud and sand where mud is a major component (e.g. >25% mud). Sediment rubbed between the fingers retains a granular component but is primarily smooth/silken. The surface appears grey or brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm sandy mud, and very soft mud. Classified as firm mud if an adult sinks <5 cm (usually if sediments are dried out or another component e.g. gravel prevents sinking) or soft mud if an adult sinks >5 cm.

Very soft mud: A mixture of mud and sand where mud is the major component (e.g. >50% mud), the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink >5 cm unless another component e.g. gravel prevents sinking. From a distance appears visually similar to firm muddy sand, firm sandy mud, and firm or soft mud. Sediment rubbed between the fingers may retain a slight granular component but is primarily smooth/silken.

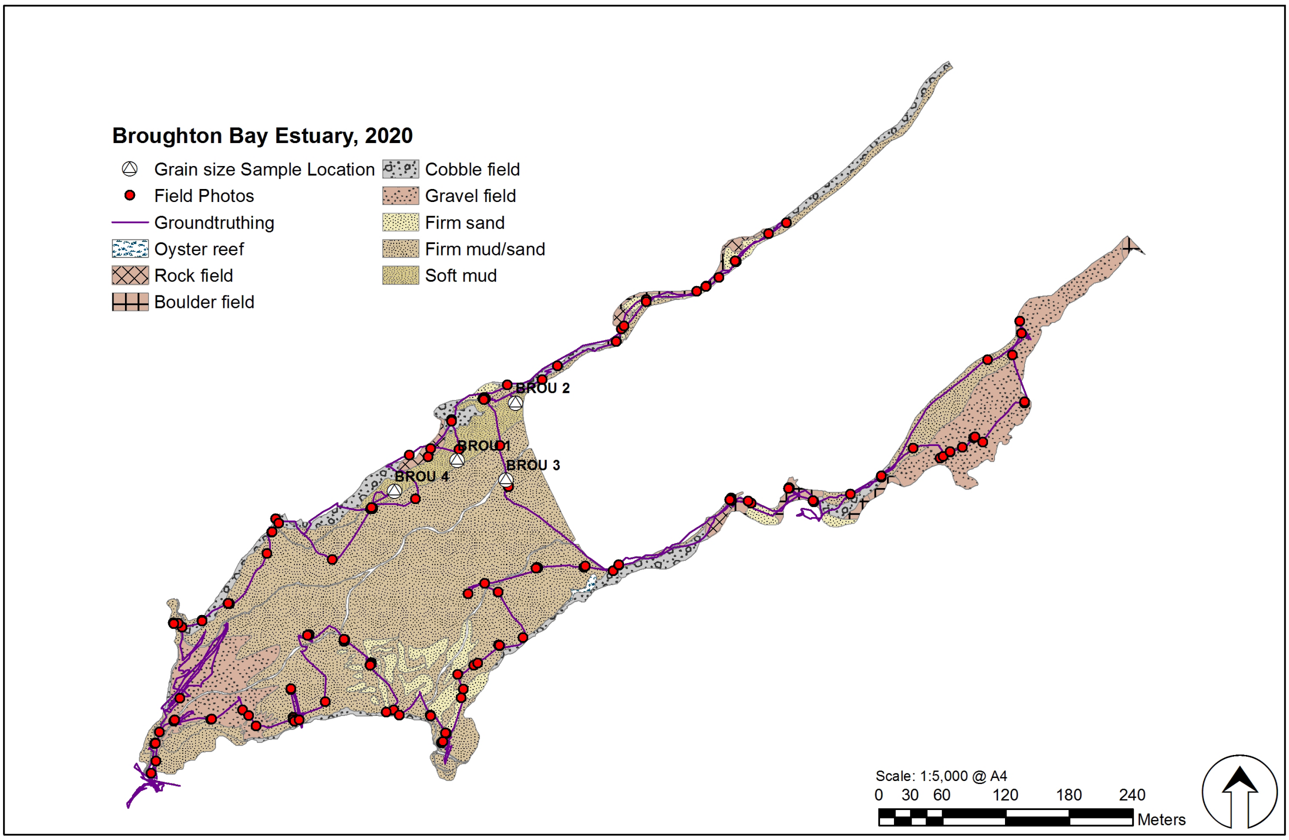
Cockle bed/Mussel reef/Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.

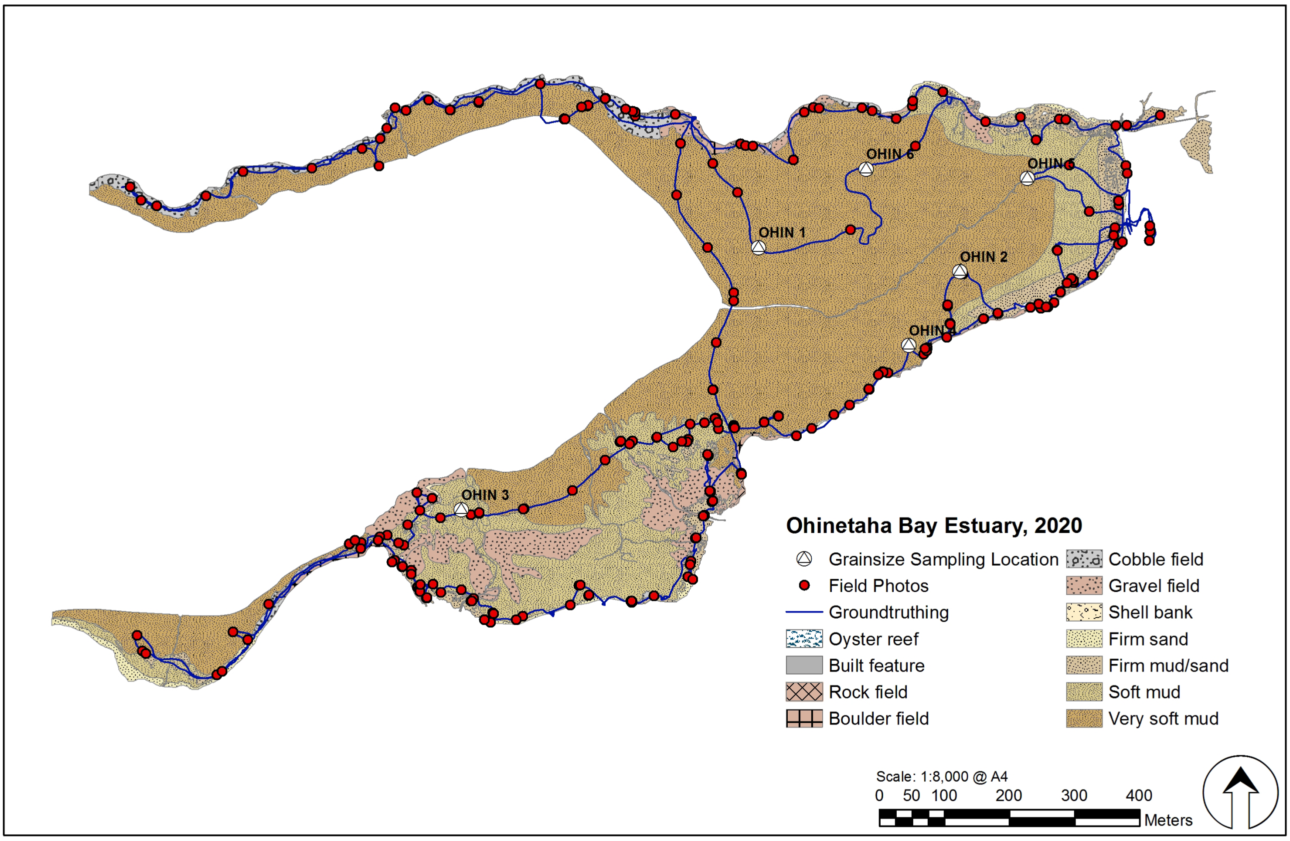
Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.

Shell bank: Area that is dominated by dead shells.

Appendix D:

Sampling, Resolution and Accuracy

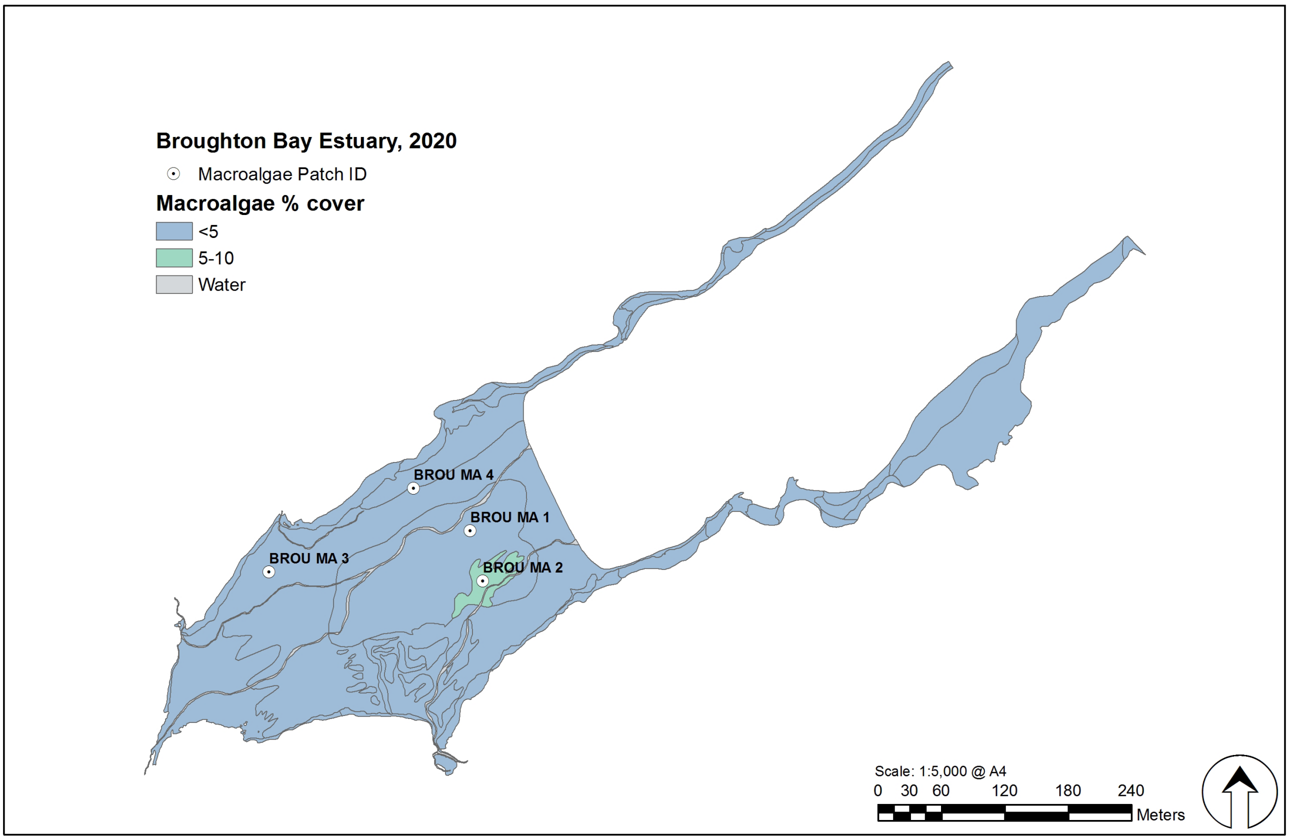


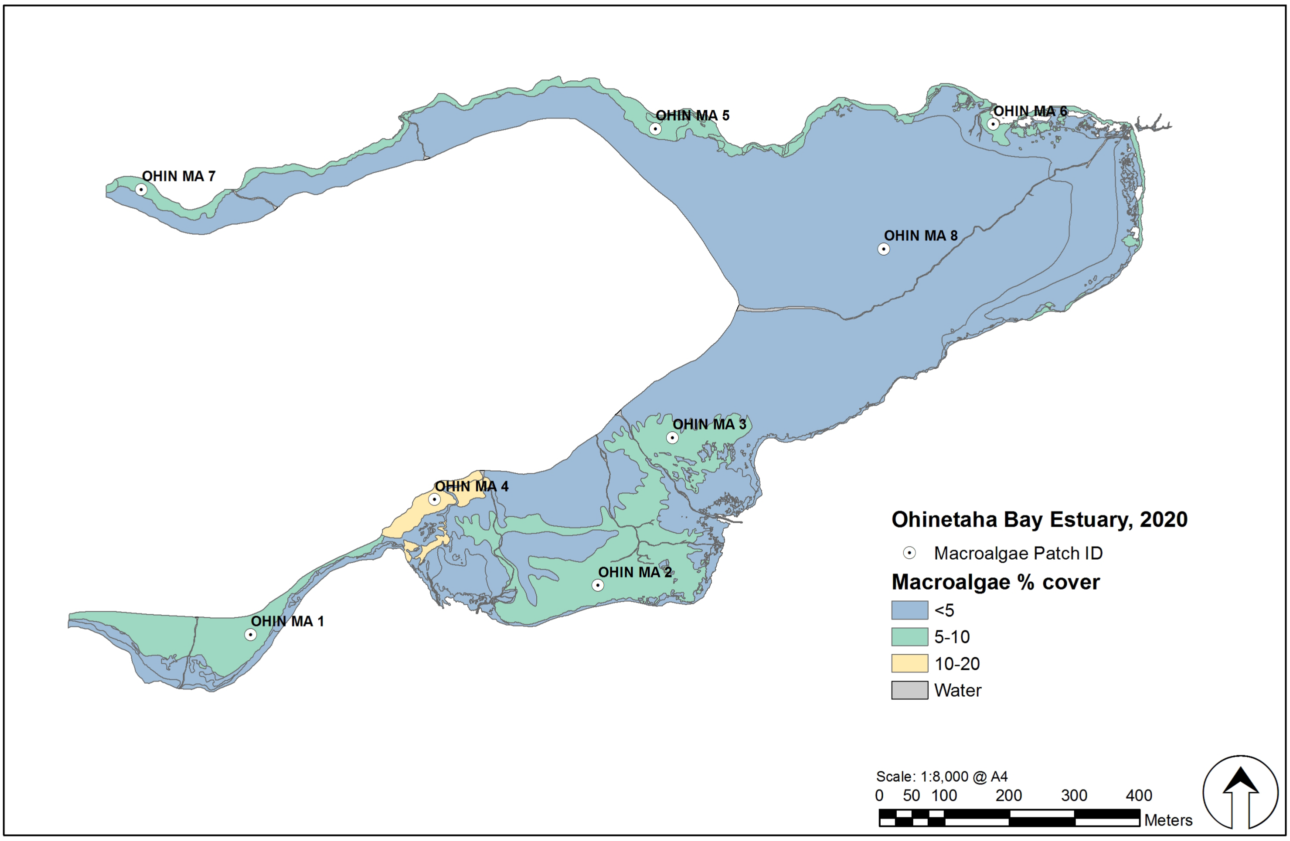


Groundtruthing, field photos and locations grain size samples used to validate substrata classifications, Broughton and Ohinetaha Bay Estuary, 2020.

Grain size results from representative sediments, Broughton and Ohinetaha Bays estuaries, 2020.												
			Gravel	Sand					Mud			
		Dry Matter of Sieved Sample	Fraction >/= 2 mm	Fraction < 2 mm, >/= 1 mm	Fraction < 1 mm, >/= 500 µm	Fraction < 500 µm, >/= 250 µm	Fraction < 250 µm, >/= 125 µm	Fraction < 125 µm, >/= 63 µm	Fraction < 63 µm			
Sample ID*	Broadscale Classification	g/100g as rcvd	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	g/100g dry wt	NZTM East	NZTM North	aRPD depth (cm)
BROU-1	Soft Mud / Gravel	76	14.8	15.8	8.8	4.6	4.3	9.3	42.5	1678775	5436766	1.0
BROU-2	Soft Mud	69	4.5	5.2	3.2	4.5	7	18.1	57.5	1678830	5436821	1.0
BROU-3	Firm Sand Mud / Gravel	82	10.9	18.3	16	12.5	8.9	12.9	20.4	1678823	5436750	2.0
BROU-4	Soft Mud / Gravel	72	15.8	12.2	9.4	7.4	5.4	8.1	41.7	1678717	5436735	1.0
OHIN-1	Very Soft Mud	50	0.2	0.4	0.6	1.9	3.5	4.5	89.0	1677447	5435824	0.5
OHIN-2	Very Soft Mud	71	1.9	2.2	1.6	1	2.3	31.5	59.5	1677677	5435922	0.5
OHIN-3	Firm Sand Mud / Gravel	76	31	13.9	10.9	9.6	7.3	6	21.4	1676692	5435440	2.0
OHIN-4	Very Soft Mud	70	5.5	8.4	6.3	3.5	1.8	10.2	64.3	1677375	5435708	0.5
OHIN-5	Very Soft Mud	65	7.2	10.2	2.4	0.9	0.8	4.2	74.3	1677550	5435969	0.5
OHIN-6	Very Soft Mud	55	0.3	0.2	0.2	0.2	0.7	4.5	93.9	1677302	5435981	0.5

*Refer to Appendix G for laboratory outputs.





Location of macroalgal patches (>5% cover) used in assessing macroalgae in Broughton and Ohintehaha Bays estuaries, February 2020.

Sediment sampling and analysis

Grain size samples were collected from representative mud and sand habitats (to validate substrata classifications) by sampling a composite of the top 20 mm of sediment (approx. 500 g in total) using a plastic trowel. Samples were placed inside a numbered plastic bag, refrigerated within 4 hours of sample collection before being frozen and sent to R.J. Hill Laboratories for grain size analysis (% mud, sand, gravel). Details of lab methods and detection limits are presented in Appendix G. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

Sampling resolution and accuracy

Broad scale mapping is intended to provide a rapid overview of estuary condition based on the mapping of features visible on aerial photographs, supported by ground-truthing to validate the visible features.

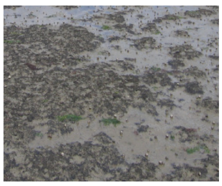
The ability to correctly identify and map features is primarily determined by the resolution of the available photos, the extent of ground-truthing undertaken, and the experience of those undertaking the mapping.

The spatial accuracy of the subsequent digital maps is determined largely by the photo resolution and accuracy of the orthorectified imagery. 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 1-2 m of their boundaries. The largest area for potential error is where boundaries are not readily visible on photographs e.g. sparse seagrass beds, or where there is a transition between features, e.g. where firm muddy sands transition to soft muds across a continuum. Defining such boundaries requires field validation. Extensive mapping experience has shown that such boundaries can be mapped to within ±10 m where they have been thoroughly ground-truthed using NEMP classifications.

Because of the inherent variation introduced when estimating boundaries not readily visible on photographs, or when grouping variable or non-uniform patches (e.g. seagrass), the overall broad scale accuracy is unlikely to be better than ±10% for such features.

Where initial broad scale mapping results indicate a need for greater resolution of boundaries (e.g. to increase certainty about the extent of soft mud areas), or to define changes within NEMP categories (e.g. to define the mud content within firm muddy sand habitat), then issue-specific approaches are recommended. The former includes more widespread ground-truthing, and the latter the use of transect or grid based grain size sampling.

Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom) in this report.

1-5%	6-10%	11-20%	21-50%	51-80%	81-100%
					
					

Appendix E:

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.

Summary of intertidal OMBT/EQR Score calculation, Broughton Bay Estuary, February 2020.			
Metric	Face Value	Final Equi-distant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	11		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 where Total % cover = Sum of {(patch size) / 100} x average % cover for patch	4	0.83	High
Biomass of AIH (g ww m^{-2}) = Total biomass / AIH where Total biomass = Sum of (patch size x average patch biomass)	18	0.96	High
Biomass of Affected Area (g ww m^{-2}) = Total biomass / AA where Total biomass = Sum of (>5% cover patch size x average patch biomass)	81	0.84	High
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	0	1.00	High
Affected Area (use the lowest of the following two metrics)		0.96	High
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	2	0.96	High
Size of AA in relation to AIH (%) = (AA / AIH) x 100	18	0.58	Moderate
Overall macroalgal Ecological Quality Rating - EQR (Average of FEDS)		0.92	High

Summary of intertidal OMBT/EQR Score calculation, Ohinetaha Bay Estuary, February 2020.			
Metric	Face Value	Final Equi-distant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	48		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 where Total % cover = Sum of {(patch size) / 100} x average % cover for patch	4	0.83	High
Biomass of AIH (g ww m^{-2}) = Total biomass / AIH where Total biomass = Sum of (patch size x average patch biomass)	15	0.97	High
Biomass of Affected Area (g ww m^{-2}) = Total biomass / AA where Total biomass = Sum of (>5% cover patch size x average patch biomass)	53	0.89	High
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	0	1.00	High
Affected Area (use the lowest of the following two metrics)		0.80	High
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	10	0.80	High
Size of AA in relation to AIH (%) = (AA / AIH) x 100	21	0.57	Moderate
Overall macroalgal Ecological Quality Rating - EQR (Average of FEDS)		0.90	High

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

1. Percentage cover of the available intertidal habitat (AIH): the percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH with macroalgal cover >5% are mapped spatially;
2. Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH,%). In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric established is the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the water body. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worst case scenario;
3. Biomass of AIH (g ww 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 ww m^{-2}): Mean biomass of Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.
5. Presence of Entrained Algae (percent of quadrats): Algae are considered entrained in muddy sediment when they are found growing >3 cm 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. Buildup 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 surfacesediment was included in the tool.

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

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

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 (see below Table).

- 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 50 ha 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 10 ha. 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 <100 g ww m^{-2}. 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 ww m^{-2} was an acceptable level above the reference level of <100 g ww m^{-2}. In Good status only slight deviation from High status is permitted so 500 g ww 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 ww m^{-2} but less than 1,000 g ww m^{-2} would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1000 g ww m^{-2} causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).

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

EQR Calculation: Each metric in the OMBT has equal weighting and is combined to produce the Ecological Quality Ratio score (EQR). The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the following categories (modified from UK-WFD 2014):

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g ww m^{-2}) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g ww m^{-2}) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae >3 cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

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Appendix F:

Sediment Loads & NZ ETI Details

Catchment-derived sediment load predictions:

Currently, there is insufficient information to identify robust sedimentation susceptibility thresholds for NZ estuaries, but in order to provide a tentative desktop estimate of the potential for ongoing sedimentation, the magnitude of modelled estimates of the Current State Sediment load (CSSL) can be compared with estimates of the historic Natural State Sediment Load (NSSL). The NSSL can be estimated by assuming a native forest land cover and the presence of sufficient catchment wetlands to retain 50 % of the load. In effect, such a ratio of CSSL/NSSL indicates whether appropriate soil conservation practices are currently undertaken in the catchment (e.g. a high ratio indicating further effort is required). Natural state sediment loads (NSSL) were estimated with all landuse set at native forest cover and corrected for wetland attenuation. Final NSSL = NFL x NSWA where NFL is Native forest load (kt yr^{-1}) and NSWA is the estimated natural state wetland attenuation for suspended sediment. In this case, NSWA is estimated as 0.5, indicating a mean wetland removal efficiency of ~50%. This assumption is based on the following study results:

- A wetland complex, draining suburban catchments in Wisconsin USA, attenuated ~71%, 21%, and 13% of the annual loads of SS, TP and TN respectively over a four year period (Kreiling et al., 2013).
- Previous studies in New Zealand (McKergow et al. 2007; Tanner et al. 2010) and around the world (Kadlec & Wallace 2009; Mitsch & Grosslink 2007) have identified the need for wetland areas of 1-5% of the contributing catchment to provide reasonable levels of nutrient attenuation in humid-climate agricultural landscapes. Depending on the specific attributes of suspended solids, smaller wetland areas in the range of 0.1-1% of contributing catchment can often achieve satisfactory suspended sediment removal.
- The average stormwater suspended sediment removal efficiency for a large number of both NZ and international wetlands showed a mean of 58% (International BMP Database 2007, as presented in Semadeni-Davies 2009).

For the present estuaries, the chosen CSSL/NSSL ratio thresholds were as follows: low 1-1.1, moderate 1.1-2, high 2-5, very high >5. Catchment sediment load estimates were derived from the NIWA CLUES modelling system[1]. The load threshold ratings were then combined (using the matrix below) with ratings for the likelihood of sediment trapping based on the assumption that high susceptibility SIDEs estuaries are physically susceptible to fine sediment accumulation.

[1] CSSL estimated using CLUES (default setting of REC2 and LCBB3 (2008/2009) land cover), NSSL estimated by setting CLUES land cover to native forest, with a further 50% reduction applied as per the points above.

	Current State Sediment Load (CSSL)/Natural State Sediment Load (NSSL)			
Estuary Category	CSSL = 1 to 1.1 x NSSL	CSSL = 1.1 to 2 x NSSL	CSSL = 2 to 5 x NSSL	CSSL > 5 x NSSL
SIDEs with areas of poorly flushed habitat	Very Low Susceptibility	Low Susceptibility	Moderate Susceptibility	High Susceptibility

NZ ETI calculation and outputs:

The NZ ETI (Robertson et al. 2016a,b, Plew et al. 2020) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness issues. An integrated online calculator is available [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/] to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary), as well as trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]. The more indicators included, the more robust the NZ ETI score becomes. The indicators used to derive an NZ ETI score and determine trophic state for Broughton and Ohinetaha Bays estuaries at the time the 2020 monitoring was undertaken (10^{th}-12^{th} February) are presented below using the broad scale monitoring results (this report). The input values used in the online calculator are presented overleaf. NZ ETI Tool 1 rates the physical and nutrient load susceptibility of both estuaries as minimal (Band A). NZ ETI Tool 2 online calculator scores Broughton Bay and Ohinetaha Bay as 0.30 and 0.45, a respective rating of minimal (Band A) and moderate (Band B). These scores reflect the absence of primary eutrophic symptoms from both estuaries and the sediment muddiness/poor oxygenation problem in Ohinetaha Bay.

NZ ETI scoring summary for Broughton Bay Estuary, February 2020.			
Primary Symptom Indicators for Shallow Intertidal Dominated Estuaries (At least 1 primary symptom indicator required)			Primary symptom value
Required	Opportunistic Macroalgae	Macroalgal Ecological Quality - Opportunistic Macroalgal Blooming Tool (OMBT) coefficient*	0.92
Required	Macroalgal Gross Nuisance Zone (GNA) %	% Gross Nuisance Area (GNA)/Estuary Area*	0.0%
Required	Macroalgal GNA (ha)	Gross Nuisance Area (GNA) (ha)*	0.0%
Optional	Phytoplankton biomass	Chl a (summer 90 pctl, mg m^{-3})	-
Optional	Cyanobacteria (if issue identified) - NOTE NZ ETI rating not yet developed		-
Supporting Indicators for Shallow Intertidal Dominated Estuaries (Must include a minimum of 1 required indicator)			Supporting Indicator Value
Required indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1 cm depth in most impacted sediments and representing at least 10% of estuary area*	-42.0
Required indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm	-
Required indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm	-
Required indicators	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area	-
Required indicators	Sediment Total Nitrogen	Mean TN (mg kg^{-1}) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area	-
Required indicators	Macroinvertebrates	Mean NZ AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10% of estuary area	-
Optional	Sediment muddiness	% estuary area with soft mud (>25 % mud content)*	3.0%
Optional	Sedimentation rate	Ratio of mean estimated annual Current State Sediment Load (CSSL) relative to mean estimated annual Natural State Sediment Load (NSSL)**	3.0
Optional	Dissolved Oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case condtions) (mg m^{-3})	-
Overall NZ ETI Score			**0.30**
			Minimal

* Based on 2020 broad scale findings (this report).
** Sediment loads estimated from NIWA's CLUES modelling system.

NZ ETI scoring summary for Ohinetaha Bay Estuary, February 2020.			
Primary Symptom Indicators for Shallow Intertidal Dominated Estuaries (At least 1 primary symptom indicator required)			Primary symptom value
Required	Opportunistic Macroalgae	Macroalgal Ecological Quality - Opportunistic Macroalgal Blooming Tool (OMBT) coefficient*	0.90
	Macroalgal Gross Nuisance Zone (GNA) %	% Gross Nuisance Area (GNA)/Estuary Area*	0.0%
	Macroalgal GNA (ha)	Gross Nuisance Area (GNA) (ha)*	0.0%
Optional	Phytoplankton biomass	Chl a (summer 90 pctl, mg m^{-3})	-
	Cyanobacteria (if issue identified) - NOTE NZ ETI rating not yet developed		-
Supporting Indicators for Shallow Intertidal Dominated Estuaries (Must include a minimum of 1 required indicator)			Supporting Indicator Value
Required indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1 cm depth in most impacted sediments and representing at least 10% of estuary area*	-168.0
		% of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm	-
		Ha of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm	-
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area	-
	Sediment Total Nitrogen	Mean TN (mg kg^{-1}) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area	-
	Macroinvertebrates	Mean NZ AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10% of estuary area	-
Optional	Sediment muddiness	% estuary area with soft mud (>25 % mud content)*	72.0%
	Sedimentation rate	Ratio of mean estimated annual Current State Sediment Load (CSSL) relative to mean estimated annual Natural State Sediment Load (NSSL)**	2.7
	Dissolved Oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case condtions) (mg m^{-3})	-
		Overall NZ ETI Score	**0.45**
			Moderate

* Based on 2020 broad scale findings (this report).
** Sediment loads estimated from NIWA's CLUES modelling system.

Appendix G:

Analytical Results

Hill Laboratories
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Certificate of Analysis

Client:	Robertson Environmental	**Lab No:**	2324354 SPv1
Contact:	Ben Robertson	**Date Received:**	18-Feb-2020
	C/- Robertson Environmental	**Date Reported:**	30-Apr-2020
	89 Halifax Street East	**Quote No:**	103698
	Nelson 7010	**Order No:**	
		Client Reference:	MDC Estuary Project
		Submitted By:	Ben Robertson

Sample Type: Sediment

Sample Name:		OHIN-1 10-Feb-2020	OHIN-2 10-Feb-2020	OHIN-3 10-Feb-2020	OHIN-4 10-Feb-2020	OHIN-5 10-Feb-2020
Lab Number:		2324354.1	2324354.2	2324354.3	2324354.4	2324354.5
7 Grain Sizes Profile as received						
Dry Matter of Sieved Sample	g/100g as rcvd	50	71	76	70	65
Fraction >/= 2 mm	g/100g dry wt	0.2	1.9	31.0	5.5	7.2
Fraction < 2 mm, >/= 1 mm	g/100g dry wt	0.4	2.2	13.9	8.4	10.2
Fraction < 1 mm, >/= 500 µm	g/100g dry wt	0.6	1.6	10.9	6.3	2.4
Fraction < 500 µm, >/= 250 µm	g/100g dry wt	1.9	1.0	9.6	3.5	0.9
Fraction < 250 µm, >/= 125 µm	g/100g dry wt	3.5	2.3	7.3	1.8	0.8
Fraction < 125 µm, >/= 63 µm	g/100g dry wt	4.5	31.5	6.0	10.2	4.2
Fraction < 63 µm	g/100g dry wt	89.0	59.5	21.4	64.3	74.3

Sample Name:		OHIN-6 10-Feb-2020	EL-1 14-Feb-2020	EL-2 14-Feb-2020	EL-3 14-Feb-2020	EL-4 14-Feb-2020
Lab Number:		2324354.6	2324354.7	2324354.8	2324354.9	2324354.10
7 Grain Sizes Profile as received						
Dry Matter of Sieved Sample	g/100g as rcvd	55	75	72	77	73
Fraction >/= 2 mm	g/100g dry wt	0.3	9.5	2.4	10.4	4.4
Fraction < 2 mm, >/= 1 mm	g/100g dry wt	0.2	4.7	0.6	9.4	2.6
Fraction < 1 mm, >/= 500 µm	g/100g dry wt	0.2	5.8	0.5	13.1	8.0
Fraction < 500 µm, >/= 250 µm	g/100g dry wt	0.2	19.4	1.3	22.6	21.4
Fraction < 250 µm, >/= 125 µm	g/100g dry wt	0.7	36.0	12.5	21.2	31.3
Fraction < 125 µm, >/= 63 µm	g/100g dry wt	4.5	16.3	57.1	15.1	25.9
Fraction < 63 µm	g/100g dry wt	93.9	8.4	25.6	8.3	6.3

Sample Name:		EL-5 14-Feb-2020	WT-1 14-Feb-2020	WT-2 14-Feb-2020	WT-3 14-Feb-2020	WT-4 14-Feb-2020
Lab Number:		2324354.11	2324354.12	2324354.13	2324354.14	2324354.15
7 Grain Sizes Profile as received						
Dry Matter of Sieved Sample	g/100g as rcvd	70	71	75	77	74
Fraction >/= 2 mm	g/100g dry wt	< 0.1	2.5	0.7	15.1	0.3
Fraction < 2 mm, >/= 1 mm	g/100g dry wt	0.1	1.3	0.4	10.3	0.1
Fraction < 1 mm, >/= 500 µm	g/100g dry wt	1.2	1.5	0.9	12.0	0.8
Fraction < 500 µm, >/= 250 µm	g/100g dry wt	19.4	2.3	3.5	14.6	3.6
Fraction < 250 µm, >/= 125 µm	g/100g dry wt	32.3	7.9	20.5	10.1	12.4
Fraction < 125 µm, >/= 63 µm	g/100g dry wt	40.6	58.4	40.5	9.2	39.2
Fraction < 63 µm	g/100g dry wt	6.4	26.0	33.4	28.7	43.7

Sample Name:		WT-5 14-Feb-2020	AHU-1 13-Feb-2020	AHU-2 13-Feb-2020	AHU-3 13-Feb-2020	AHU-4 13-Feb-2020
Lab Number:		2324354.16	2324354.17	2324354.18	2324354.19	2324354.20
7 Grain Sizes Profile as received						
Dry Matter of Sieved Sample	g/100g as rcvd	73	73	71	75	76
Fraction >/= 2 mm	g/100g dry wt	0.5	16.7	1.6	0.8	0.2
Fraction < 2 mm, >/= 1 mm	g/100g dry wt	0.2	5.3	0.9	0.1	0.1
Fraction < 1 mm, >/= 500 µm	g/100g dry wt	0.4	5.5	0.9	0.2	0.2
Fraction < 500 µm, >/= 250 µm	g/100g dry wt	2.4	8.5	2.2	1.7	5.4

Sample Type: Sediment						
	Sample Name:	WT-5 14-Feb-2020	AHU-1 13-Feb-2020	AHU-2 13-Feb-2020	AHU-3 13-Feb-2020	AHU-4 13-Feb-2020
	Lab Number:	2324354.16	2324354.17	2324354.18	2324354.19	2324354.20
7 Grain Sizes Profile as received						
Fraction < 250 µm, >/= 125 µm	g/100g dry wt	32.6	13.8	7.3	27.7	40.1
Fraction < 125 µm, >/= 63 µm	g/100g dry wt	55.9	19.4	50.4	62.3	45.8
Fraction < 63 µm	g/100g dry wt	8.1	30.8	36.7	7.2	8.1

	Sample Name:	BROU-1 12-Feb-2020	BROU-2 12-Feb-2020	BROU-3 12-Feb-2020	BROU-4 12-Feb-2020	
	Lab Number:	2324354.21	2324354.22	2324354.23	2324354.24	
7 Grain Sizes Profile as received						
Dry Matter of Sieved Sample	g/100g as rcvd	76	69	82	72	-
Fraction >/= 2 mm	g/100g dry wt	14.8	4.5	10.9	15.8	-
Fraction < 2 mm, >/= 1 mm	g/100g dry wt	15.8	5.2	18.3	12.2	-
Fraction < 1 mm, >/= 500 µm	g/100g dry wt	8.8	3.2	16.0	9.4	-
Fraction < 500 µm, >/= 250 µm	g/100g dry wt	4.6	4.5	12.5	7.4	-
Fraction < 250 µm, >/= 125 µm	g/100g dry wt	4.3	7.0	8.9	5.4	-
Fraction < 125 µm, >/= 63 µm	g/100g dry wt	9.3	18.1	12.9	8.1	-
Fraction < 63 µm	g/100g dry wt	42.5	57.5	20.4	41.7	-

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
7 Grain Sizes Profile as received			
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	1-24
Fraction >/= 2 mm	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-24
Fraction < 2 mm, >/= 1 mm	Wet sieving using dispersant, as received, 2.00 mm and 1.00 mm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-24
Fraction < 1 mm, >/= 500 µm	Wet sieving using dispersant, as received, 1.00 mm and 500 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-24
Fraction < 500 µm, >/= 250 µm	Wet sieving using dispersant, as received, 500 µm and 250 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-24
Fraction < 250 µm, >/= 125 µm	Wet sieving using dispersant, as received, 250 µm and 125 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-24
Fraction < 125 µm, >/= 63 µm	Wet sieving using dispersant, as received, 125 µm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-24
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-24

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Dates of testing are available on request. Please contact the laboratory for more information.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Appendix H:

Representative Field Photographs

Broughton Bay Estuary

Photo 1-6: Saltmarsh, including narrow strips of rushland and herbfield, and the fringing native vegetated terrestrial margin near the main stream channels at the head of the estuary.

Broughton Bay Estuary




Photo 7-10: Localised area of soft mud-dominated habitat in the lower estuary deposition zone and a narrow band of gravel/cobble habitat lining the adjacent shoreline.


Photo 11-12: Central intertidal flats with relatively well oxygenated firm sand muds supporting sparse macroalgal cover (<5%) and cockles in several localised, high density patches further towards the low tide mark.

Broughton Bay Estuary

Photo 13-16: Seagrass rooted in firm mud sands in the mid-upper estuary margins.

Photo 17: Firm sandy mud substrata harbouring a patch of low density macroalgae (combination of *Gracilaria chilensis* and *Ulva intestinalis*) within the mid-lower estuary.

Broughton Bay Estuary

Photo 18-23: Sabellid tube worm (*Spirobranchus cariniferus*), macroaglae (*Hormosira banksii*), and mussels attached to rocky substratum along the lower estuary intertidal shoreline.

Ohinetaha Bay Estuary

Photo 24-29: Rushland (searush, jointed wirerush and three-square) bordered seaward by herbfield (glasswort, primrose, remuremu) at the margins towards the head of the estuary, with the predominantly native scrub and forest catchment featured in the background.

Ohinetaha Bay Estuary

Photo 30-33: Poorly oxygenated, soft muddy sediments throughout the central basin and lower estuary reaches.

Photo 34-35: Cockle shell banks interspersed with soft muds, middle reaches, on the true left arm of the estuary.

Ohinetaha Bay Estuary

Photo 36-39: Seagrass habitat localised to patches in the mid-upper estuary margins.

Photo 40: Lower tidal reaches dominated by unvegetated, poorly oxygenated soft mud habitat.

Ohinetaha Bay Estuary






Photo 40-46: Firm sands, and Pacific oysters attached to rocky substratum, along the mid-lower estuary intertidal shoreline.

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