coastalmanagement

Okiwa and Ngakuta Bays

Broad Scale Habitat Mapping 2018

Prepared for

Marlborough District Council

June 2018

Cover Photo: Okiwa Bay, seagrass nestled within raised gravel beds in the lower intertidal zone, March 2018.

Intertidal rushland at the head of Okiwa Bay, March 2018

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by

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EXECUTIVE SUMMARY

Ngakuta and Okiwa Bays are located in Grove Arm at the south-western end of Queen Charlotte Sound/Tōtaranui, west of Picton, Marlborough. They are modified, moderate sized (Ngakuta 12ha, Okiwa 85ha), mesotidal (<1.6m spring tidal range), shallow (mean depth ~0.75m at high water), well-flushed (residence time <1 day), and seawater-dominated intertidal delta estuaries. The catchments are dominated by native scrub and forest (97% Ngakuta, 57% Okiwa). The bays are priorities within Marlborough District Council's (MDC's) long-term coastal monitoring programme. This report presents the results of the March 2018 broad scale estuary habitat mapping, including discussion of estuary condition and issues and monitoring recommendations.

BROAD SCALE RESULTS

Dominant Estuary Feature	Ngakuta Bay			Okiwa Bay		
	ha	%	Rating	ha	%	Rating
Intertidal saltmarsh	0.9	7.4	Moderate	5.3	6.2	Moderate
Intertidal seagrass (>20% cover)	1.1	8.8	Good	2.5	3.0	Good
Intertidal macroalgal beds (>50% cover)	0.0	0.0	Very Good	32.7	38.4	Moderate
Intertidal substrate (unvegetated)	9.9	82.2	-	39.9	47.0	-
Subtidal	0.2	1.6	-	4.6	5.4	-
Total Estuary	**12.0**	**100**		**85.0**	**100**	
Soft mud extent	0.2	2	Good	9.2	11	Moderate
Reduced sediment oxygenation	0.2	2	Good	9.2	11	Poor
Gross Eutrophic Zones	0	0	Very Good	0	0	Very Good
Vegetated 200m terrestrial margin		62	Good		46	Moderate
NZ Estuary Trophic Index (ETI) score	0.15		Very Good	0.46		Moderate

ESTUARY CONDITION AND ISSUES

Broad scale habitat mapping undertaken in March 2018, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification), have been used to assess overall estuary condition. Okiwa Bay substrate was dominated by firm sands and firm sandy muds, the latter with a high mud content (~40%) but containing extensive cockle beds. On the lower intertidal edge of the delta there were extensive beds of macroalgae, but conditions remained moderate due to limited entrainment in sediments and underlying sediment oxygenation remaining good in those areas. There had been a large increase in reported macroalgal expression since the previous monitoring undertaken in 2011. Soft mud habitat (11%) was rated poor for sediment oxygenation. Seagrass was uncommon in mud habitats but was extensive in Thompson Bay to the north and at the edges of Okiwa Bay. Saltmarsh, although significantly reduced in extent from historical cover, flanked much of the upper estuary and appeared in healthy condition with relatively few weeds and introduced grasses in the intertidal zone. Common catchment stressors of fine sediment and nutrients were considered moderate issues.

Ngakuta Bay substrate was dominated by firm muddy sands and gravels with only small areas of soft mud. It was not expressing eutrophic symptoms (no significant macroalgal growth), had relatively large beds of seagrass, healthy saltmarsh, and a native forest/scrub dominated catchment. Historical habitat loss and modification has been limited in extent although much of the shoreline is now protected with seawalls. Commonly observed catchment based stressors, particularly excessive inputs of fine sediment and nutrients, were not significant issues.

The results place Ngakuta Bay in a GOOD state, and Okiwa Bay in a MODERATE state in relation to ecological health.

RECOMMENDED MONITORING

The following monitoring recommendations are proposed for consideration by MDC:

Broad Scale Habitat Mapping. To characterise any issues of change in habitat (e.g. soft mud extent, saltmarsh or seagrass area), unless obvious changes are observed in the interim, it is recommended that broad scale habitat mapping be undertaken at ten yearly intervals for Ngakuta Bay (next scheduled for consideration in 2028), and at five yearly intervals for Okiwa Bay (next scheduled for consideration in 2023).

Macroalgae. Because of the large reported increase in macroalgal cover from 2011 to 2018 it is recommended that MDC consider collecting additional information from local residents to characterise the changes over the interim years and consider the use of citizen based science approaches to maintain a watching brief on future changes. Summarising any known changes within the catchment over the past five years that may help explain the increased algal growth and reviewing available water quality data to indicate the likely influence of marine derived nutrient inputs to the head of Grove Arm, and the 2018 summer marine "heat wave" is also recommended.

Fine Scale Monitoring. To provide detailed assessment of the sediment dwelling biological community, and to characterise key estuary indicators such as sediment heavy metals and nutrients, it is recommended that two fine scale intertidal monitoring sites be established in Okiwa Bay, one site located within the dominant firm sandy mud habitat of the estuary, and one site in a deposition zone of soft muds (i.e. to reflect the worst 10% of the estuary). Because concerns have been raised in relation to the potential impact of land disturbance contributing to increased sediment deposition throughout the Marlborough Sounds, it is recommended that a series of sediment plates be buried in deposition areas within Okiwa Bay to act both as a reference point and a site for measuring potential impacts of sediment related changes in Queen Charlotte Sound.

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 Wriggle Coastal Management to map the broad scale intertidal habitat features of Okiwa Bay and Ngakuta Bay, located in the Grove Arm of Queen Charlotte Sound/Tōtaranui, Marlborough (Figure 1). The purpose of the work was to provide MDC with baseline information on the ecological condition of each site for state of the environment monitoring purposes and to help support planning and resource consent decision-making. The following report describes the methods and results of field sampling undertaken on 20-21 March 2018.

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 (see Appendix 1). The tiered approach includes:

i. **Ecological Vulnerability Assessment** (EVA) of estuaries to major 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 Okiwa and Ngakuta Bays to key issues has not yet been specifically assessed.

ii. **Broad Scale Habitat Mapping** (NEMP approach). This component documents the key intertidal bio-physical features and habitats, enables changes to these habitats to be assessed over time, and is used to define fine scale monitoring needs and management priorities. Broad scale baseline mapping of both bays was first undertaken in 2011 (Gillespie et al. 2012).

iii. **Fine Scale Monitoring** (NEMP approach). This component monitors physical, chemical and biological indicators within intertidal sediments to provide more detailed information on habitat condition, commonly within the dominant substrate type, as well as in the most susceptible part of each estuary (commonly upper estuary deposition zones).

The current report focuses on detailed broad scale habitat mapping undertaken in March 2018 to characterise the current state of key habitat features and uses a range of established broad scale indicators to assess ecological condition. Key indicators are described in Appendix 1 and include mapping and assessment of:

- Substrate types
- Sediment oxygenation
- Macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*)
- Seagrass (i.e. *Zostera muelleri*)
- Gross Eutrophic Zones (GEZs)
- Saltmarsh vegetation
- 200m terrestrial margin land cover
- Catchment land cover

Assessment of results uses a suite of indicator ratings developed for estuarine assessment (Table 1), many of which are included in the recently developed NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b). The ETI is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness.

1.3 REPORT STRUCTURE

The current report presents a brief introduction to the areas being assessed (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 or risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 4), and to guide monitoring recommendations (Section 5).

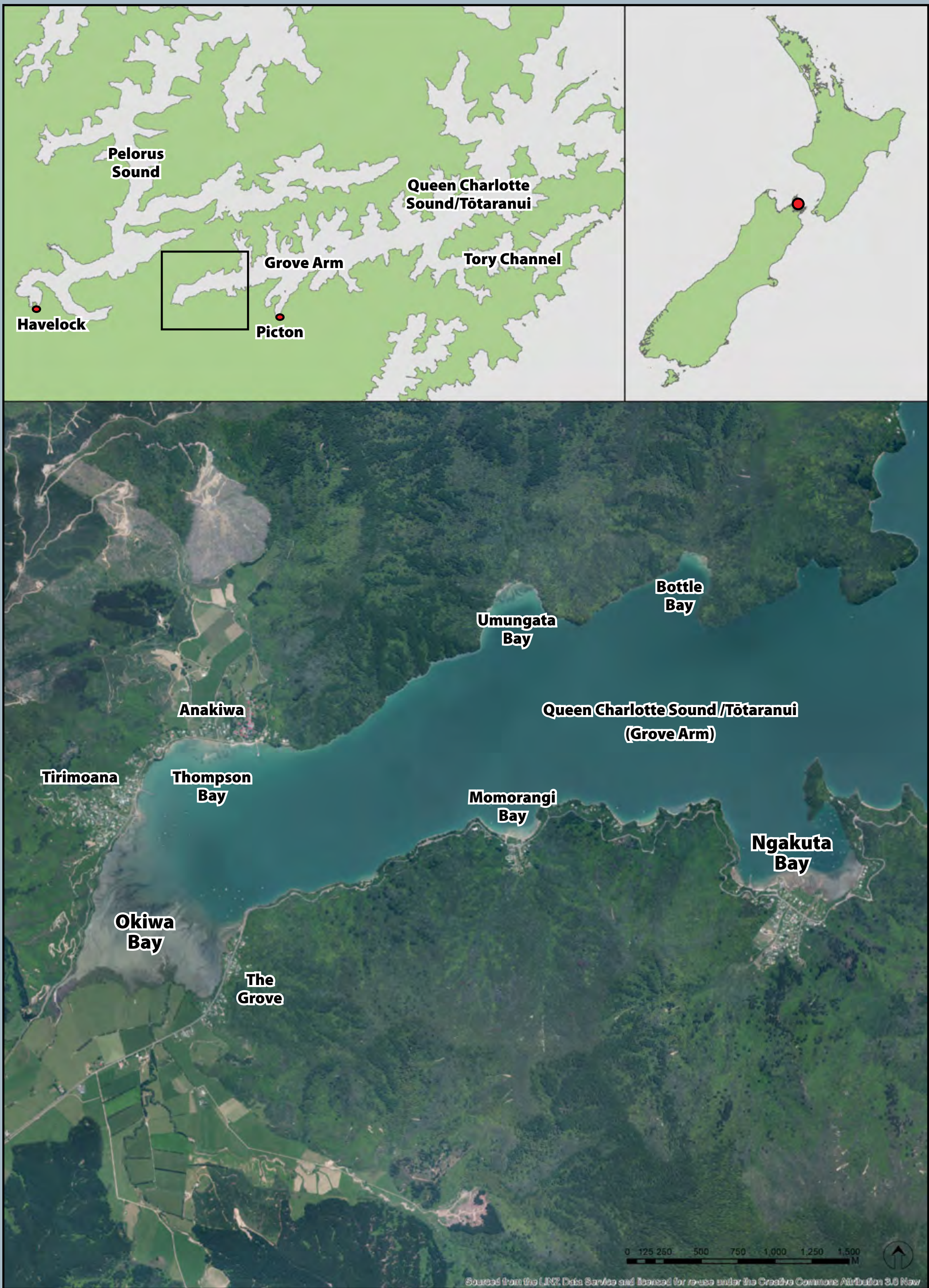


Figure 1. Location of Okiwa Bay and Ngakuta Bay, Grove Arm, Marlborough.

1. INTRODUCTION (CONTINUED)

1.4 STUDY SITES

The study sites defined by MDC are located in Grove Arm at the south-western end of Queen Charlotte Sound, west of Picton (Figure 1). Ngakuta Bay is situated midway along the southern shore of Grove Arm, and Okiwa Bay is situated at the head of Grove Arm. To the north of Okiwa Bay at Anakiwa is Thompson Bay. Although physically separated from Okiwa Bay by low cliffs north of Tirimoana and having different physical characteristics, Thompson Bay was mapped and reported on by Gillespie et al. (2012) as a contiguous part of Okiwa Bay. This combined coverage has been continued in the current study for consistency although there is merit in future assessments separating the two areas.

Like much of the Marlborough Sounds, Queen Charlotte Sound 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 and sheltered bays where sediment deposition from catchment erosion contributes to the natural build up of river and stream deltas (Figure 1). Both bays are dominated by marine tidal flows with relatively small freshwater inflows, and have gently sloping deltas that extend seawards until dropping off into the deeper waters of Grove Arm. The extent and nature of the intertidal and 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 substrate 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.

Okiwa Bay at the head of Grove Arm has a 35.3km^2 catchment fed via several small streams and tributaries that discharge onto a moderately large (85ha) intertidal delta. The southern part of Okiwa Bay supports the largest saltmarsh and wetland habitat in Queen Charlotte Sound, and is one of the larger wetland areas in the whole of the Marlborough Sounds, providing important habitat for several species of waterfowl (Davidson et al. 2011), as well as whitebait. Historically the lower valley at the head of Okiwa Bay is also likely to have supported extensive wetland and saltmarsh features. Present day land cover comprises 57% native forest, 25% exotic plantation forest, 16% grassland (including dairy farms) and 1% residential settlements at Tirimoana, Anakiwa and The Grove. Where valley floors have been developed into pasture there has generally been historical modification of the estuary margins primarily from channelisation and drainage, however saltmarsh is still relatively plentiful.

Ngakuta Bay has a much smaller catchment (6.8km^2) with two small streams draining onto a 12ha intertidal delta. Land cover in the steep, erodible catchment is dominated by native forest and scrub (96.5%) with small areas of exotic forest (0.7%), grassland (0.9%) and residential settlement (1.8%). The intertidal delta is dominated by cobble and gravel substrates near the stream inputs, and sandy substrates elsewhere. Due to the steep hillsides surrounding Ngakuta Bay, the natural extent of saltmarsh is relatively small.

Okiwa and Ngakuta Bays have relatively low nutrient loads - estimated catchment N areal loadings of ~58 and 41mg N.m^{-2}.d^{-1} respectively which are below the proposed guideline of ~100mgN.m^{-2}.d^{-1}, for shallow intertidally dominated estuaries (SIDEs) (Robertson et al. 2016b). Consequently both bays are predicted to have low susceptibility to eutrophication.

The ratio of the estimated current suspended sediment load (CSSL) compared to the estimated natural state sediment load (NSSL) is 1-1.1, an ETI rating of very good, reflecting the relatively high forest and scrub cover in the Ngakuta catchments, as well as on the steeper slopes in the Okiwa catchment. The bays are both rated as having low vulnerability to muddiness. However Okiwa Bay is vulnerable to increased sediment inputs if exotic forest harvesting in the catchment is not managed appropriately.

Ecologically, both bays are important for freshwater fish and birds, and Okiwa Bay has the largest area of intertidal flats in Queen Charlotte Sound. Grove Arm is reported to be subject to frequent toxic microalgal blooms (Mackenzie et al. 1998, 2004, cited in Gillespie et al. 2012).

Both Okiwa and Ngakuta bays have localised high use and are valued for their aesthetic appeal, bathing, boating, fishing, whitebaiting and beach access. The Outward Bound Trust of NZ has been based at Anakiwa since 1962, while historically Okiwa Bay and the surrounding lowlands were important areas for native forest harvesting (kahikatea) and dairy farming.

2. METHODS

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: 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 3 lists the definitions used to classify substrate 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.
- 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 to assess estuary condition in response to common stressors, and assess future change.

Site boundaries were set as the seaward edge of the tidal delta (as generally defined in the MDC work brief) to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For the current study, LINZ rectified colour aerial photos (~0.1m/pixel resolution) flown in 2017/18 were provided by MDC, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in March 2018 to ground truth the spatial extent of dominant vegetation and substrate types (see Appendix 6). From representative broad scale substrate types, 9 grain size samples were analysed to validate substrate classifications (Figures 3 and 4, Appendix 4). 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 Figure 2). Notes on sampling, resolution and accuracy are presented in Appendix 4.

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).
- 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) was 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 using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photos to produce habitat maps showing the dominant cover of: substrate, macroalgae (e.g. *Ulva, Gracilaria*), seagrass, saltmarsh vegetation, and the 200m 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.

Figure 2. Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom).

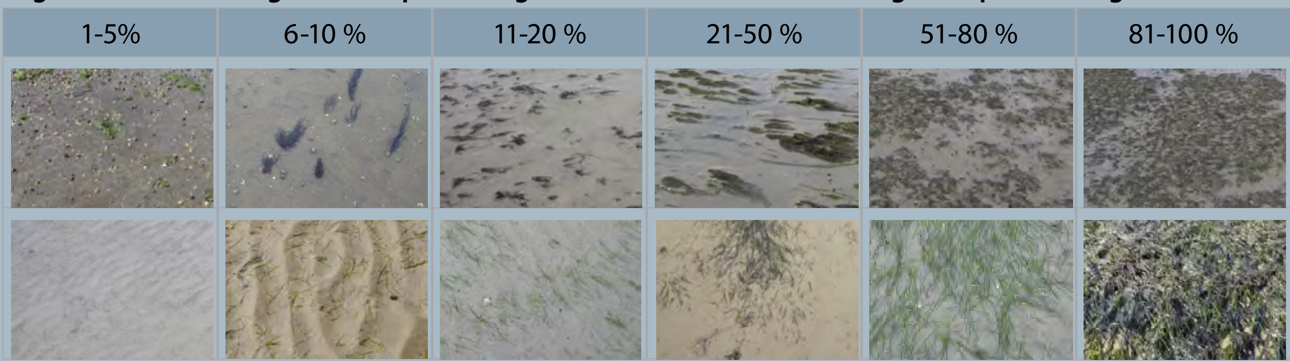


Table 1. Summary of estuary condition and risk indicator ratings used in the present report.

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
BROAD AND FINE SCALE INDICATORS — ETI Condition Rating	Very Good - Band A	Good - Band B	Moderate - Band C	Poor - Band D
Risk Rating	Very Low Risk	Low Risk	Moderate Risk	High Risk
Soft mud (% of unvegetated intertidal substrate)*	<1%	1-5%	>5-15%	>15%
Sediment Mud Content (%mud)*	<5%	5-10%	>10-25%	>25%
Apparent Redox Potential Discontinuity (aRPD)**	>2cm (Good or Very Good)		0.5-2cm	<0.5cm
Sediment Oxygenation (aRPD <0.5cm or RP@3cm<-150mV)*	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha 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	>20% decrease
Gross Eutrophic Zones (ha or % of intertidal area)	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Saltmarsh Extent (% of intertidal area)	>20%	>10-20%	>5-10%	0-5%
Supporting indicator — **Extent** (% remaining from est. natural state)	>80-100%	>60-80%	>40-60%	<40%
Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	<25%
Percent Change from Monitored Baseline	<5%	5-10%	>10-20%	>20%
NZ ETI score*	Band A (0-0.25)	Band B (0.25-0.50)	Band C (0.50-0.75)	Band D (0.75-1.0)

* NZ ETI (Robertson et al. 2016b), ** Hargrave et al. (2008), Keeley et al. (2012), See NOTES in Appendix 2 for further information.

Herbfields on raised gravel beds in front of rushland in central Ngakuta Bay.

3. RESULTS AND DISCUSSION

3.0. BROAD SCALE MAPPING SUMMARY

The 2018 broad scale habitat mapping ground truthed and mapped intertidal estuary substrate and vegetation as well as the dominant land cover of the 200m terrestrial margin. The dominant estuary features are summarised in Tables 2 and shown in Figures 3-9.

Both bays are intertidally dominated deltas that drain almost completely on the low tide. Ngakuta Bay and Thompson Bay in the north of Okiwa Bay are relatively long and narrow whereas Okiwa Bay proper has large and wide intertidal flats. Saltmarsh (6-7%) was located predominantly at the head of each bay where valley floors meet the sea. Saltmarsh is naturally limited by the surrounding hillsides in Ngakuta Bay but was historically much more extensive in Okiwa Bay. Intertidal seagrass was a relatively small but significant feature in each estuary (3-8%), while dense beds of (>50% cover) opportunistic macroalgae were only recorded in Okiwa Bay. No gross eutrophic zones were present. In Okiwa and Ngakuta Bays respectively, the 200m wide terrestrial margin retained a high proportion of dense vegetation (46-62%), and native forest cover in the surrounding catchments was also relatively high (57-96%).

In the following sections, various factors related to each of these key habitats (e.g. area of soft mud) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification (Tables 2 & 3). In addition, the GIS files underpinning this written report provide a more detailed spatial record of the key features present throughout each estuary and are intended as the primary supporting tool to help the Council address a suite of estuary issues and management needs, and to act as a baseline to assess future change.

Table 2. Summary of dominant broad scale features, Ngakuta and Okiwa Bays, March 2018.

Dominant Estuary Feature	Ngakuta Bay		Okiwa Bay	
	ha	%	ha	%
Intertidal saltmarsh	0.9	7.4	5.3	6.2
Intertidal seagrass (>20% cover)	1.1	8.8	2.5	3.0
Intertidal macroalgal beds (>50% cover)	0.0	0.0	32.7	38.4
Intertidal substrate (unvegetated)	9.9	82.2	39.9	47.0
Intertidal Total	11.8	98.4	80.4	94.6
Subtidal Total	0.2	1.6	4.6	5.4
Total Estuary	**12.0**	**100**	**85.0**	**100**
200m Terrestrial Margin (densely vegetated)		61.7		45.6
Catchment native forest cover	563	96.5	2024	57.3

Table 3. Supporting data used to assess estuary ecological condition.

Supporting Condition Measures	Ngakuta Bay	Okiwa Bay
Catchment Area (Ha)*	583	3532
Mean freshwater flow (m^3/s)*	0.1	0.74
Catchment nitrogen load (TN/yr)*	1.80	17.96
Catchment phosphorus load (T/Pyr)*	0.25	3.89
Catchment sediment load (KT/yr)*	1.54	14.12
Estimated N areal load in estuary ($mg/m^2/d$)	41.03	57.68
Estimated P areal load in estuary ($mg/m^2/d$)	5.68	12.49
Intertidal soft mud extent (%)	21	55
Macroalgal OMBT EQR score	1	0.45
Saltmarsh (estimated natural % remaining)	>80	<40
ETI susceptibility (Tool 1)	LOW	MODERATE
NZ ETI score (Tool 2)	0.16	0.65

*source NIWA Coastal Explorer database and CLUES model output.

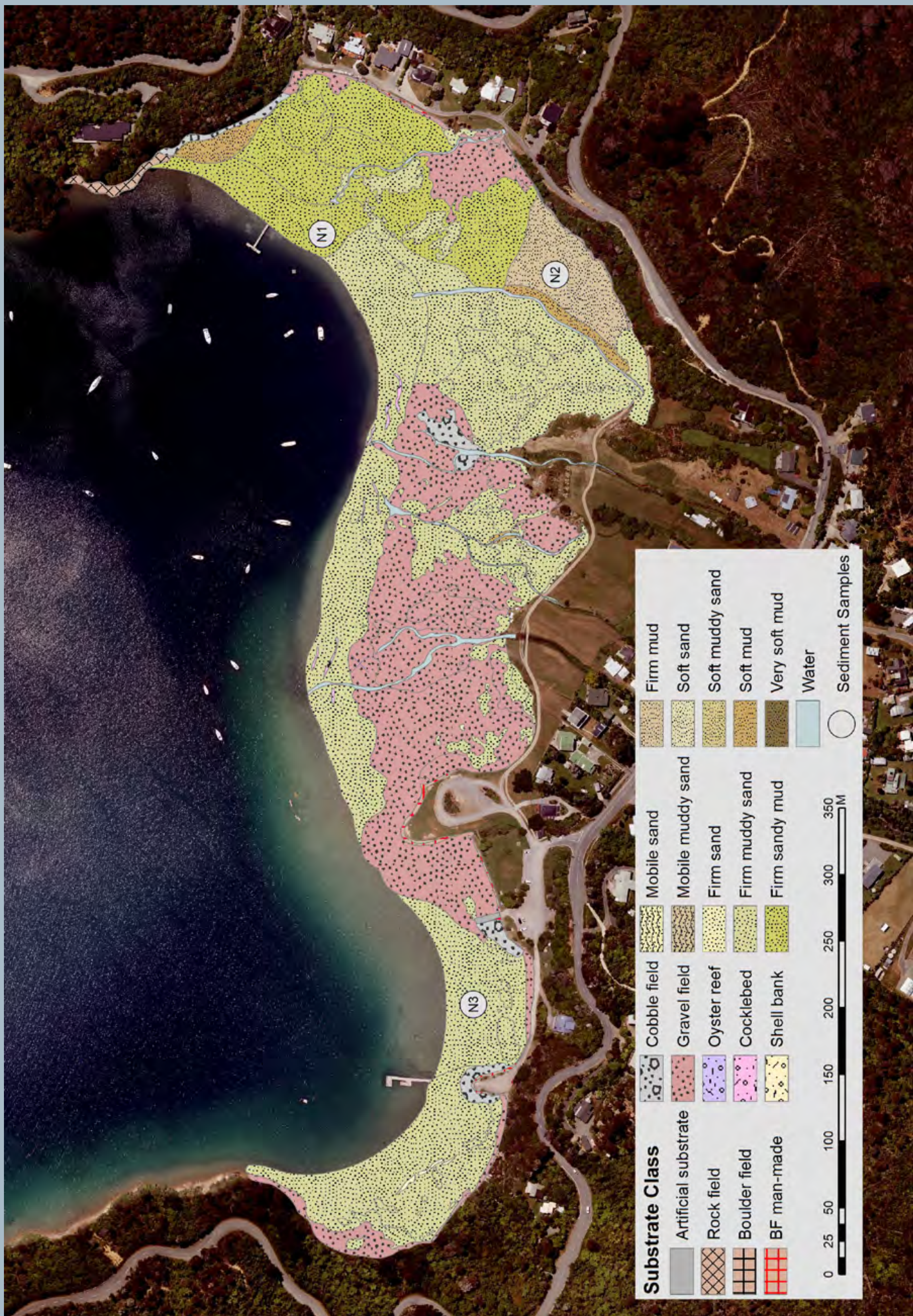


Figure 3. Map of dominant intertidal substrate - Ngakuta Bay, March 2018.

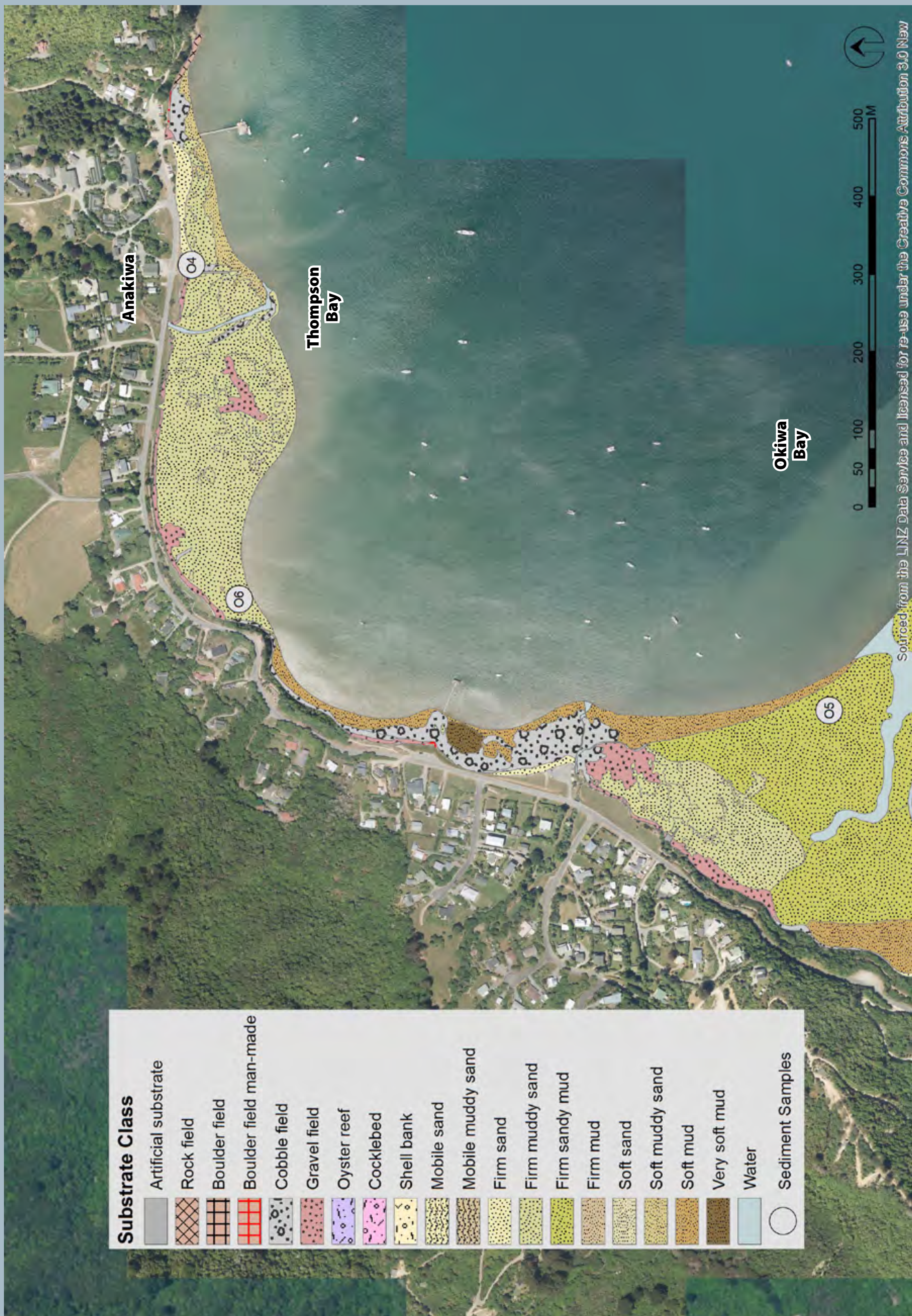


Figure 4a. Map of dominant intertidal substrate - Thompson Bay and Okiwa Bay (north), March 2018.

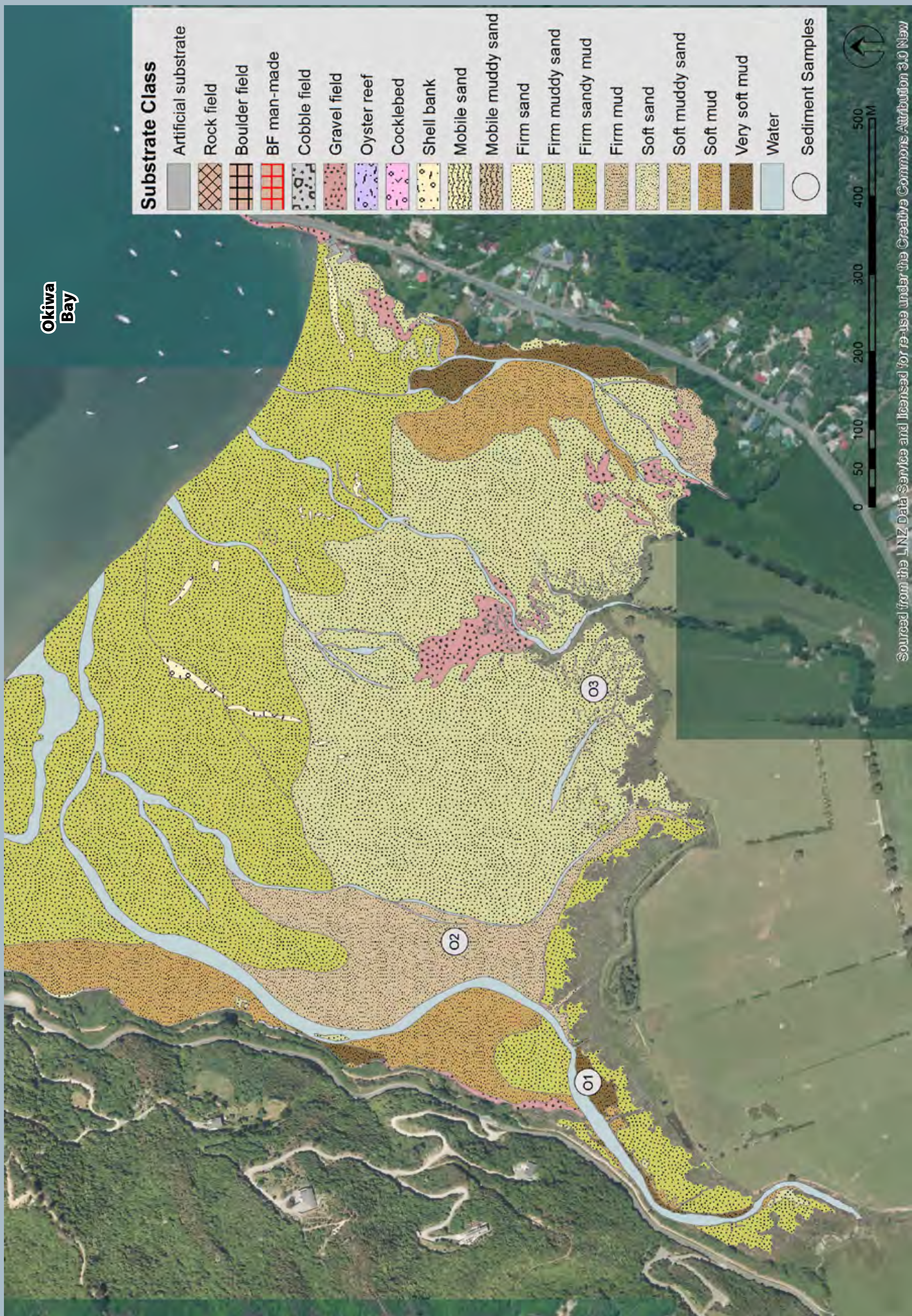


Figure 4b. Map of dominant intertidal substrate - Okiwa Bay (south), March 2018.

3. RESULTS AND DISCUSSION (CONTINUED)

3.1. INTERTIDAL SUBSTRATE

Results summarised in Table 4 and Figures 3 and 4 show intertidal substrate was dominated by different features at each site. Ngakuta Bay had extensive perched, centrally located cobble/gravel fields around mobile stream deltas, with firm muddy sands dominating the western end of the bay, and firm sandy muds at the eastern end. A similar pattern was evident in Thompson Bay at the north end of Okiwa Bay. In the main intertidal basin of Okiwa Bay to the south, stream mouth cobble sand gravels were also evident but in a much smaller proportion, with substrate dominated by large intertidal flats comprising firm muddy sand (35%), firm sandy mud (34%), and firm, soft and very soft muds (18%). Firm sandy mud habitat in the lower third of the estuary supported extensive beds of cockles, although because the beds were covered in macroalgae as well as muds they are hard to distinguish visually using aerial photography. Because of this they have been classified as firm sandy mud. Raised and defined beds of dead cockle shells were classified as shell bank.

Within vegetated areas, substrate among herbfields was predominantly cobble and gravel dominated, while substrate among rushland was dominated by firm mud or muddy sand. Seagrass beds (Section 3.4) were present in both bays growing in sand and mud substrates, often located in small depressions among raised gravel beds. Hard substrates (e.g. rock, boulder and cobble) were limited in extent and located mainly at the upper intertidal margins. No significant beds of mussels or other biogenic features e.g. tube worm reefs, were recorded as dominated habitats. Macroalgae was predominantly present on firm sandy muds and muddy sands in the lower intertidal reaches of Okiwa Bay (see Section 3.4).

Table 4. Summary of dominant intertidal substrate in Ngakuta and Okiwa Bays, March 2018.

Dominant Estuary Feature	Ngakuta Bay		Okiwa Bay	
	ha	%	ha	%
Intertidal substrate within saltmarsh				
Gravel field	0.3	2.8	0.4	0.5
Firm muddy sand	0.6	4.7	2.3	2.8
Firm mud/sandy mud			2.5	3.1
Soft mud			0.1	0.2
Intertidal substrate outside of saltmarsh				
Artificial substrates	0.1	0.6	0.1	0.1
Rock field/Boulder field	0.1	0.4	0.1	0.1
Cobble field	0.2	1.8	1.5	1.8
Gravel field	3.0	25.7	2.5	3.1
Shell bank	0.04	0.3	0.3	0.3
Firm sand	-	-	0.4	0.5
Firm muddy sand	5.0	42.4	28.5	35.4
Soft muddy sand			0.5	0.6
Firm sandy mud	1.9	15.9	27.2	33.8
Firm mud	0.5	3.8	5.0	6.2
Soft mud	0.2	1.7	7.5	9.4
Very soft mud			1.7	2.1
Grand Total	**11.8**	**100**	**80.4**	**100**

3.2. EXTENT OF SOFT MUD

Adverse impacts are commonly encountered when estuaries receive excessive inputs of fine sediment resulting in turbidity, shallowing, increased nutrients, increased 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 commonly used to assess soft mud:

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 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.

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 mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Table 3 shows that 21% and 55% of the habitat were classified as being dominated by muds in Ngakuta and Okiwa Bays, although the extent of soft muds was lower, at 2% and 11% respectively, risk ratings of LOW and MODERATE. This is relatively low compared to other estuaries in the Marlborough Sounds (Figure 5). The largest soft mud deposition zones in both bays were along the eastern edges of the bays in relatively low-lying quiescent zones. In the firm mud habitat along the lower seaward edge of the bays, sediments were firm to walk on because of extensive beds of cockles growing in the muds. Without the presence of cockles, sediment would be classified as soft mud as the measured mud content in this habitat was ~40%, above the HIGH risk indicator rating band (>25%). This result indicates that elevated fine sediment inputs to Okiwa Bay, and to a lesser extent Ngakuta Bay, appear to accumulate in the lower (seaward) edge of the estuaries and that biological communities in these areas are likely to be adversely impacted. Because of the potential for increased sediment inputs to occur following future forest harvesting in the Okiwa Bay catchment it is recommended that a series of sediment plates be buried in predicted areas of deposition on the intertidal flats to track future sediment changes.

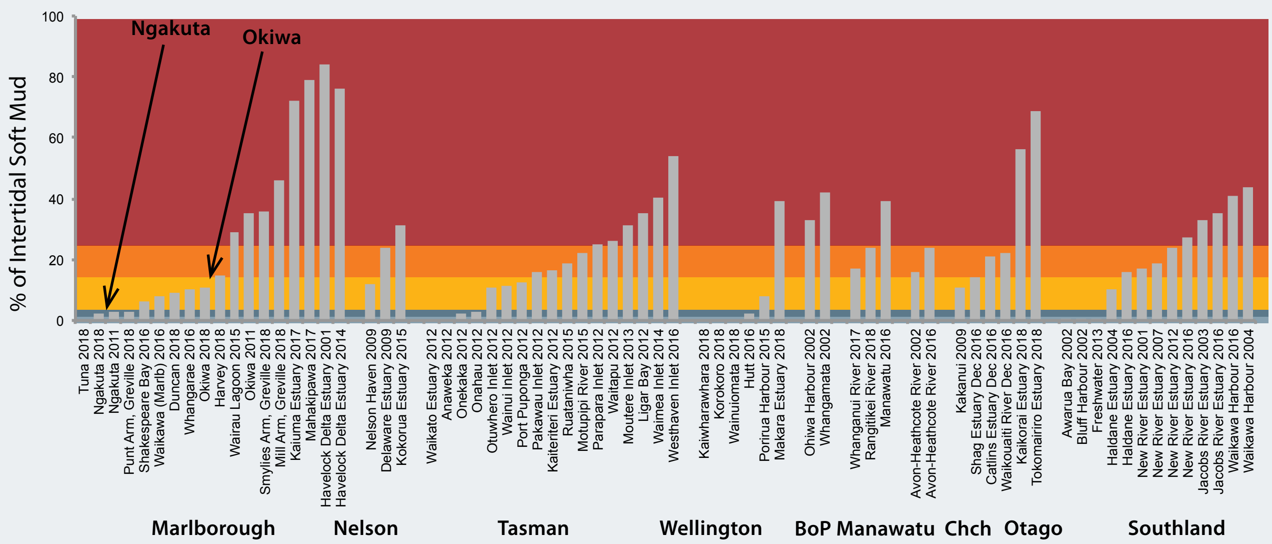


Figure 5. Percentage of intertidal estuary with soft mud habitat for various NZ tidal lagoon and delta estuaries (shallow, intertidal dominated, residence time <3 days - data from Wriggle monitoring reports 2006-2018 and Robertson et al. 2002).


Ngakuta Bay: Dominant gravel habitat on the upper shore and by stream margins.


Okiwa Bay: Firm muddy sand (left) and firm mud habitat (right).

Thompson Bay: Raised gravel beds and seagrass.

Okiwa Bay: soft poorly oxygenated muds.

3.3. SEDIMENT OXYGENATION

The primary indicator used to assess sediment oxygenation was the visually apparent aRPD depth. This indicator was measured within representative intertidal sediments and results used to assess which parts of the estuary had sediment oxygen depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) might be expected. Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that reduced oxygen zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

The broad scale field measurements found sand and gravel sediments in the estuaries to be generally well oxygenated with the average aRPD depth at ~2-5cm. This appears to be maintained largely as a consequence of open interstitial spaces within the sediment matrix allowing for the free exchange of oxygen from either the atmosphere or from seawater. Included in this was the large area of firm sandy mud habitat in Okiwa Bay where the presence of cockles, which are very effective bioturbators of sediment, act to facilitate good oxygen exchange with underlying sediments. The only areas indicating reduced sediment oxygenation were within relatively small areas of soft or very soft muds (Figures 3 and 4). Where muds supported seagrass, oxygen levels were good, but in unvegetated muds the average aRPD depth was ~0.5 to 1cm equating to a measured RP of -50 to -150mV at 1cm. While this indicates stress to ecological communities living in the sediments is likely, it is mitigated somewhat by only very soft mud-dominated habitat appearing to have elevated levels of organic enrichment. As these areas are limited in extent (2% of Okiwa Bay), and no gross eutrophic zones were present, a LOW risk rating for this indicator has been applied.

3.4. OPPORTUNISTIC MACROALGAE

Opportunistic macroalgae are a primary symptom of estuary eutrophication. They are highly effective at utilising excess nitrogen enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Macroalgae that becomes detached can also accumulate and decay in subtidal areas 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 subsequent impacts.

Opportunistic macroalgal growth was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 6), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT). 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/low, poor, good, moderate, high - Section 2, Table 1, Appendix 7). 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. If the estuary supports <5% opportunistic macroalgal cover within the AIH, the overall quality status is reported as HIGH with no further sampling required. This was the case for Ngakuta Bay and Thompson Bay in March 2018 and consequently the macroalgae quality status is rated HIGH, and the risk rating LOW with no further enumeration needed. Intertidal macroalgal cover in Okiwa Bay exceeded the 5% threshold so was fully enumerated as outlined below.

The overall opportunistic macroalgal EQR for Okiwa Bay south in March 2018 was 0.45 (Table 5, Figure 6), and indicates moderate symptoms of opportunistic macroalgal growth are being expressed. In other words, macroalgal growth is relatively widespread, biomass is elevated but not to levels where difficult to reverse ecological problems become common, and macroalgae is only entrained in sediment in relatively small areas (but likely to be persistent where entrained).

Growths were dominated by the red alga *Gracilaria chilensis* growing in the lower estuary, and to a lesser extent by the green alga *Ulva* which was present as a subdominant cover and occurring as both drift algal deposits as well as localised growths along channel margins.

Much of the algae was attached to cockles in the lower estuary with underlying sediments not showing evidence of oxygen depletion (Figure 6 - top left).

It was also evident that the shallow gradient of the intertidal flats was allowing shallow seawater to pond at low tide enabling the algae to remain free floating (Figure 6 - top right). This ponding is largely maintained by macroalgal growths limiting the free draining of the tidal flats but is also important in maintaining relatively good underlying sediment conditions by preventing smothering growths from depleting oxygen levels in underlying sediment.

Benthic microalgae were also present in the west of Okiwa Bay, evident by a rich green film coating mounds of sediment. These areas were limited to a few square metres and represent a relatively minor component of the estuary.

In contrast to the above results, Gillespie et al. (2012) reported 0.5ha of macroalgae in Okiwa Bay and 0.6ha in Ngakuta Bay. The very large increase in reported macroalgal growth in Okiwa Bay from 2012 to 2018 indicates a significant increase in the expression of nutrient driven macroalgal growth over the past 6 years. While the risk rating for current growth is MODERATE, the rapid increase has a risk rating of HIGH and it is recommended that further assessment of changes in macroalgal growth in Okiwa Bay be undertaken. Seeking knowledge of changes to the estuary between 2012 and 2018 from local residents would provide a simple and low cost way to inform the current situation, as would the use of citizen based science approaches to maintain a watching brief on future changes. It would also be valuable to summarise any known changes within the catchment over the past 5 years, such as intensification or expansion of farming or land disturbance, that may explain the increased algal growth. In tandem, a review of available water quality data from Queen Charlotte Sound would provide an indication of the likely influence of marine derived nutrient inputs to the head of Grove Arm.

Table 5. Summary of intertidal opportunistic macroalgal cover, Okiwa Bay south, March 2018.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	71		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	41.6	0.334	Poor
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	238.7	0.574	Moderate
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	430.5	0.446	Moderate
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	8.8	0.549	Moderate
Affected Area (use the lowest of the following two metrics)		0.356	Poor
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	39.4	0.653	Good
Size of AA in relation to AIH (%) = (AA / AIH) x 100	55.4	0.356	Poor
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.45**	**MODERATE**

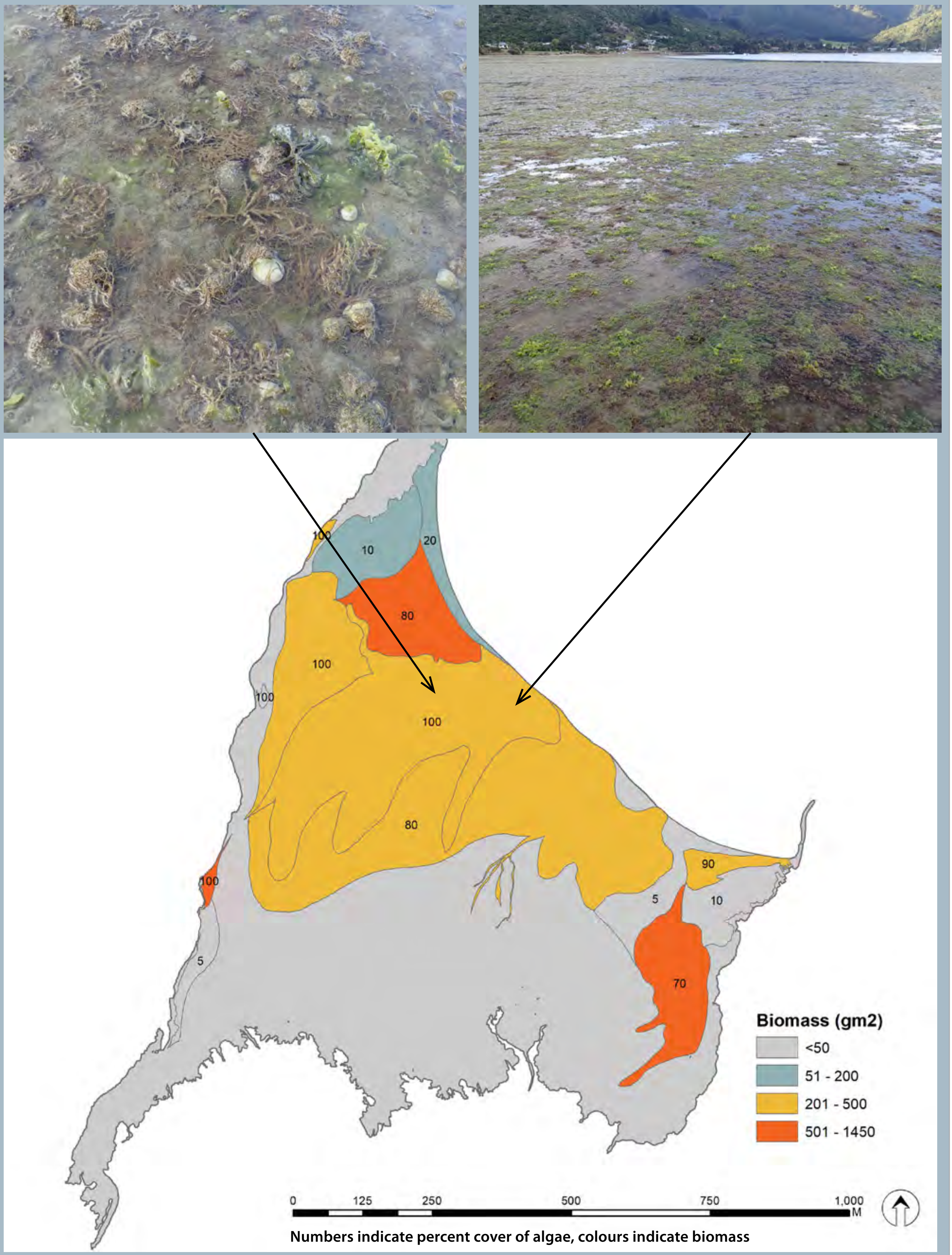


Figure 6. Map of intertidal opportunistic macroalgal biomass (g.m^{-2}) - Okiwa Bay south, March 2018.

3.5. SEAGRASS

Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Though tolerant of a wide range of 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 sulphides).

Figure 6 shows intertidal seagrass beds were present in both bays. Seagrass was only recorded in high density (80-100%) patches with strongly defined edges, often marked by a change in substrate. Most beds were growing in sand and muddy sand nestled within depressions in gravel habitat. Thompson Bay had the highest intertidal percentage cover of seagrass (21%), Ngakuta (8.9%), and Okiwa the lowest (1.4%). This pattern correlates with sediment type, seagrass extent decreasing as the area of sediment dominated by muds increases.

In the absence of any comprehensive rating of seagrass extent within NZ estuaries, which can be highly variable in the extent of seagrass that they support, changes from a documented baseline currently represent the most reliable method for monitoring seagrass extent and assessing change. The results of the current study were compared to baseline maps of seagrass extent for this purpose and indicated an increase in seagrass at both bays. However this increase most likely reflects much higher resolution photographs being available in 2018 that in 2011 and a consequent improvement in mapping accuracy rather than an expansion in seagrass. Of most significance was the continued presence of seagrass in areas it was previously recorded from, indicating stable beds with no evidence of a decline in extent.

While not widespread there were a couple of seagrass patches in Thompson Bay where a unidentified algal slime was present on seagrass fronds (see photos below). However most seagrass was clean and free of algal growth.

Consistent with results previously reported by Gillespie et al. (2012), blackened seagrass leaves symptomatic of a disease caused by the slime mould *Labrynthula* sp. (often referred to as the fungal wasting disease) were evident in both Ngakuta and Thompson/Okiwa Bays (see photo below). This feature, commonly observed on seagrass beds throughout NZ, does not appear to be having a significant impact on seagrass health at this point in time.

Based on the presence of dense beds of healthy seagrass in each bay, the absence of significant macroalgae growth among seagrass, and no evidence of a significant dieback in seagrass despite fungal wasting disease symptoms since 2012, a condition rating of GOOD has been applied.

3. RESULTS AND DISCUSSION (CONTINUED)

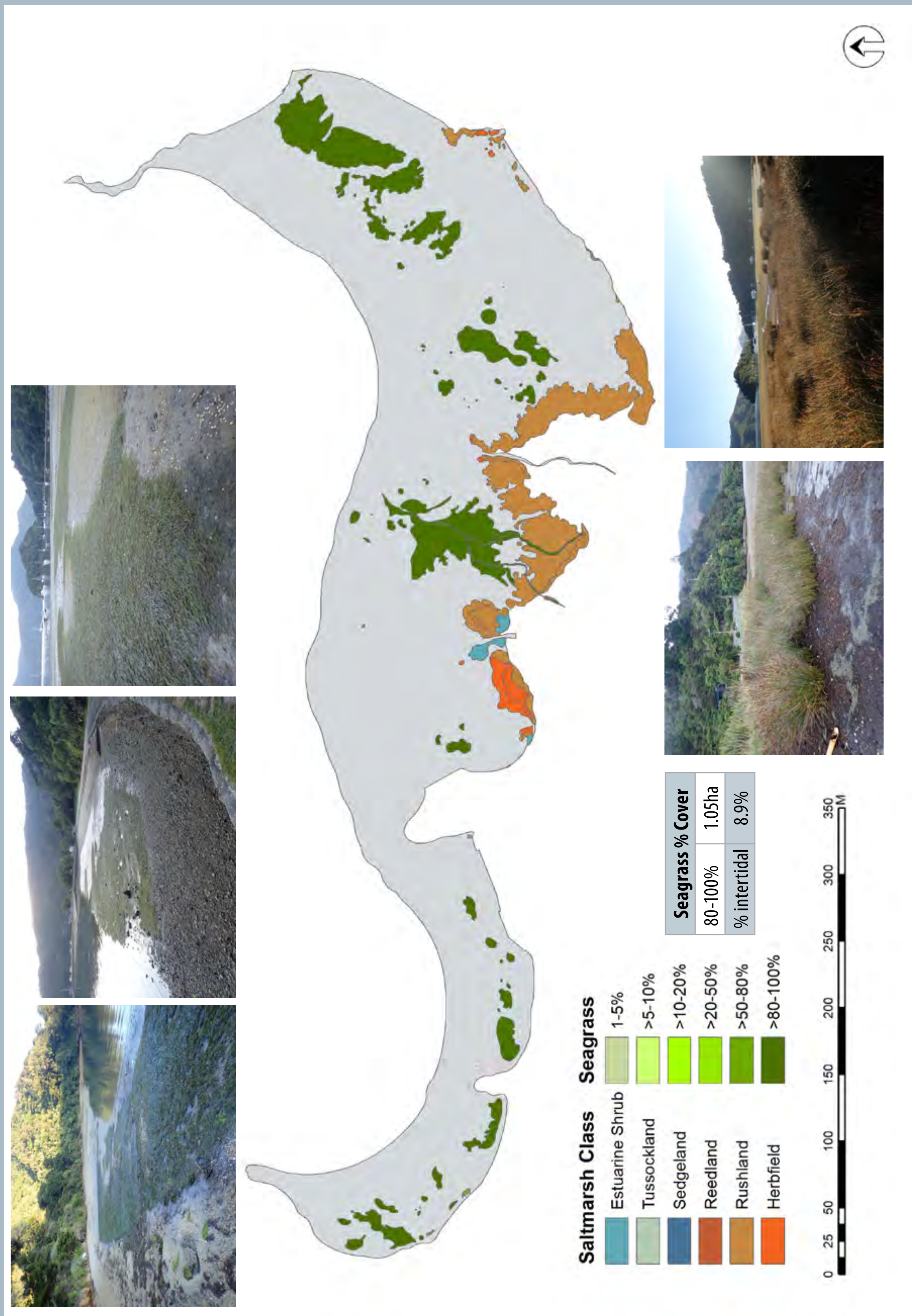


Figure 7. Map of intertidal saltmarsh and seagrass (*Zostera muelleri*) - Ngakuta Bay, March 2018.

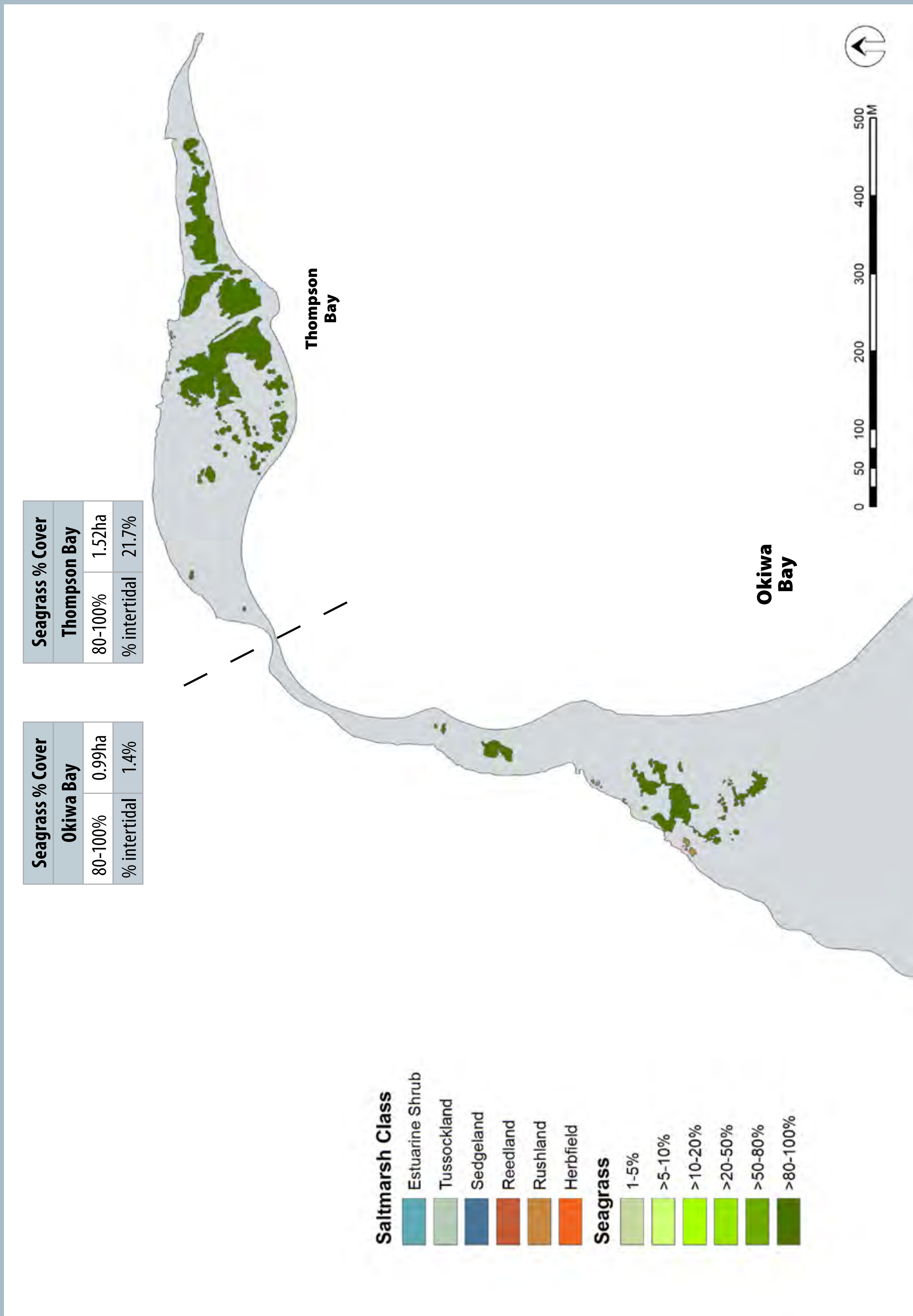
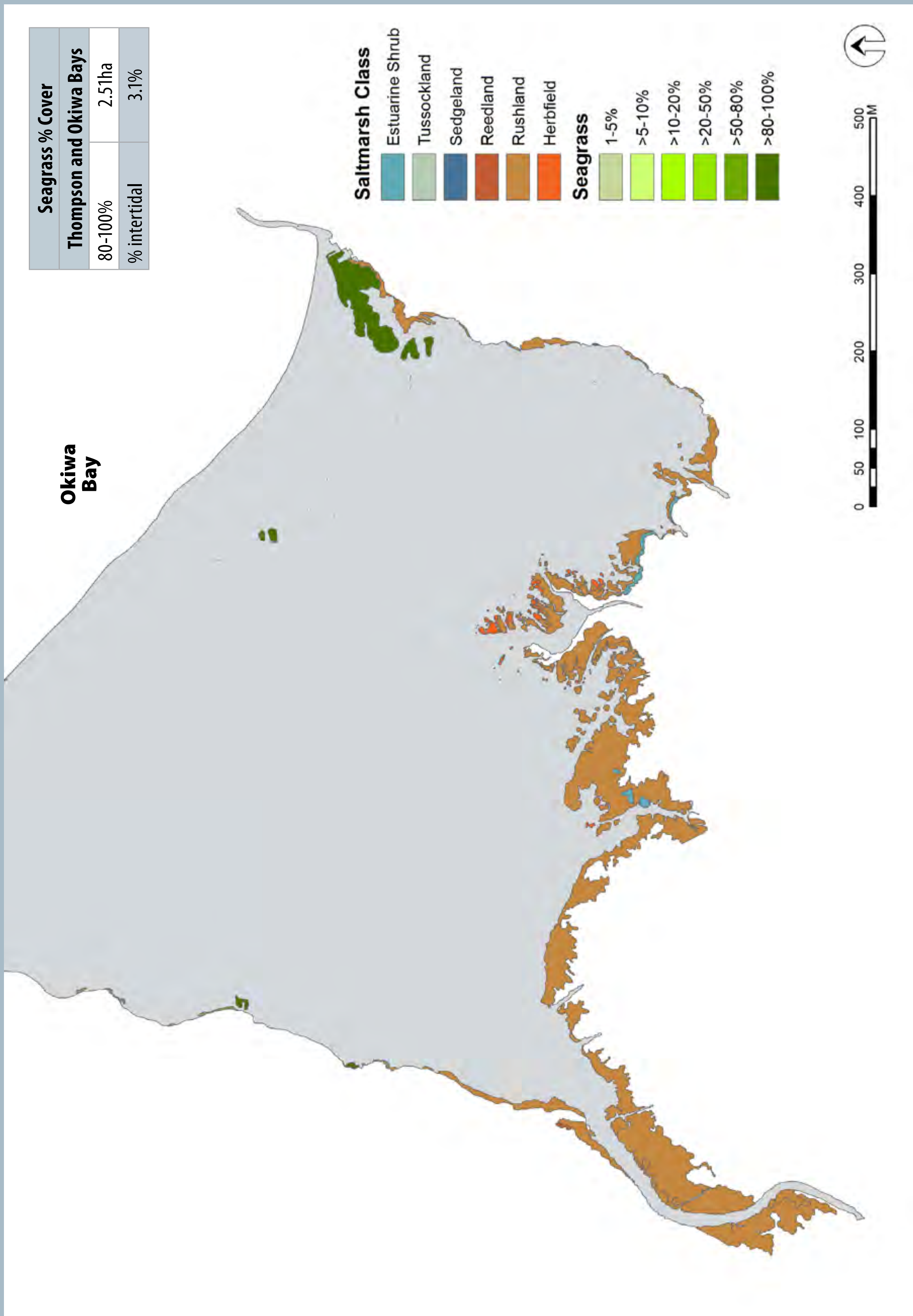


Figure 8a. Map of intertidal saltmarsh and seagrass (*Zostera muelleri*) - Okiwa Bay (north), March 2018.



Seagrass % Cover	
	Thompson and Okiwa Bays
80-100%	2.51ha
% intertidal	3.1%

Figure 8b. Map of intertidal saltmarsh and seagrass (*Zostera muelleri*) - Okiwa Bay (south), March 2018.

3. RESULTS AND DISCUSSION (CONTINUED)

3.6. SALTMARSH

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 is relatively sparse in the lower (more exposed and saltwater dominated) parts of the estuary, with the lower extent of saltmarsh growth limited for most species to above the height of mean high water neap (MHWN).

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 6 and Figures 7, 8a and 8b summarise the 2018 results. Saltmarsh areas were relatively small in relation to overall estuary area (6-7%), a condition rating of MODERATE. Saltmarsh was dominated by rushland comprising searush (with smaller areas of jointed wire rush near the terrestrial margin) in relatively wide beds at the head of each estuary, and also in narrow strips and as isolated beds along the edges of the bays. Herbfields were prominent in Ngakuta Bay growing seaward of the rushland beds and were also common as a subdominant cover among rushland in both bays. Primrose and remuremu were the dominant species, and formed a dense turf community among gravel beds. Saltmarsh ribbonwood was the other dominant saltmarsh class in the upper estuary, often with a mix of terrestrial grasses and weeds and native shrubs at the terrestrial edge. The seaward edges of intertidal saltmarsh were free of weeds and grasses and appeared in good condition. Page 21 presents photos of representative saltmarsh growing throughout Okiwa Bay.

Gillespie et al. (2012) reported slightly more saltmarsh in both bays in 2012 but due to the quality of aerial photos at that time, the boundary between saltmarsh and terrestrial areas was difficult to map

Table 6. Summary of dominant saltmarsh cover, Ngakuta and Okiwa Bays, March 2018.

Saltmarsh Class, Dominant and subdominant species	Ngakuta Bay ha	Ngakuta Bay %	Okiwa Bay ha	Okiwa Bay %
Estuarine Shrub	0.034	3.8	0.1	1.8
Plagianthus divaricatus (Saltmarsh ribbonwood)				
Apodasmia similis (Jointed wirerush)	0.03			
Juncus kraussii (Searush)			0.06	
Leptospermum scoparium (Manuka)			0.04	
Rushland	0.765	86.7	5.1	96.0
Apodasmia similis (Jointed wirerush)	0.003		0.04	
Juncus kraussii (Searush)			0.24	
Juncus gerardii (Saltmarsh rush)			0.003	
Juncus kraussii (Searush)	0.24		1.59	
Apodasmia similis (Jointed wirerush)	0.10		2.13	
Festuca arundinacea (Tall fescue)	0.01			
Juncus (gregiflorus) edgariae (Wiwi)			0.07	
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.05		0.92	
Samolus repens (Primrose)	0.13		0.01	
Sarcocornia quinqueflora (Glasswort)	0.03		0.08	
Schoenoplectus pungens (Three-square)			0.04	
Selliera radicans (Remuremu)	0.20		0.01	
Reedland			0.0	0.2
Typha orientalis (Raupo)			0.01	
Sedgeland			0.0	0.0
Schoenoplectus pungens (Three-square)			0.002	
Herbfield	0.084	9.5	0.1	2.1
Samolus repens (Primrose)	0.03		0.07	
Apodasmia similis (Jointed wirerush)			0.003	
Isolepis cernua (Slender clubrush)	0.004			
Juncus kraussii (Searush)	0.001			
Sarcocornia quinqueflora (Glasswort)	0.04			
Selliera radicans (Remuremu)			0.03	
Samolus repens (Primrose)	0.01			
Grand Total	**0.88**	**100**	**5.3**	**100**

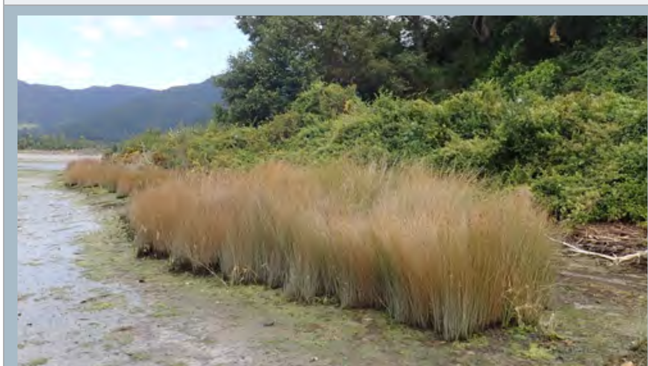
3. RESULTS AND DISCUSSION (CONTINUED)

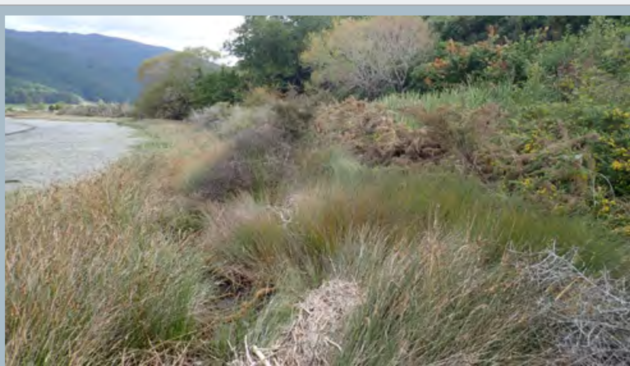
accurately. As such the small decrease in saltmarsh recorded in the current study appears due to sampling accuracy rather than meaningful changes in extent. The only area where recent changes were apparent was the erosion of a small area of rushland in the western end of Thompson Bay.

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 available habitat within Ngakuta Bay is naturally restricted by the steep surrounding landforms and would not have been particularly extensive. It is estimated that 40-60% of saltmarsh has been lost through drainage and conversion to grassland, a supporting risk rating of MODERATE.

In Okiwa Bay, saltmarsh and wetland areas at the gently sloping head of the bay would have been naturally extensive. These low lying flat areas, highly valued for pastoral farming, were traditionally cleared and drained early after European settlement. The current state suggests losses of >60% of saltmarsh are likely to have occurred in Okiwa Bay, a supporting risk rating of HIGH.

The combined overall risk rating for both Ngakuta and Okiwa Bays was assessed as MODERATE recognising that while saltmarsh is not extensive, future losses from reclamation and drainage are unlikely due to the increased understanding of their ecological importance.





Jointed wire rush, sea rush & saltmarsh ribbonwood on the western edge of Okiwa Bay.

Jointed wire rush (foreground) and searush.

Juncus gerardii, sea rush & saltmarsh ribbonwood.

Rushland with herbfield in the sheltered upper tidal reaches of Okiwa Bay.

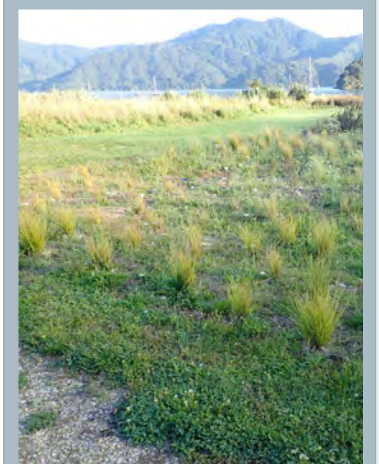
3. RESULTS AND DISCUSSION (CONTINUED)

3.7. 200m TERRESTRIAL MARGIN

Native forest growing by the estuary edge at The Grove, Okiwa Bay.

Flapgate and channelisation in Okiwa Bay.

Developed grassland and amenity area in Ngakuta Bay.



Restoration plantings in Ngakuta Bay.
Right: seawall in Ngakuta Bay.

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 improves estuary biodiversity. The results of the 200m terrestrial margin mapping of the estuary are presented in Table 7 and Figure 9 and show Ngakuta and Okiwa Bays had 62% and 46% of the margin densely vegetated, risk indicator ratings of LOW and MODERATE. The majority of the 200m margin was regenerating native species, although exotic weeds like gorse and broom were common amongst scrub at Okiwa Bay. Residential development and roading were the other dominant features (32.2% and 25.8% in Ngakuta and Okiwa Bays respectively), while pasture (26.5%) was also significant in Okiwa Bay.

The greatest area of margin modification was the valley floor of Okiwa Bay where land was cleared over 100 years ago and converted largely to pasture. Historically this area supported lowland wetlands which, apart from their high ecological value, are also very effective at assimilating catchment derived nutrient and sediment inputs. Drainage of this land has resulted in reduced access for migratory species through habitat loss and the presence of low stopbanks and flap gates to minimise tidal inundation.

Seawalls and armouring were also present throughout much of the upper reaches of Ngakuta Bay, near the Grove in Okiwa Bay, and in Thompson Bay. Combined with the steep hillsides the presence of these features breaks the natural connectivity between the land and the sea and restricts the opportunities for the natural migration of estuarine species in response to predicted sea level rise.

Table 7. Summary of 200m terrestrial margin land cover, Ngakuta and Okiwa Bays, March 2018.

Class	Ngakuta Bay	Okiwa Bay
Indigenous Forest	6.9	3.7
Scrub/Forest	54.8	13.5
Scrub		24.8
Estuarine Shrub		3.7
High Producing Exotic Grassland		26.5
Low Producing Grassland		0.9
Park/amenity area	6.1	1.2
Built-up Area (settlement)	26.1	22.8
Road	6.1	3.0
Total	**100**	**100**
% Dense vegetated 200m margin	**62**	**46**

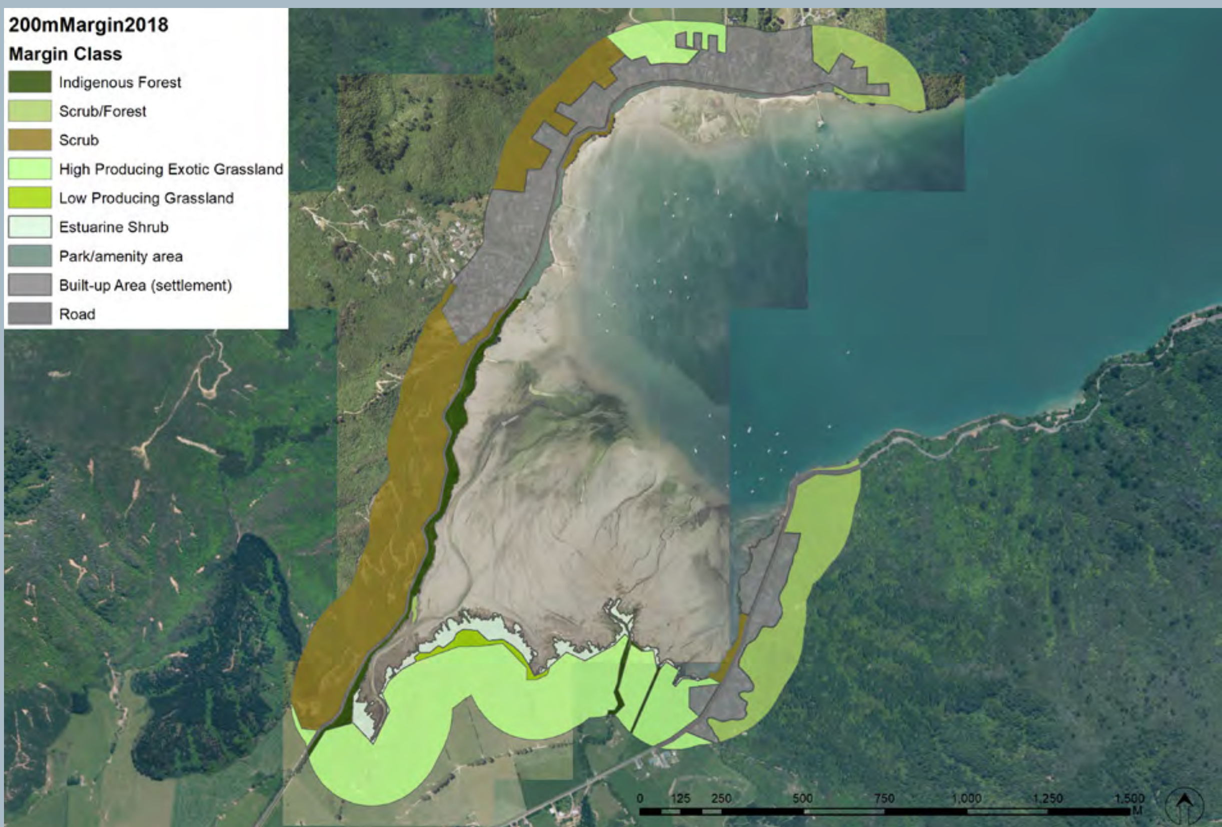
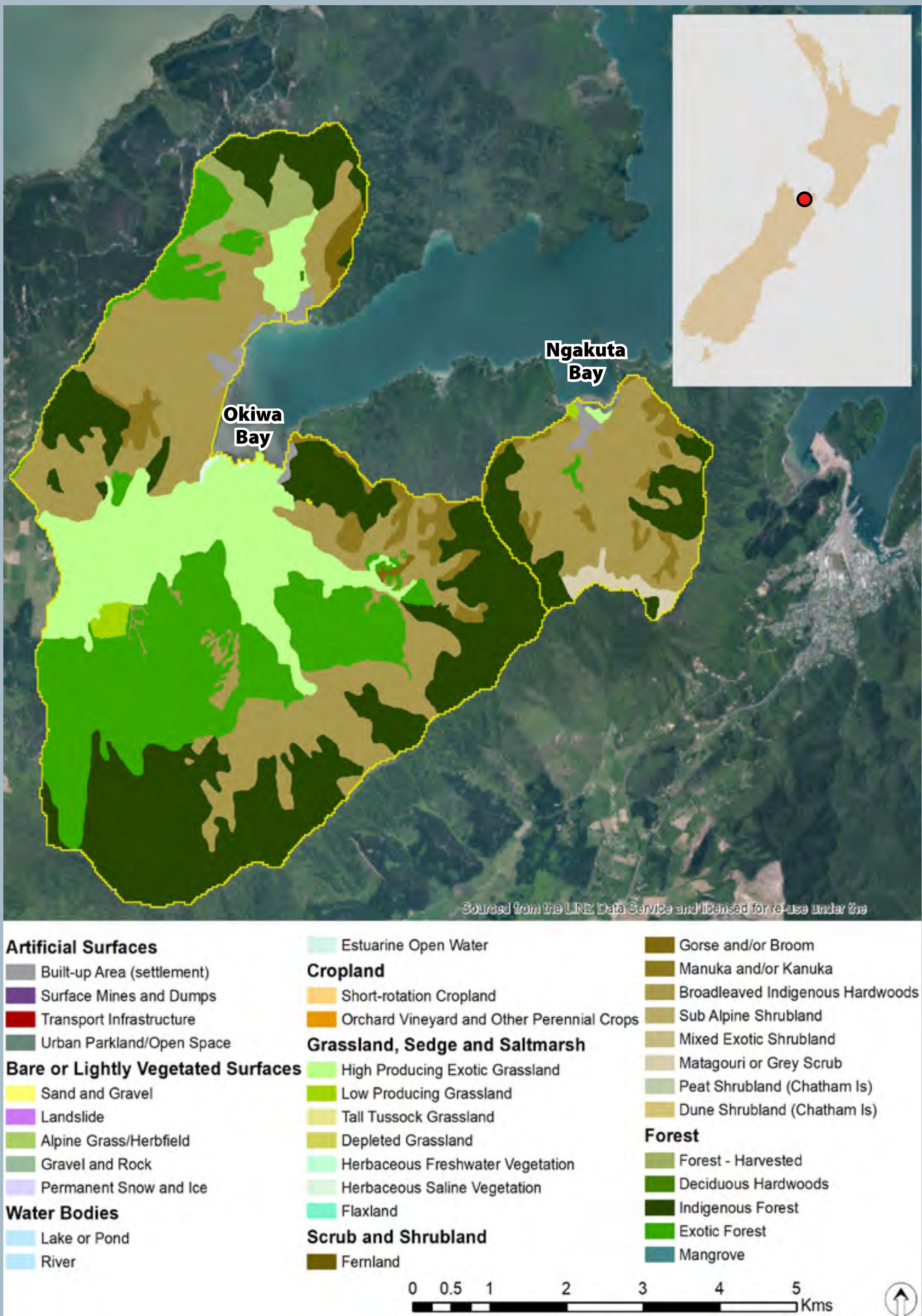


Figure 9. Map of 200m Terrestrial Margin - Dominant Land Cover, Ngakuta Bay (top) and Okiwa Bay (bottom) , March 2018.



Dominant Land Cover (%) LCDB4 (2012/13)	Okiwa	Ngakuta
Indigenous Forest	28	24
Indig. Hardwoods	26	57
Manuka and/or Kanuka	3	10
Matagouri/Grey Scrub	-	6
Gorse and Broom	1	-
Exotic Forest	25	0.7
High Prod. Grassland	16	0.6
Low Prod. Grassland	0.5	0.3
Built-up Area	1	1.8
Total	100	100

Figure 10. Summary of Catchment Land Cover (LCDB4 2012/13), Okiwa and Ngakuta Bays.

Land cover in the wider catchment is shown in Figure 10 highlighting that most native forest is generally located on the steeper upper catchment slopes, with scrub and exotic forestry on the intermediate slopes in the middle catchment, and pasture and settlements on the valley floors. The Ngakuta catchment has 97% indigenous native forest and scrub, <1% high producing grassland; and <1% exotic forest. The Okiwa catchment has 57% indigenous native forest and scrub; 16% high producing grassland; and 25% exotic forest (source LCDB4, 2012/13). The high cover of native forest and scrub in the Ngakuta catchment means it is at low risk from common terrestrial stressors of sediment, nutrients and pathogens. The harvesting of exotic forestry, and dairy farming in the valley floor represent the highest potential for future sediment, nutrient and pathogen inputs in the Okiwa catchment.

3.8. NZ ESTUARY TROPHIC INDEX

The NZ ETI (Robertson et al. 2016a,b) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness. 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 ETI score becomes. Where established ratings are not yet incorporated into the NIWA ETI online calculator they are included via spreadsheet calculator.

The indicators used to derive an ETI scores for Ngakuta Bay Okiwa Bay are presented below using the broad scale monitoring results presented in this report.

ETI Tool 1 rates the physical and nutrient load susceptibility of Ngakuta Bay and LOW and Okiwa Bay as MODERATE.

ETI Tool 2 rates eutrophic symptom scores for Ngakuta Bay as VERY GOOD and Okiwa Bay as MODERATE indicating that there are developing symptoms in response to nutrient enrichment and fine mud deposition at Okiwa Bay.

Table 8. Primary and supporting indicator values used to calculate an ETI score for Ngakuta and Okiwa Bays, 2018.

ETI scoring summary for Ngakuta and Okiwa Bays, March 2018.				Ngakuta	Okiwa
PRIMARY SYMPTOM INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)				**Primary Symptom Value**	
Required	Opportunistic Macroalgae	OMBT EQR	shallow inter-tidal	1	0.45
Required	Macroalgal GEZ %	% Gross Eutrophic Zone (GEZ)/Estuary Area	shallow inter-tidal	0	0
Required	Macroalgal GEZ Ha	Ha Gross Eutrophic Zone (GEZ)	shallow inter-tidal	0	0
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	-	-
Optional	Cyanobacteria (if issue identified) NOTE ETI rating not yet developed		water column	-	-
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 1cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-	-
Required Indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow inter-tidal	2	11
Required Indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow inter-tidal	0.2	9.2
Required Indicators	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-	-
Required Indicators	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-	-
Required Indicators	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-	-
Optional Indicators	Muddy sediment	Proportion of estuary area with >25% mud content	shallow inter-tidal	2	11
Optional Indicators	Sedimentation Rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL)	shallow inter-tidal	1.0	1.1
Optional Indicators	Dissolved oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) (mg.m^3)	water column	-	-
NZ ETI Score				**0.16**	**0.65**
				VERY GOOD	MODERATE

3.9. COMPARISON WITH OTHER ESTUARIES

A brief summary has been prepared of the key features within estuaries recently monitored by MDC and is presented in Figure 11 and Table 9. Figure 11 summarises the intertidal percent of reported saltmarsh, seagrass, macroalgae and mud, the latter measure including firm muds in Okiwa Bay.

Comparisons need to take into account the fact that the estuaries reflect a variety of sizes and types and some are naturally limited in the extent of features like saltmarsh that they can support due to surrounding landforms. However, it is considered worthwhile to report available data as they are gathered to enable patterns and trends to be investigated. Notwithstanding, it is clear that the extent of macroalgae in Okiwa Bay is large compared to the other estuaries, and there has been a large increase since 2011. Seeking to understand the possible cause for such a change is important if effective management is to be undertaken.

There is also a correlation between mud extent and seagrass, with seagrass extent being low where mud is high, particularly in the larger estuaries e.g. Havelock, Mahakipawa, and Kaiuma.

As these factors are known to strongly relate to two of the most common stressors on estuarine systems in NZ (fine sediment and nutrient inputs) it is likely that human activities have had, and will continue to have, a strong influence on the ecological quality of estuaries, and are thus important targets for policy and management initiatives.

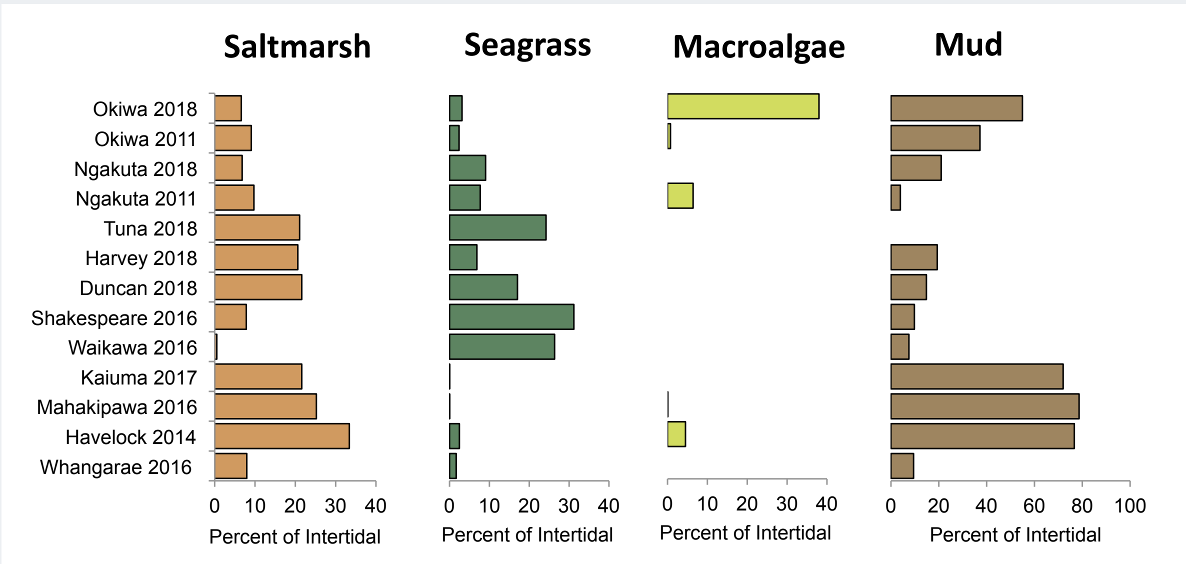


Figure 11. Summary of key features (% of intertidal area) from estuaries in Marlborough.

Table 9. Percent of intertidal area of saltmarsh, seagrass, macroalgae and mud in selected Marlborough estuaries.

Dominant Intertidal Estuary Feature (%)	Ngakuta[1]		Okiwa[1]		Whangarae[2]	Havelock[3]	Mahakipawa[4]	Kaiuma[5]	Waikawa[6]	Shakespeare[7]	Duncan[8]	Harvey[8]	Tuna[8]
	2011	2018	2011	2018	2016	2014	2016	2017	2016	2016	2018	2018	2018
Saltmarsh	9.6	7.4	8.5	6.2	8.0	33.4	25.2	21.6	0.5	7.9	21.6	20.6	21.1
Seagrass (>20% cover)	7.6	8.8	2.3	3.0	1.7	2.5	0.0	0.0	26.4	31.2	17.0	6.9	24.2
Macroalgal beds (>50% cover)	6.4	0.0	0.7	38.4	0.0	4.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mud	3.9	21.0	37.2	55.0	9.5	76.7	78.7	72.0	7.5	9.8	14.8	19.4	0.0

1. Gillespie et al. (2012), 2. Stevens and Robertson (2016), 3. Stevens and Robertson (2014), 4. Skilton and Thompson (2017), 5. Stevens and Robertson (2017), 6. Stevens and Robertson (2016a), 7. Berthelsen et al. (2016), 8. Stevens (2018).

4. SUMMARY AND CONCLUSION

Broad scale habitat mapping undertaken in March 2018, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification) have been used to assess overall estuary condition.

Okiwa Bay substrate was dominated by firm sands and firm sandy muds, the latter with a high mud content (~40%) and supporting extensive cockle beds. On the lower intertidal edge of the delta there were extensive beds of macroalgae, but conditions remained moderate due to limited entrainment in sediments and good sediment oxygenation. There had been a large increase in reported macroalgal expression since the previous monitoring undertaken in 2011. Soft mud habitat (11%) was rated poor for sediment oxygenation. Seagrass was uncommon in mud habitats but was extensive in Thompson Bay to the north and at the edges of Okiwa Bay. Saltmarsh, although significantly reduced in extent from historical cover, flanked much of the upper estuary and appeared in healthy condition with relatively few weeds and introduced grasses in the intertidal zone. Commonly observed catchment based stressors, particularly excessive inputs of fine sediment and nutrients, were moderate issues.

Ngakuta Bay substrate was dominated by firm muddy sands and gravels with only small areas of soft mud. It was not expressing eutrophic symptoms (no significant opportunistic macroalgal growth), had relatively large beds of seagrass, healthy saltmarsh, and a native forest/scrub dominated catchment. Historical habitat loss and modification has been limited in extent although much of the shoreline is now protected with seawalls Commonly observed catchment based stressors, particularly excessive inputs of fine sediment and nutrients, were not significant issues.

In relation to overall ecological health the combined results place Ngakuta Bay in a GOOD state, and Okiwa Bay in a MODERATE state.

Native scrub and forest on steep hillsides flanking seagrass beds in the western end of Ngakuta Bay.

5. RECOMMENDED MONITORING

Ngakuta and Okiwa Bays have been identified by MDC as priorities 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 broad scale mapping component of the long term programme. Recommendations for ongoing monitoring for Ngakuta and Okiwa Bays are as follows:

Broad Scale Habitat Mapping
To characterise any issues of change in habitat (e.g. soft mud extent, saltmarsh or seagrass area), unless obvious changes are observed in the interim it is recommended that broad scale habitat mapping be undertaken at ten yearly intervals for Ngakuta Bay (next scheduled for consideration in 2028), and at five yearly intervals for Okiwa Bay (next scheduled for consideration in 2023).

Macroalgae
Because of the large reported increase in macroalgal cover from 2011 to 2018 it is recommended that MDC consider collecting additional information from local residents to characterise the changes over the interim years and consider the use of citizen based science approaches to maintain a watching brief on future changes.

It would also be valuable to summarise any known changes within the catchment over the past five years, such as intensification or expansion of farming or land disturbance, that may explain the increased algal growth. In tandem, a review of available water quality data from Queen Charlotte Sound would provide an indication of the likely influence of marine derived nutrient inputs to the head of Grove Arm and the 2018 summer marine "heat wave" is also recommended.

Fine Scale Monitoring
To provide detailed assessment of the sediment dwelling biological community, and to characterise key estuary indicators such as sediment heavy metals and nutrients, it is recommended that two fine scale intertidal monitoring sites be established in Okiwa Bay using guidance set out in the National Estuary Monitoring Protocol and recent extensions e.g. the NZ ETI. It is recommended that one site be located within the dominant firm sandy mud habitat of the estuary, and one site in a deposition zone of soft muds (to reflect the worst 10% of the estuary). Ideally annual data would be collected over 3-4 years to establish a robust baseline to compare against possible future change.

Because concerns have been raised in relation to the potential impact of land disturbance contributing to increased sediment deposition throughout the Marlborough Sounds, it is recommended that a series of sediment plates be buried in deposition areas within Okiwa Bay to act both as a reference point and a site for measuring potential impacts of sediment related changes in Queen Charlotte Sound. It is recommended that measurements of sediment accrual and sediment grain size be collected annually for 5 years to establish a baseline for the site.

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APPENDIX 1. SUMMARY OF THE MAJOR ENVIRONMENTAL ISSUES AFFECTING MOST NEW ZEALAND ESTUARIES.

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand'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 2007, 2010, 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 of fine sediments 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; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sediment Changes	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 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

2. Eutrophication

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 Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	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 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

APPENDIX 1. SUMMARY OF THE MAJOR ENVIRONMENTAL ISSUES AFFECTING MOST NEW ZEALAND ESTUARIES.

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

In the last 60 years, 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 Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	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 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).

5. Habitat Loss

Estuaries have 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 Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	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 substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

APPENDIX 2. NOTES SUPPORTING INDICATOR RATINGS (TABLE 1)

The estuary monitoring approach used by Wriggle 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 1), 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 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.
    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) 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 substrate 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 (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen 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 and Appendix 2), 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.

As a baseline measure of seagrass presence, a continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: ***SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100.*** Because estuaries are likely to support variable natural seagrass extents, the SC rating is intended to highlight estuaries with low seagrass cover for further evaluation (i.e. estimate natural seagrass cover to determine current state), and to provide an estuary specific metric against which future change can be assessed. It is not intended that the SC be used to directly compare different estuaries. The "early warning trigger" for initiating management action is a trend of decreasing SC.

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 3. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

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 substrates 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 ≥10cm 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 >10cm 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*.

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 have edges." 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 substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and is mapped separately to the substrates 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 substrates they overlie.

SUBSTRATE (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 substrate 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 (>200mm 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 4. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

Sediment sampling and analysis

Grain size samples were collected from representative mud and sand habitats (to validate substrate classifications) by sampling a composite of the top 20mm of sediment (approx. 250gms 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 5. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

Grain size results from representative sediments Ngakuta and Okiwa Bays, March 2018.

Broad Scale Classification	Site #	% mud	% sand	% gravel	NZTM EAST	NZTM NORTH
Gravel field (gf)	O4	1	36	63	1676904	5431476
Firm muddy SAND (fmS)	O3	11	55	34	1676386	5429866
Firm muddy SAND (fmS)	O6	14	62	24	1676474	5431415
Firm muddy SAND (fmS)	N3	25	75	0	1680466	5430509
Firm sandy MUD (fsM)	O5	41	38	21	1676331	5430655
Firm sandy MUD (fsM)	N1	42	55	3	1681045	5430623
Firm sandy MUD (fsM)	O2	53	44	3	1676060	5430045
Firm MUD (fM)	N2	64	36	0	1681014	5430448
Very soft MUD (vsM)	O1	69	31	0	1675879	5429873

See Figures 3 and 4 for site locations.

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 1-2m 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 ±10m 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.

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	1953330	SPv1
Contact:	Leigh Stevens	**Date Received:**	28-Mar-2018	
	C/- Salt Ecology Limited	**Date Reported:**	10-May-2018	
	21 Mount Vernon Place	**Quote No:**	91327	
	Washington Valley	**Order No:**		
	Nelson 7010	**Client Reference:**	Okiwa and Ngakuta Bays	
		Submitted By:	Leigh Stevens	

Sample Type: Sediment

Sample Name:		Ngakuta N1 21-Mar-2018	Ngakuta N2 21-Mar-2018	Ngakuta N3 21-Mar-2018	Okiwa 01 20-Mar-2018	Okiwa 02 20-Mar-2018
Lab Number:		1953330.1	1953330.2	1953330.3	1953330.4	1953330.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	72	72	77	65	71
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	2.7	0.2	0.2	0.1	2.8
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	55.0	36.1	75.1	31.2	43.8
Fraction < 63 µm*	g/100g dry wt	42.3	63.7	24.7	68.6	53.4

Sample Name:		Okiwa 03 20-Mar-2018	Okiwa 04 20-Mar-2018	Okiwa 05 20-Mar-2018	Okiwa 06 20-Mar-2018	
Lab Number:		1953330.6	1953330.7	1953330.8	1953330.9	
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	85	96	77	83	-
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	33.7	62.9	21.5	24.2	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	54.8	36.3	37.9	62.1	-
Fraction < 63 µm*	g/100g dry wt	11.4	0.9	40.6	13.7	-

Summary of Methods

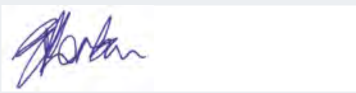
The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-9
3 Grain Sizes Profile*		0.1 g/100g dry wt	1-9
3 Grain Sizes Profile			
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-9
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-9
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-9

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

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.



Graham Corban MSc Tech (Hons)
Client Services Manager - Environmental

IANZ ACCREDITED LABORATORY

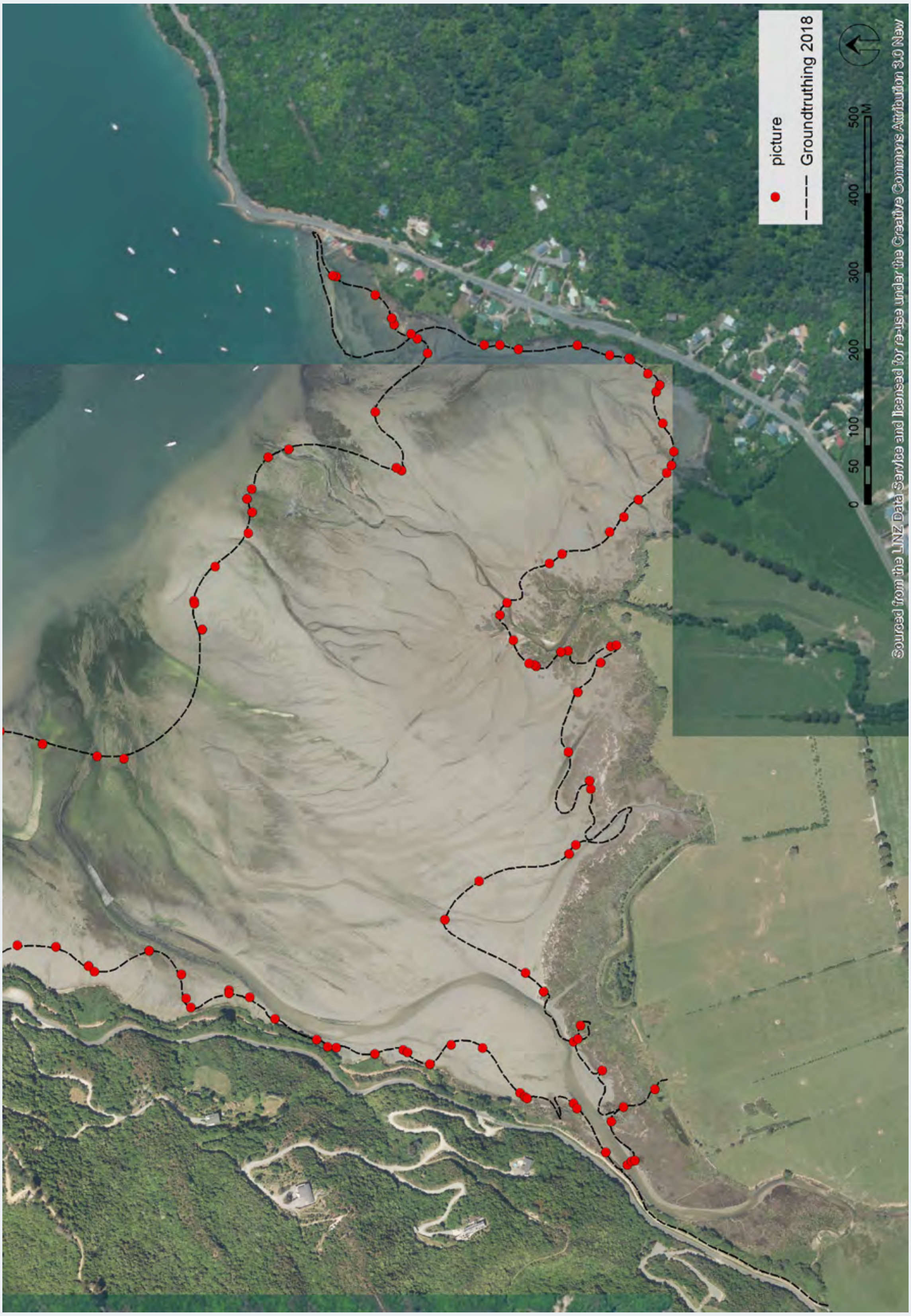
This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

This laboratory summary has been edited to fit onto a single page.

APPENDIX 6. GROUNDTRUTHING

Thompson Bay and Okiwa Bay north - showing ground truthing coverage and location of field photos.

APPENDIX 6. GROUNDTRUTHING



Okiwa Bay south - showing ground truthing coverage and location of field photos.

APPENDIX 6. GROUNDTRUTHING

Ngakuta Bay - showing ground truthing coverage and location of field photos.

APPENDIX 7. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

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

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

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

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH 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 ($g.m^{-2}$).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded.

For quality assurance of the percentage cover estimates, two independent readings should be within +/- 5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

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

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

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

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

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

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.

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

Derivation of Threshold Values.

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A2).

- **Reference Thresholds.** A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen, so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning.
  The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g m^{-2} wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed.
  An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.
- **Class Thresholds for Percent Cover:**
  High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.
  Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).
  Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).
- **Class Thresholds for Biomass.** Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 g.m^{-2} wet weight was an acceptable level above the reference level of <100 g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500 g.m^{-2} represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 g.m^{-2} but less than 1,000 g.m^{-2} would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).
- **Thresholds for Entrained Algae.** Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously 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.

Each metric in the OMBT has equal weighting and is combined to produce the ecological quality ratio score (EQR).

Table A2. The final face value thresholds and metrics for levels of ecological quality status in the 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.m^2) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^2) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

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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:

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

The EQR calculation process is as follows:

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

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

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A3).

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

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

Table A3 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range.
Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.
The final EQR score is calculated as the average of equidistant metric scores.

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

References

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APPENDIX 7. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

Table A3. Values for the normalisation and re-scaling of face values to EQR metric.

METRIC	QUALITY STATUS	FACE VALUE RANGES			EQUIDISTANT CLASS RANGE VALUES		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g m-2)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g m-2)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

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

Table A4. The final face value thresholds and metrics for levels of ecological quality status used to rate opportunistic macroalgae in the current in the study (modified from UK-WFD 2014).

MACROALGAL INDICATORS (OBMT approach - WFD_UKTAG 2014)					
QUALITY RATING	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) [>5% macroalgae] (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g.m^2 wet wgt) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^2 wet wgt) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

APPENDIX 8. OKIWA BAY MACROALGAL DATA

Macroalgal cover >5% used in calculating the OMBT EQR (see Figure A1 below for locations).

Patch ID	Patch area (ha)	Quadrat No	Percent cover of macroalgae	Mean Biomass (g.m^{-2} wet weight)	Presence (1) or absence (0) of entrained algae	aRPD depth (cm)	Presence (1) or absence (0) of soft mud	Dominant species
1	0.62	2	5	50	1	1	1	*Ulva sp.*
2	0.14	0	100	800	1	1	1	*Gracilaria chilensis, Ulva sp.*
3	3.64	0	100	400	0	0	1	*Gracilaria chilensis, Ulva sp.*
4	0.05	0	100	50	0	0	1	*Ulva sp.*
5	2.10	0	10	100	0	0	0	*Gracilaria chilensis, Ulva sp.*
6	0.09	0	100	300	0	0	0	*Ulva sp.*
8	2.74	0	80	900	0	0	0	*Gracilaria chilensis, Ulva sp.*
9	0.98	0	20	150	0	0	1	*Gracilaria chilensis, Ulva sp.*
10	10.68	0	100	500	0	0	1	*Gracilaria chilensis, Ulva sp.*
11	11.99	0	80	400	0	0	1	*Gracilaria chilensis, Ulva sp.*
12	0.64	0	90	300	0	0	0	*Gracilaria chilensis, Ulva sp.*
13	1.44	0	10	50	0	0	0	*Gracilaria chilensis*
14	2.70	0	70	750	1	1	1	*Gracilaria chilensis*
15	1.56	0	5	50	0	0	1	*Gracilaria chilensis*

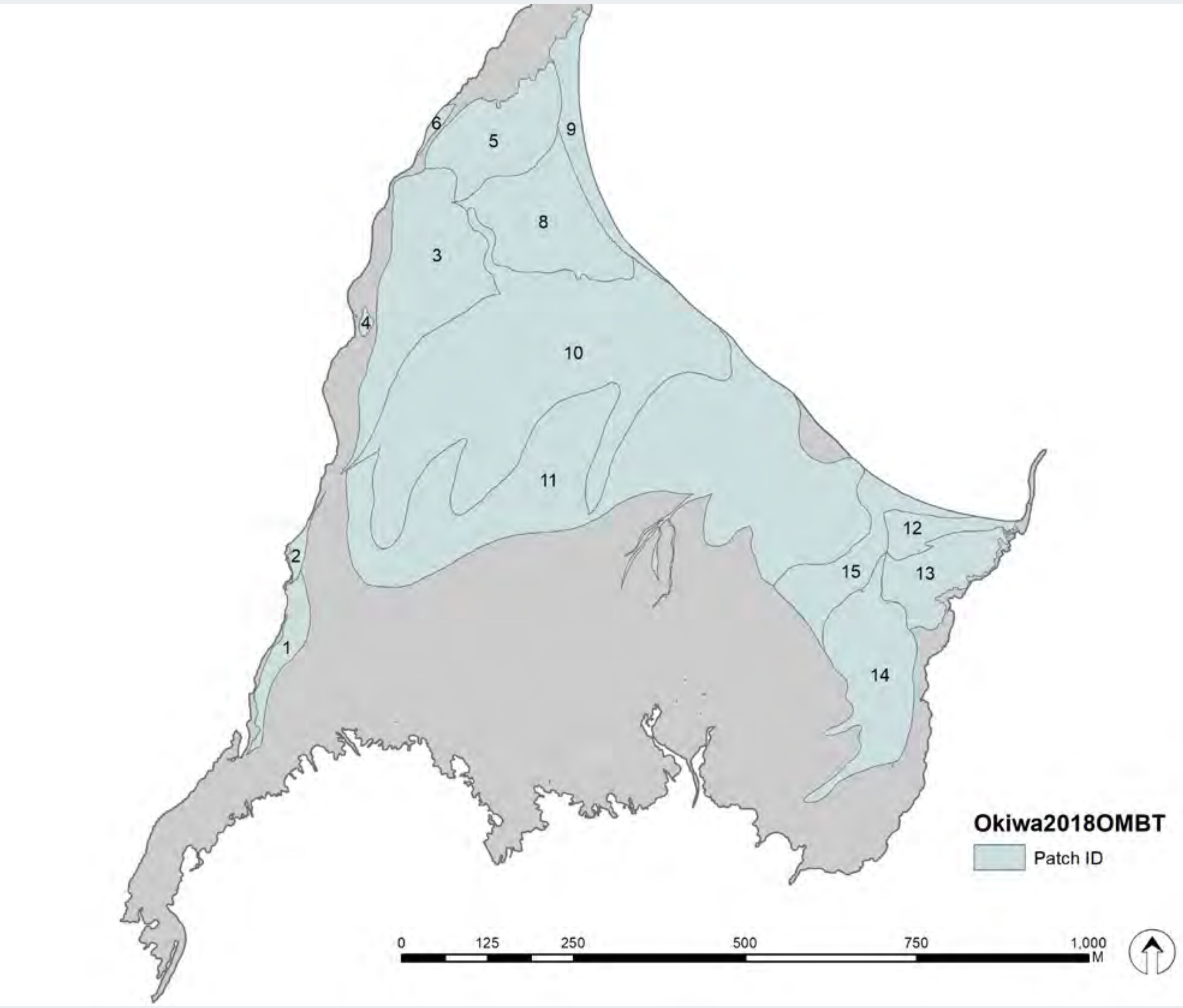

Figure A1. Location of macroalgal patches (>5% cover) used in assessing Okiwa Bay, March 2018.