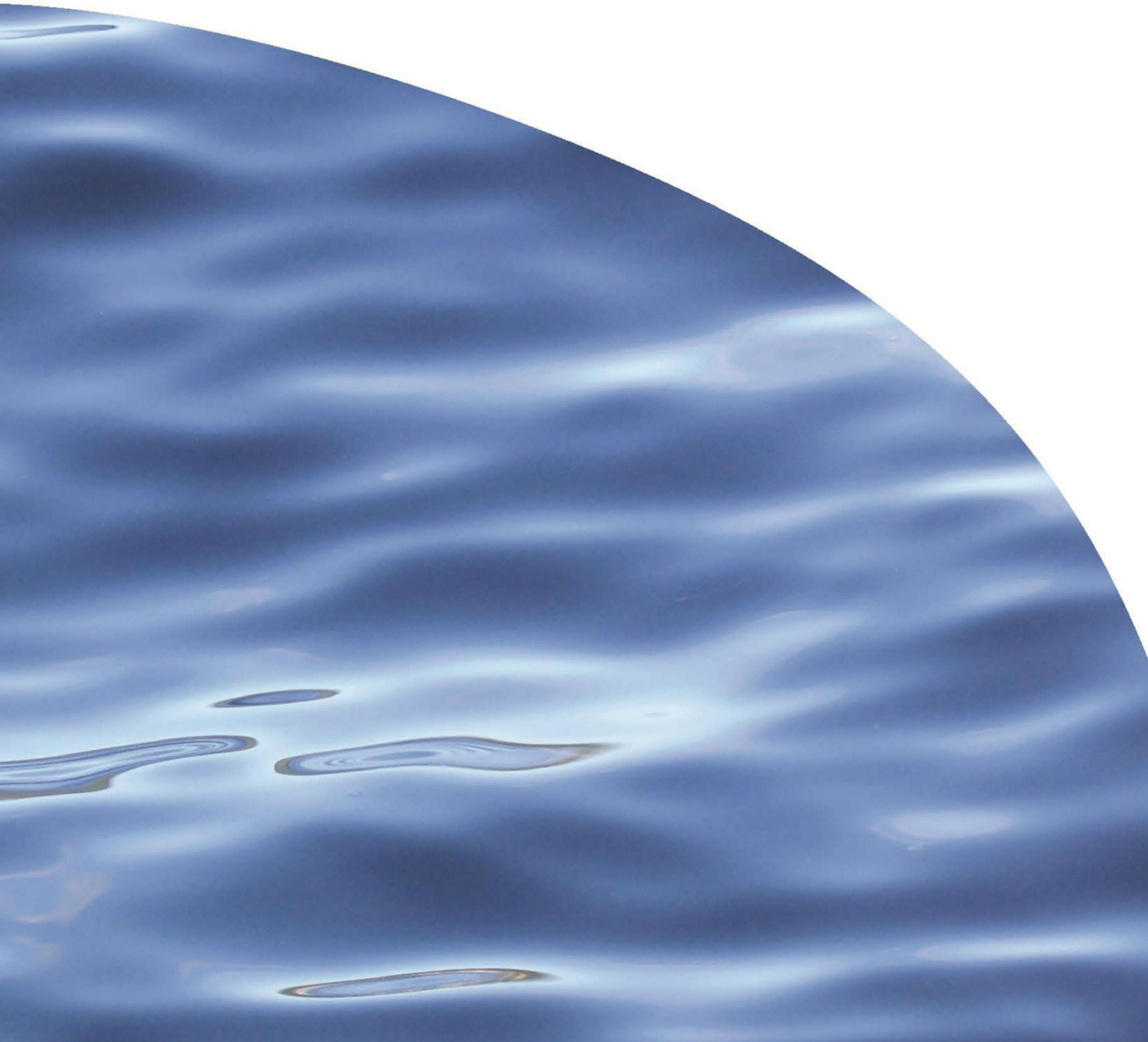
REPORT NO. 3208

BROAD-SCALE SURVEY OF WHATAMANGO BAY ESTUARY 2018



BROAD-SCALE SURVEY OF WHATAMANGO BAY ESTUARY 2018

ANNA BERTHELSEN, LISA FLOERL, DEANNA CLEMENT

Prepared for Marlborough District Council

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Paul Gillespie

APPROVED FOR RELEASE BY:
Grant Hopkins

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EXECUTIVE SUMMARY

Cawthron Institute (Cawthron) was commissioned by the Marlborough District Council (MDC) to undertake state of the environment monitoring in the form of a broad-scale survey of the Whatamango Bay estuary in Queen Charlotte Sound/Tōtaranui. This comprised an assessment of estuary condition or ‘health’ following the standardised Estuary Monitoring Protocol (EMP), modified to align with components of the Estuarine Trophic Index (ETI). It involved one ‘point in time’ survey of the estuary based on broad-scale mapping of intertidal and estuary margin habitats.

The monitoring provided a reference point from which to compare the Whatamango Bay estuary against trophic indicator ratings and with other estuaries. Future surveys could also use it to assess changes within the estuary. An assessment of the overall condition or ‘health’ of the estuary was made, as well as recommendations for future monitoring and management.

Overall, the Whatamango Bay estuary was in generally **good** health and exhibiting minimal eutrophic symptoms. Our reasons for this conclusion included:

- The high proportion of seagrass, although we suspected that there had been some loss of this ecologically important habitat in recent years.
- The high proportion of firm mud/sand and other naturally occurring unvegetated substrates, e.g. cobble/gravel fields. The sediments were generally well oxygenated.
- Saltmarsh habitat was present.
- Macroalgae was relatively low in abundance.
- The estuary margin was predominantly forested in native vegetation.

However, following interim thresholds based on trophic status, the proportion of soft mud was considered high enough to be causing stress to sensitive aquatic organisms. Some modification of the estuary and its margin had occurred, and exotic plants were present in the margin.

Additional monitoring and management recommendations included:

- Future broad-scale surveys to use up to date aerial images for mapping and to use standardised reporting methodologies.
- Carry out fine-scale surveys for a more complete picture of estuary health.
- Carry out more regular mapping of seagrass at high resolution.
- Ensure strict sediment controls for any relevant activities within the catchment and estuary.
- Plant the estuary margin and catchment with more native vegetation.

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GLOSSARY

Affected Area (AA)	Total area with macroalgal cover > 5%.
Anoxic	Total absence of available oxygen
Available Intertidal Habitat (AIH)	The estuary area between high and low water spring tide able to support opportunistic macroalgal growth. We considered suitable habitats to include dominant mud/sand, sand and cobble/gravel field habitats. We excluded the region 5 m either side of a ~100 m stretch of the Graham River channel beginning from where the river joins the intertidal zone.
DSDE	Deeper Subtidal Dominated, (longer residence time) Estuary
EMP	Estuary Monitoring Protocol
Entrainment	Macroalgae are considered entrained when they are found growing > 3 cm deep within muddy sediments
EQR	Ecological Quality Rating
Estuary margin	Terrestrial area immediately surrounding an estuary
ETI	New Zealand Estuary Trophic Index
Eutrophication	The process of eutrophication is caused by excessive nutrient input and is indicated by a variety of symptoms, such as macroalgal blooms and anoxic sediment.
GIS	Geographical Information System
GNA	Gross Nuisance Area Area where opportunistic macroalgae exceed 50% cover and the underlying sediments exhibit aRPD at the surface (i.e. aRPD 0-0.5 cm) (often with muddy sediments i.e. > 25% mud content) (Robertson et al. 2016b).
GPS	Global Positioning System
Intertidal	Area of seabed between Mean Low Water Springs and Mean High Water springs.
MDC	Marlborough District Council
MHWS	Mean High Water Spring
MLWS	Mean Low Water Spring
Organotin compounds	Chemical compounds based on tin with hydrocarbon substitutes
Pā	Fortified village

Patch/area	An area containing similar characteristics of a certain type of vegetation (e.g. percent cover of macroalgae). This could be either discrete from, or alongside, other patches.
Primary indicator	Variables considered to exhibit unambiguous responses to eutrophication. These include macroalgae, phytoplankton biomass, and cyanobacteria (Robertson et al. 2016a).
Primary production	The synthesis of organic compounds from atmospheric or aqueous carbon dioxide. It principally occurs through the process of photosynthesis, which uses light as its source of energy.
RP	Redox potential A measure of the tendency of a chemical species to acquire electrons and thereby be reduced.
aRPD	apparent Redox Potential Discontinuity Defined as the transitional zone between aerobic (oxygenated) sediments and anaerobic (deoxygenated) sediments.
Secondary indicator	Variables that have variable or ambiguous relationships with eutrophication but are useful in its measurement (Robertson et al. 2016a).
Secondary production	The generation of biomass of heterotrophic (consumer) organisms in a system. This is driven by the transfer of organic material between trophic levels, and represents the quantity of new tissue created through the use of assimilated food.
Semi-volatile organic compounds	Any moderately volatile organic compound as defined according to specific analytical criteria.
SIDE	Shallow intertidal dominated estuary
SSRTRE	Shallow, short residence time tidal river estuary
Subtidal	Any water present on the estuary at low tide or below MLWS
Trophic indicator	Ecological variable that responds to eutrophication
Trophic state	Status along the ecological gradient of estuary trophic condition from a scale of minimal eutrophication to very high eutrophication.
Urupā	Burial ground
Wāhi taonga	Significant sites
Wāhi tapu	Sacred place or site

1. INTRODUCTION

As part of their coastal monitoring strategy (2012), the Marlborough District Council (MDC) aims to incorporate significant intertidal habitats within the Marlborough region into a long-term monitoring programme. Accordingly, an estuarine monitoring schedule has been developed as part of the overall coastal monitoring programme with all estuaries in Marlborough to be mapped and surveyed from 2014 to 2023 (MDC 2017). The MDC prioritised the Whatamango Bay estuary (Figure 1) for monitoring in 2018 and commissioned Cawthron Institute (Cawthron) to conduct this work.

1.1. Scope and objective

The MDC estuarine monitoring programme comprises an assessment of estuary condition or 'health' following the standardised Estuary Monitoring Protocol (EMP) (Robertson et al. 2002), that is modified to align with components of the Estuarine Trophic Index (ETI) (Robertson et al. 2016b). This report focusses on Stage Two of the EMP, broad-scale habitat mapping with the following scope:

- mapping of the intertidal zone and terrestrial estuary margin based on EMP and ETI protocols
- summary of estuary condition and recommendations for ongoing monitoring and management.

1.2. Background

1.2.1. New Zealand estuaries and their health

The intertidal and margin habitats associated with estuaries provide a link between terrestrial and marine environments. Estuaries are functionally important and provide a number of ecosystem services, including primary and secondary production, nutrient retention/processing and sediment trapping. These roles contribute to the capacity of estuaries to function as a land/sea buffer that is critical to the sustainability of coastal ecosystems. Unfortunately, estuaries are also subject to a range of anthropogenic stressors that can compromise their health and these ecosystem services (Ellis et al. 2015).

High value habitats within estuaries (e.g. saltmarsh, seagrass, tidal flats) contribute to estuary health by providing enhanced decomposition and nutrient cycling processes, trapping of sediments while providing food and habitats for a diversity of species (Gillespie & MacKenzie 1981; Matheson et al. 2009). Human activities can directly (e.g. saltmarsh reduction through land reclamation) or indirectly (e.g. seagrass vulnerability to human-induced sedimentation) result in the **loss of high value**

habitats[1]. This loss can compromise important estuary functions, leading to a variety of adverse effects e.g. reduced productivity, biodiversity, increased sediment mobility.

The deposition of land-derived sediments in estuaries is a natural process that occurs wherever there is substantial freshwater inflow (Robertson et al. 2002). However, human activities, such as the removal of native vegetation (e.g. forests and wetland) and land development, have led to more rapid infilling of estuaries with fine sediment (i.e. silt and/or mud); a process called sedimentation. **Increasing mud content** can alter sediments' ecological characteristics. Mud can also adversely impact benthic animals, for example by smothering and clogging filter-feeding apparatus, and therefore is a strong determinant of benthic community composition (Thrush et al. 2004).

Nutrient (e.g. nitrogen, phosphorus) and organic carbon levels are often elevated in the environment due to land-use practices such as fertiliser application for agriculture, and point source discharges such as those from sewage/waste water treatment plants. The nutrients and organic carbon can then enter estuaries through catchment runoff and discharge pipes and, when excessively high, can lead to enriched and potentially eutrophic conditions (Ferreira et al. 2011; Robertson et al. 2016b). The process of **eutrophication** is indicated by a variety of symptoms (e.g. macroalgal blooms, anoxic sediment), which can adversely impact animal communities (Paerl 2006). The response to nutrients can be exacerbated by the increased presence of mud (e.g. lower pore water exchange, increased sediment bound nutrients) or hydrological changes (e.g. reduced dilution and flushing due to artificial closure of an estuaries entrance) (Robertson et al. 2016b).

Contaminants, such as heavy metals/metalloids, semi-volatile organic compounds (SVOCs) and organotin compounds can originate from human-related activities such as industrial/commercial activities, use of stormwater drains, roading and agricultural practices. The contaminants may then be discharged or flushed into an estuary where they can be highly toxic to marine life (Bryan 1971; Mucha et al. 2003; Moore et al. 2002). Animals belonging to a higher position on the food chain can also be adversely impacted through bioaccumulation of particular contaminants within their tissues that may potentially affect reproductive success and/or immune-responses.

1.2.2. Estuary monitoring protocol (EMP)

In 2002, a national set of standardised estuarine monitoring methodologies, termed the Estuarine Monitoring Protocol or EMP, was created by Cawthron as a tool to assess the ecological condition of New Zealand estuaries (Robertson et al. 2002). Use of this protocol ensures long-term consistency of monitoring datasets, allowing comparisons of past monitoring efforts within the same estuary. It also provides a

[1] Four commonly occurring stressors that are relevant to information obtained from EMP and ETI surveys of Whatamango Bay estuary are highlighted in bold text.

means of cross-referencing with other estuaries that have been similarly assessed, in order to make health comparisons.

The EMP methodology includes three stages. The first is a general overview of background descriptive information and preparation of a preliminary decision matrix, designed to facilitate community engagement with the monitoring process and prioritise monitoring efforts. The second and third stages involve broad-scale mapping of intertidal habitats (the focus of the current work) and fine-scale assessment of a suite of benthic characteristics at selected intertidal reference sites. In combination, the results of these three stages indicate an overall level of estuarine condition and provide a point-in-time baseline for assessment of any changes over time.

1.2.3. Estuarine Trophic Index (ETI)

The New Zealand Estuary Trophic Index (ETI) was developed in response to regional councils' need for a nationally consistent approach to the assessment of estuary eutrophication[2]. The ETI provides several different tools to determine an estuary's susceptibility to eutrophication by assessing its current trophic state[3] and estimating how changes to nutrient load (through limits) may alter the trophic status (Robertson et al. 2016a; Robertson et al. 2016b; Zeldis et al. 2017).

1.3. Whatamango Bay and estuary

Whatamango Bay is part of Queen Charlotte Sound/Tōtaranui, located approximately 6.5 km north-east of Picton (Figure 1). The wider Whatamango Bay area (from Karaka Point to Ahuriri Bay) is approximately 2.6 km long and 0.6 km wide, with a large proportion of it being subtidal and relatively deep (approximately 10–27 m). The bay's catchment is approximately 1828 ha in size and is predominantly forested, with indigenous forest followed by exotic forest and manuka and/or kanuka shrubland the most prevalent land use categories (Figure 2).

Whatamango Bay estuary is one of two (the other is Ahuriri Bay to the east) larger intertidal regions within the wider bay area (Figure 1). It comprises an area of gently sloping beach exposed for approximately 200 m at low tide. The estuary salinity regime is likely to be largely influenced by the tidal flow of saltwater. However the Graham River flows out across the intertidal flats on the western side of the estuary, forming a permanent channel at low tide. The influence of the lower salinity river water on estuarine ecology will be high in this area, particularly at low tide and during times of high flow. We note that water quality characteristics for the Whatamango Bay could

[2] The process of eutrophication is caused by excessive nutrient input and is indicated by a variety of symptoms, such as macroalgal blooms and anoxic sediment.
[3] Status along the ecological gradient of estuary trophic condition from a scale of minimal eutrophication to very high eutrophication.

be partly influenced by the Ahuriri catchment; so the state of the two estuaries may not be independent of one another.

Inset:

Figure 1. Location of Whatamango Bay estuary within Queen Charlotte Sound/Tōtaranui in the Marlborough region. Inset: Whatamango and Ahuriri estuaries.

Using a classification system designed for estuary response to eutrophication (Robertson et al. 2016a), we consider the Whatamango Bay estuary intertidal zone to be a 'shallow intertidal dominated estuary'[4] (SIDE) . However, classification is dependent on scale and the larger area of Queen Charlotte Sound/Tōtaranui (inclusive of Whatamango Bay) is considered a 'deeper subtidal dominated, longer residence time estuary' (DSDE) (Zeldis et al. 2017).

[4] Due to its shallow (< 3 m) nature and high proportion (at least 40%) of intertidal area. We have no information regarding the residence time of water within the estuary, but have assumed this is less than three days.

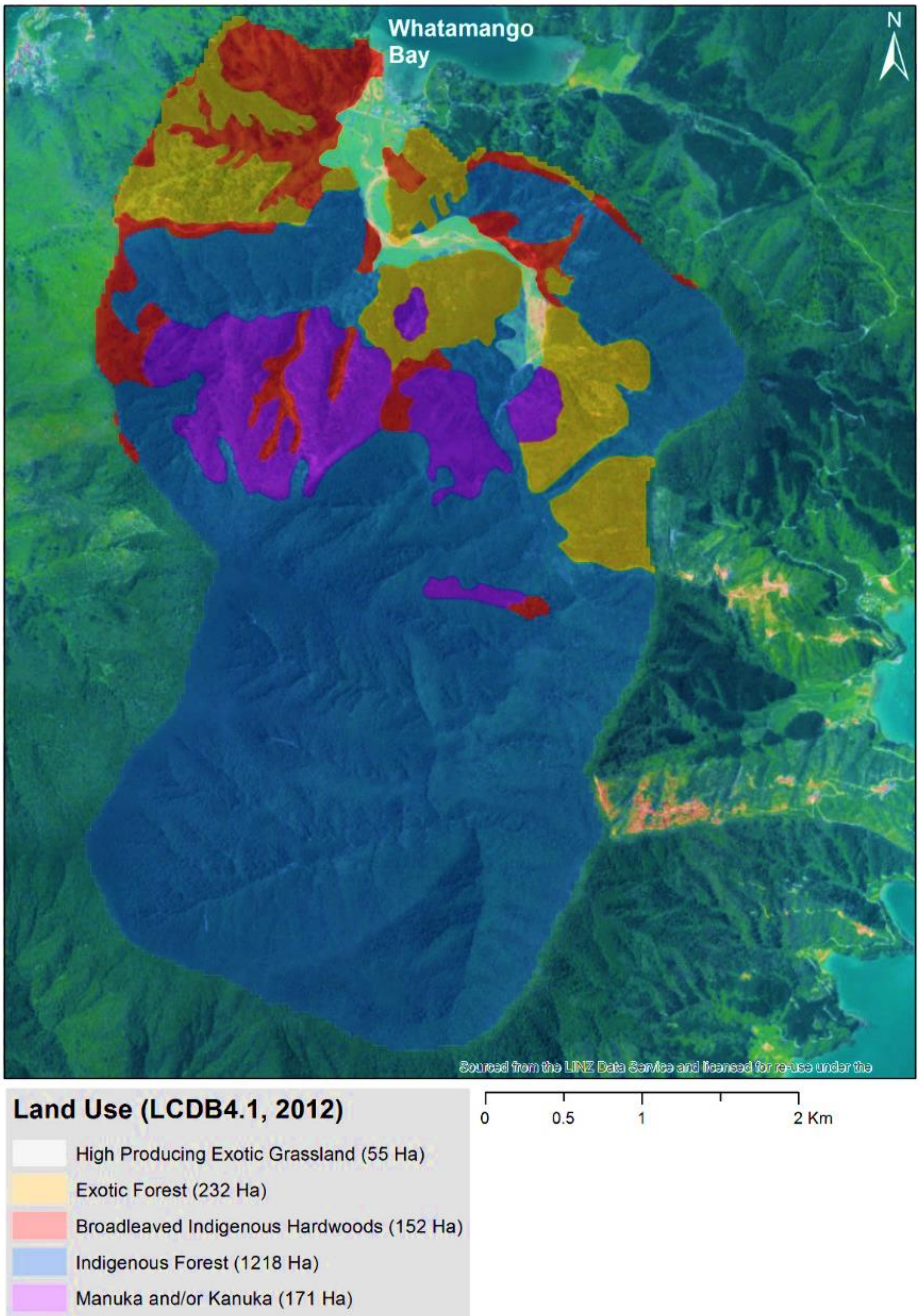

Figure 2. Key land uses within the catchment of Whatamango Bay estuary. This information was derived from the New Zealand Land Cover database.

1.3.1. Ecological, cultural, recreational and commercial significance

New Zealand estuarine habitats are often of high ecological value and contain resources of significant cultural, recreational and commercial benefit. The Whatamango Bay estuary intertidal area is approximately 10 ha and comprises of sand and mudflats, seagrass beds (*Zostera muelleri*), saltmarsh and shellfish beds (Davidson et al. 2011). It has fringes of native scrub. It was considered ecologically significant within the Marlborough region by Davidson et al. (2011) for the following reasons:

- estuarine environments are relatively uncommon within the Marlborough region
- reef heron (*Egretta sacra*) regularly visit the area
- high tide roosts are used by Caspian tern (*Hydroprogne caspia*), gulls, shags and waterfowl.

The conservation status of reef heron and Caspian tern is 'nationally endangered' and 'nationally vulnerable', respectively (Robertson et al. 2017).

Culturally, Whatamango is an area of importance to Te Ātiawa o Te Waka-a-Māui, who are the kaitiaki of this area and have many wāhi tapu and wāhi taonga, including urupā, located in the bay (Te Tau Ihu Statutory Acknowledgments 2014). The bay was once an important shark fishery and the name Whatamango refers to the stage of a storehouse on which dog fish or sharks were dried. The bay was a renowned source of shellfish due to being rich in pipi beds and mussels, and fish (flounder) were also harvested. Various cultivations were present on adjacent lands, and a pā was located on a steep headland between Waikawa (to the west) and Whatamango Bay (Te Tau Ihu Statutory Acknowledgments 2014).

Currently, Whatamango Bay is used recreationally for water-based activities including boating. A campground and houses, both rural in character and residential in density, are present within the catchment above the estuary. The Port Underwood Road, linking Picton to Port Underwood, runs alongside the estuary. Commercially, portions of the wider catchment are used for exotic forestry (Figure 2).

1.3.2. Historical use and/or impacts

We could find little information documenting previous human impacts within Whatamango Bay estuary. However, the presence of exotic forest and grassland as well as regenerating native vegetation (e.g. manuka/kanuka) in the catchment (Figure 2) indicated that historic forest clearance may have led to an increased amount of fine sediment entering the estuary historically.

2. METHODS

2.1. Broad-scale mapping of habitat areas

2.1.1. Habitat mapping using aerial photographs

The broad-scale assessment uses field-verified habitat mapping of the intertidal environment as a key proxy for estuary condition (Robertson et al. 2002). We mapped habitat features within Whatamango Bay estuary utilising high resolution (0.1 m), geo-referenced and ortho-rectified aerial photos taken on 17 February 2015. Along with printed laminated photographs traditionally used for ground-truthing, we uploaded the imagery to Collector for ArcGIS (an ArcGIS Online app) to facilitate orientation and to collect some boundary data directly as GIS feature classes. This approach proved to be essential since the extent of seagrass in the centre of the estuary varied significantly between the 2015 image and current extent observed in 2018.

Although the most recent aerial photographs available were from 2015, we note that the mapping of habitat boundaries (and any future changes to such boundaries) are most accurately delineated from current images. The sole premise of the broad-scale stage of the EMP recognises that it is not practical to physically ground-truth (see paragraph below) all habitat boundaries of estuaries efficiently (Robertson et al. 2002). Hence, aerial images are intended to serve as remote surrogates from which representative habitats and their boundaries can be clearly defined and a subset subsequently verified; reducing overall sampling time and making the EMP a more efficient process for councils to undertake regularly.

2.1.2. Ground-truthing and classification/coding of habitats

Cawthron scientists conducted a ground-truthing field survey on 16 February 2018, covering much of the estuary from the Mean High Water Spring[5] (MHWS) to the approximate Mean Low Water Spring (MLWS) (Figure 3). We also mapped the estuary margin (from MHWS up to 200 m inland) to assess the types and structures of habitats surrounding the estuary's borders[6]. Dominant substrate or biota with a spatial coverage greater than two metres in diameter, and visible on the aerial photos, were classified using an interpretation of the Atkinson (1985) system and based on the estuarine national classification system developed by Ward and Lambie (1999). We took georeferenced photographs of key habitats during ground-truthing.

[5] For most of the estuary this was defined by a definite step in land height around the estuary border. This meant that some saltmarsh habitats higher than this step were considered to be in the estuary margin above MHWS.

[6] Only dominant habitats were identified for the terrestrial margin, except for saltmarsh which we identified to the full EMP resolution.

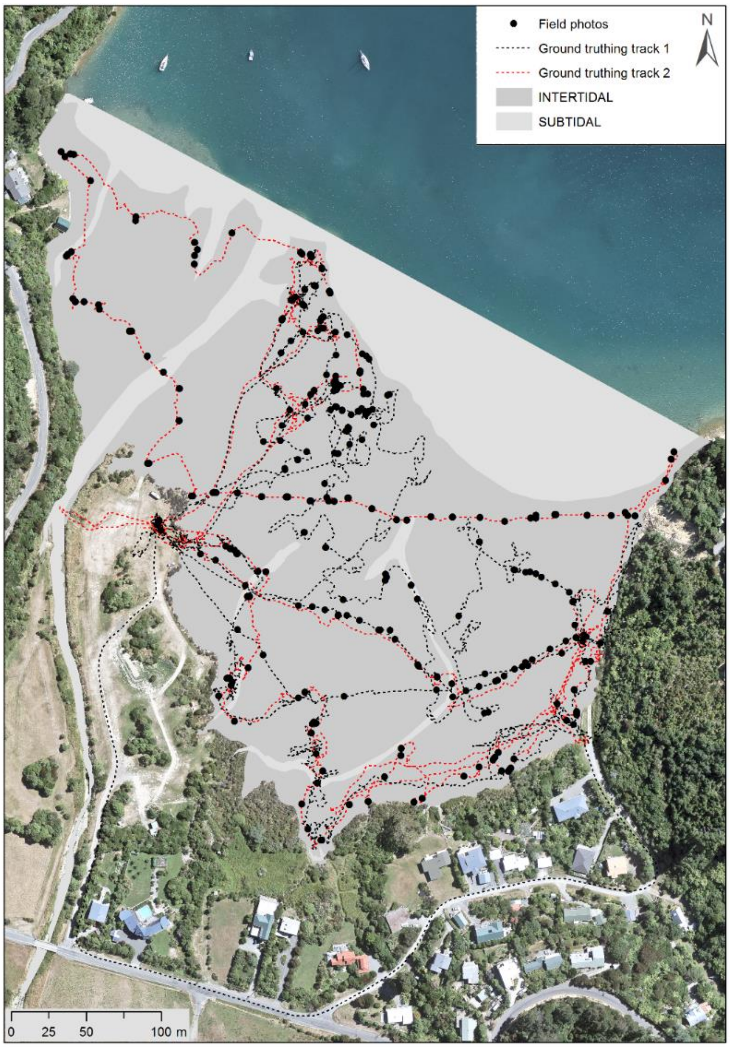

Figure 3. The extent of ground-truthing in Whatamango Bay estuary 2018. GPS tracks of field scientists conducting ground-truthing are shown.

We aimed to code the resulting habitat types according to EMP protocols and previous estuary reports (e.g. Gillespie et al. 2011a; Berthelsen et al. 2015) to ensure consistency between monitoring periods and facilitate comparisons between estuary surveys. Note that substrate classification was based on surface layers only and does not consider underlying substrate (e.g. gravel fields covered by sand would be classed as sand). However, we did classify substrate underlying macroalgae and seagrass. Boundaries around habitat features were digitised using ArcMap version 10.6 to build an ESRI Geodatabase containing spatial data, populated with habitat and substrate type data. The database was projected in NZGD 2000 New Zealand Transverse Mercator and also contains separate layers for the extent of saltmarsh and seagrass.

2.1.3. Discrepancies between historical vs current habitat boundaries

The large discrepancies between the 2015 and 2018 Whatamango Bay estuary habitat boundaries meant that more extensive verification sampling was necessary. A more recent (December 2017) aerial image of Whatamango Bay estuary was made available to us after we digitised the habitat maps. Habitat boundaries differed significantly between the 2015 and 2017 images (Figure 4). To ensure the most accurate results, we compared our digitised habitat boundaries against those from the 2017 images and slightly aligned some of our boundaries to match the 2017 image. We did not do this for macroalgae due to its highly variable nature.

Figure 4. Aerial images of the Whatamango Bay estuary from 2015 (left) and 2017 (right) showing substantial differences in habitat boundaries - particularly for seagrass which is represented by the darker regions in the middle/eastern region of the estuary. However note that differences in tidal state between the two images (i.e. the 2015 image was taken during a higher tide than the 2017 image) can influence how habitats are visually represented. For example, seagrass exposed during low tide is often more difficult to see compared to seagrass covered with water. Compare to Figure 8 to see actual boundaries of seagrass habitat in 2018. Photo credit Marlborough District Council.

2.1.4. Sediment substrates

For some sediment substrates (e.g. soft mud/sand), it is impossible to accurately map boundaries solely from digital images and therefore we must rely on field-collected information (Townsend & Lohrer 2015). The classification of soft sediment substrates as described in the EMP (Robertson et al. 2002) can be subjective as they are determined by noting the 'softness', based on how deep a person's feet sink into the sediment substrate while carrying out the ground-truthing exercise.

In particular, the distinction between soft and very soft mud/sand substrata can be affected by the amount of interstitial water present at the time of the survey. The depth to which one sinks into the sediment is influenced by many variables, for example a person's weight and shoe size, the water content of the sediment (which can vary depending on when after emersion the site was visited) and biota and shell hash present (Townsend & Lohrer 2015). During this survey we utilised the EMP definitions for sediment substrata; however, in order to reduce subjectivity we limited the number of soft sediment substrate categories by grouping together 'soft' and 'very soft'. This aligns with sediment substrata definitions outlined in the ETI.

Previous calibration studies have examined the relationship between grain size and sediment substrate types. Data displayed in the ETI indicate that ground-truthed 'soft mud' boundaries coincide with sediments containing a mud[7] content of >25% (Robertson et al. 2016b). However, other studies show that substrate classes do not solely correlate with grain size, with 'firm' sand/mud substrates sometimes comprising a mud content of > 25% (Berthelsen et al. 2015, Stevens & Robertson 2016b). Despite some uncertainty in the composition of different sediment substrates, we have assumed that our 'soft mud/sand' (i.e. soft mud) category comprised a mud content of > 25% in order to align with the ETI.

2.2. ETI trophic indicators

The ETI describes both primary and secondary trophic indicators (Robertson et al. 2016b, Zeldis et al. 2017). It defines primary indicators as variables exhibiting unambiguous responses to eutrophication, e.g. macroalgae, phytoplankton biomass, and cyanobacteria (Robertson et al. 2016a). Secondary indicators are considered to be variables that have variable or ambiguous relationships with eutrophication but are useful in its measurement (Robertson et al. 2016a). The ETI outlines 'ecological quality ratings' (EQRs) and EQR bands for each indicator, and these describe the trophic state of that indicator. Calculations for EQRs range from being either relatively simple to more complex, requiring input of multiple data sources—usually in the form of individual trophic EQRs or other 'sub-metrics' (e.g. 'multi-metric' indicators). For example, the Opportunistic Macroalgal Blooming Tool (OMBT), which provides an

[7] Mud is defined as grain size < 63 µm.

EQR for the trophic state of macroalgae within an estuary's soft sediment substrates[8], requires input of measures of the spatial extent, density, biomass, and degree of sediment entrainment (macroalgae growing > 3 cm deep within muddy sediments) of opportunistic (i.e. bloom forming) macroalgae.

2.2.1. ETI trophic indicators used in current survey

To assess the Whatamango Bay estuary, we utilised indicators relevant to our broad-scale survey, which included: one primary (macroalgae calculated using the OMBT) and five[9] secondary (relating to sediment oxygenation and extent of soft mud, seagrass and gross nuisance areas[10]) trophic indicators. Table 1 outlines and describes these trophic indicators, while Table 2 defines the EQR bands for determining the trophic status of each indicator. The bands are based on the ecological gradient of estuary trophic condition from a scale of minimal eutrophication (A) to very high eutrophication (D). Note that for many trophic indicators, the bands are considered interim pending further research. The ETI also categorises estuaries into typologies based on their susceptibility to eutrophication, with the ETI trophic indicators and their EQR bands tailored to these 'types'.

Final estuary trophic state

A final estuary trophic state EQR can be calculated based on these indicator EQRs and other similar metrics, as well as information on estuary typology, to assess the overall trophic status of an estuary. This calculation requires the input of data from at least one primary trophic indicator and at least one secondary trophic indicator to provide a weight of evidence approach. For Whatamango Bay estuary we utilised the indicators (or related metrics) previously mentioned (Table 1, Table 2, Appendix 1) for the final estuary trophic state calculation, which was made using Zeldis et al. (2017).

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[8] As opposed to hard/rocky shores to which the opportunistic macroalgal blooming tool (OMBT) is not applicable (WFD-UKTAG 2014).

[9] Although we did not utilise the trophic indicator relating to seagrass in the current survey as we had no historical data to input into the calculation.

[10] Gross Nuisance Area (GNA) is defined as an area where opportunistic macroalgae exceed 50% cover and the underlying sediments exhibit aRPD at the surface (i.e. aRPD 0–0.5 cm) (often with muddy sediments i.e. > 25% mud content) (Robertson et al. 2016b).

Table 1. Indicators for assessing the trophic state of New Zealand estuaries used in the current survey with a brief description of data collection methods and calculations according to ETI protocols (Robertson et al. 2016b; Zeldis et al. 2017).

Trophic indicator	Data collection method - overview	Ecological quality rating (EQR) calculation	Ecological link between trophic indicator and eutrophication
Opportunistic Macroalgal Blooming Tool (OMBT) Measures the spatial extent, density, biomass, and degree of sediment entrainment of opportunistic macroalgae Primary indicator	GIS-based broad-scale mapping Fine-scale data collected from discrete points and extrapolated to a similar density area	Calculated using the OMBT template downloaded from the Water Framework Directive United Kingdom website based on a composite of five sub-metrics (see Appendix 2 for metric details). The metrics have equal weighting and therefore the 'actual' or 'face value' scores are adjusted on a sliding scale to produce the EQR value	Macroalgal blooms, often stimulated under enriched conditions, can result in a number of problems (e.g. smothering of sediments and seagrass beds, reduced benthic light) that have negative implications for ecosystem health
Percent estuary area of soft mud Secondary indicator	GIS-based broad-scale mapping	See Appendix 1	The response of organisms to excessive nutrients can be exacerbated by the presence of mud (e.g. lower pore water exchange, increased sediment bound nutrients)
Seagrass extent Secondary indicator	GIS-based broad-scale mapping	Percentage of estimated natural state cover i.e. the current area of seagrass as a percentage of the estimated original/natural area of seagrass	Seagrass loss can be caused by smothering by excessive macroalgal cover (in association with increased organic enrichment of sediments), low water clarity, poor oxygenation and an increase in mud within sediments

Trophic indicator	Data collection method - overview	Ecological quality rating (EQR) calculation	Ecological link between trophic indicator and eutrophication
Redox Potential (RP) Measures sediment oxygenation Secondary indicator	Fine-scale data collected from discrete points and extrapolated to an area	No calculation required for individual sites See Appendix 1 for measure based on area	Available oxygen within sediments can be reduced by the variety of symptoms exhibited by eutrophication. Reduced oxygen can adversely affect animal communities living within the sediments
apparent Redox Potential Depth (aRPD) Visual indicator of sediment oxygenation Secondary indicator	Fine-scale data collected from discrete points and extrapolated to an area	Determine whether aRPD is at the surface (0 cm) over 10% of estuary (or > 30 ha) or not	
Gross Nuisance Area (GNA) Zones of extreme sediment degradation Secondary indicator	Derived from other trophic indicators and metrics	See Appendix 1 for description of input data	Indicates excessive opportunistic macroalgae associated with anoxic sediment – common symptoms of eutrophication
Final estuary trophic status Overall status of an estuary based on an ecological gradient of estuary trophic condition	Derived from other trophic indicators and metrics, as well as information on estuary typology	See Appendix 1 for description of input data Calculated using Zeldis et al. (2017)	Utilises at least one primary indicator and at least one secondary indicator to calculate where on the eutrophication gradient the estuary is placed

Table 2. Ecological Quality Rating (EQR) bands for trophic indicators used in this survey. These follow the ETI protocol (Robertson et al. 2016b; Zeldis et al. 2017), with the exception of GNA for which the EQR bands were taken from Stevens and Robertson (2017).

Trophic indicator and status	**A** (High)	**B** (Good)	**C** (Moderate)	**D** (Bad)
OMBT See Appendix 2 for sub-metric bands	≥0.8 – 1.0	≥0.6 – <0.8	≥0.4 – <0.6	0.0 – <0.4
Percent estuary area of soft mud* (%)	<1%	1–5%	>5–15%	>15%
Seagrass extent of estimated natural state cover* (%)	100%	>95–99%	85–95%	<85%
RP* (mV - for individual sites – measured at 1 cm depth)	>+100	+100 to -50	-50 to -150	>-150
aRPD* (% or ha)	Unreliable	Unreliable	Unreliable	At surface (0 cm) over 10% of estuary or > 30 ha
Gross Nuisance Area* (GNA) (% or ha)	<0.5 ha or < 1%	0.5–5 ha or 1–5%	6–20 ha or >5–10%	>20 ha or >10%
Final estuary trophic state	0–0.25	0.25–0.50	0.50–0.75	0.75–1.0

*EQR bands for this indicator are considered interim only pending further research.

2.2.2. Methods for data-gathering to calculate ETI trophic indicators

Field work was also undertaken on 3 April 2018 to collect additional data necessary for calculation of the tropic indicators listed above, collection that was contingent on knowing the broad-scale habitat mapping results (i.e. area of macroalgae, substrate boundaries).

Macroalgae

To collect data for use in the OMBT, we classified areas covered by macroalgae into four categories based on percentage cover (< 5%, 5–10%, 10–20%, 20–50%[11]) during ground-truthing. Gridded quadrats (size 0.25 m^2) were used to increase accuracy when assigning the percent cover categories by eye.

We gathered additional information on macroalgal entrainment (macroalgae growing > 3 cm deep within muddy sediments) and biomass. Entrainment was identified by eye in the field, and if necessary a ruler used to determine its depth into the sediment. To record biomass, we placed quadrats (1 m^2) in areas (described as 'patches' in OMBT terminology) that contained a similar percent cover of macroalgae. We then collected all macroalgae within each quadrat and washed, squeezed and weighed it to

[11] Macroalgal percent cover in areas/patches did not exceed 50% in our survey.

determine its wet weight. In larger areas, we repeated this process to obtain up to three biomass values and took fifteen measures of macroalgal biomass overall from within the estuary.

In order to convert the spatially discrete fine-scale biomass values into broad-scale data, we extrapolated the biomass values by assigning them to the area of macroalgae from which they were collected. This required the assumption of uniform biomass and therefore reduced the accuracy of the result. To calculate the OMBT we used an average value when more than one biomass value was collected from within an area. As it was not practical to sample every area, we estimated biomass for areas we did not sample by taking the average value from all patches with the same percent cover. This was done under the assumption that, as macroalgae was relatively low in density (always <50% cover), the relationship between biomass and percent cover was retained in different areas. Our results indicated that a full OMBT survey was not required (i.e. area of cover of the available intertidal habitat (AIH, the area between high and low water spring tide able to support opportunistic macroalgal growth) < 5%, WFD-UKTAG 2014); however, we calculated it anyway for future reference as we had already obtained data to do this.

Seagrass

We classified the percent cover of seagrass into three categories (< 20%, 20–50% and > 50%) using gridded quadrats and the same methodology as for macroalgae.

To calculate the ETI trophic indicator for seagrass we required historical information on seagrass distribution. However, these data were not available as our survey was the baseline (i.e. first) broad-scale survey of Whatamango Bay estuary (MDC 2017).

Redox

We took seventeen measurements of redox potential (RP) at representative sites in the most impacted[12] substrate covering more than ten percent of the estuary (firm mud/sand in this case), including at sites where macroalgal biomass samples were collected. Each measurement was taken within the substrate at 1 cm depth using a HANNA Oxidation Reduction Potential (ORP) probe. To calculate the RP EQR, we took an average of all the RP measurements—as this was one of the sub-metrics required to calculate the EQR for final estuary trophic state (Appendix 1).

In many of the same locations, we also determined the aRPD by collecting cores with a 62 mm diameter Perspex tube pushed to a depth of at least 150 mm into the seabed. The cores were extruded onto a white viewing tray, sectioned longitudinally and the depth of any apparent redox discontinuity was recorded based on the presence of a darker layer within the sediment.

[12] We have interpreted this as substrates assumed to comprise the highest percentage of mud.

2.3. Regional/national comparisons

In order to determine the health of the Whatamango Bay estuary in the context of estuarine health in general across the region, we compared our broad-scale survey results against those from other Marlborough/Nelson estuaries. Comparisons between estuaries were hindered by differences in reporting, as well as potentially mapping, methodologies (see Section 3.1.1). In the original EMP, and some subsequent surveys, the reported area values for unvegetated substrates did not include the area of substrates underlying macroalgae and seagrass (e.g. Robertson et al. 2002; Clark et al. 2008; Berthelsen et al. 2016). However in other surveys, percent area values for unvegetated habitats did include substrates under these vegetation types (e.g. Stevens & Robertson 2016a), including under saltmarsh in some cases (e.g. Skilton & Thompson 2017). Whether or not a habitat containing seagrass was reported as seagrass also differed between surveys. Habitats reported as a proportion of total area also varied between surveys due to differences in the habitat types included in the defined intertidal area.

In the current survey, we have reported the area of unvegetated substrates both including those underlying seagrass and macroalgae as well as excluding them. When reporting overall seagrass area, we combined all areas containing seagrass, regardless of its percent cover. Our calculations of intertidal area include saltmarsh habitats and excluded subtidal water, which we have defined as any water on the estuary at low tide or below the MLWS. All of our habitat area percentage values are calculated as a proportion of intertidal area.

National comparisons were made against ETI trophic indicator thresholds, as these have been specifically developed for New Zealand estuaries.

3. RESULTS AND DISCUSSION

3.1. Estuary habitat characteristics

A total of 9.1 ha of intertidal estuary habitat was mapped within the Whatamango Bay estuary (Table 3). Subtidal water covered 3.0 ha and we excluded this from the intertidal zone area. Figure 5 shows the estuary areas covered by the dominant habitat categories. An additional 27.2 ha of estuary margin (to 200 m above MHWS) was also mapped (see Section 3.1.3). Individual GIS layers and georeferenced photographs can be accessed and evaluated through the DVD-ROM in Appendix 3. The Ecological Quality Ratings (EQRs) for all trophic indicators were in the 'high' band indicating minimal eutrophic conditions, with the exception of percent estuary area of soft mud which was considered 'medium' (Table 4). These results are described in more detail in the following sections.

Table 3. Key broad-scale habitats within the Whatamango Bay estuary intertidal zone (between MLWS and MHWS), 2018. Substrates underlying vegetation are not included.

Class	Dominant habitat	Area (ha)	Proportion of intertidal (%)
Unvegetated		**3.67**	**40.17**
	Cobble field	2.03	22.24
	Gravel field	0.69	7.56
	Soft mud/sand	0.32	3.49
	Firm mud/sand	0.32	3.49
	Firm sand	0.11	1.19
	Soft sand	0.10	1.05
	Bedrock	0.06	0.69
	Driftwood	0.04	0.41
	Wharf	0.00	0.05
	Rock Wall man-made	0.00	0.01
	Man-made structure	0.00	0.00
Seagrass meadow		**2.90**	**31.74**
	Zostera muelleri > 50% cover	2.88	31.52
	Zostera muelleri 20-50% cover	0.01	0.16
	Zostera muelleri < 20% cover	0.01	0.06
Macroalgal Bed		**1.98**	**21.68**
	Gracilaria chilensis 1-5% cover	1.15	12.55
	Gracilaria chilensis 5-10% cover	0.66	7.21
	Gracilaria chilensis 10-20% cover	0.14	1.48
	Gracilaria chilensis 20-50% cover	0.02	0.17
	Ulva sp. 20-50% cover	0.01	0.15
	Ulva sp. < 20% cover	0.01	0.12
Rushland		**0.39**	**4.30**
	Juncus kraussii (searush)	0.39	4.30
Herbfield		**0.11**	**1.16**
	Selliera radicans (remuremu)	0.08	0.88
	Samolus repens (primrose)	0.03	0.28
Estuarine Shrubs		**0.09**	**0.93**
	Plagianthus divaricatus (saltmarsh ribbonwood)	0.09	0.93
Total		**9.13**	**100.00**

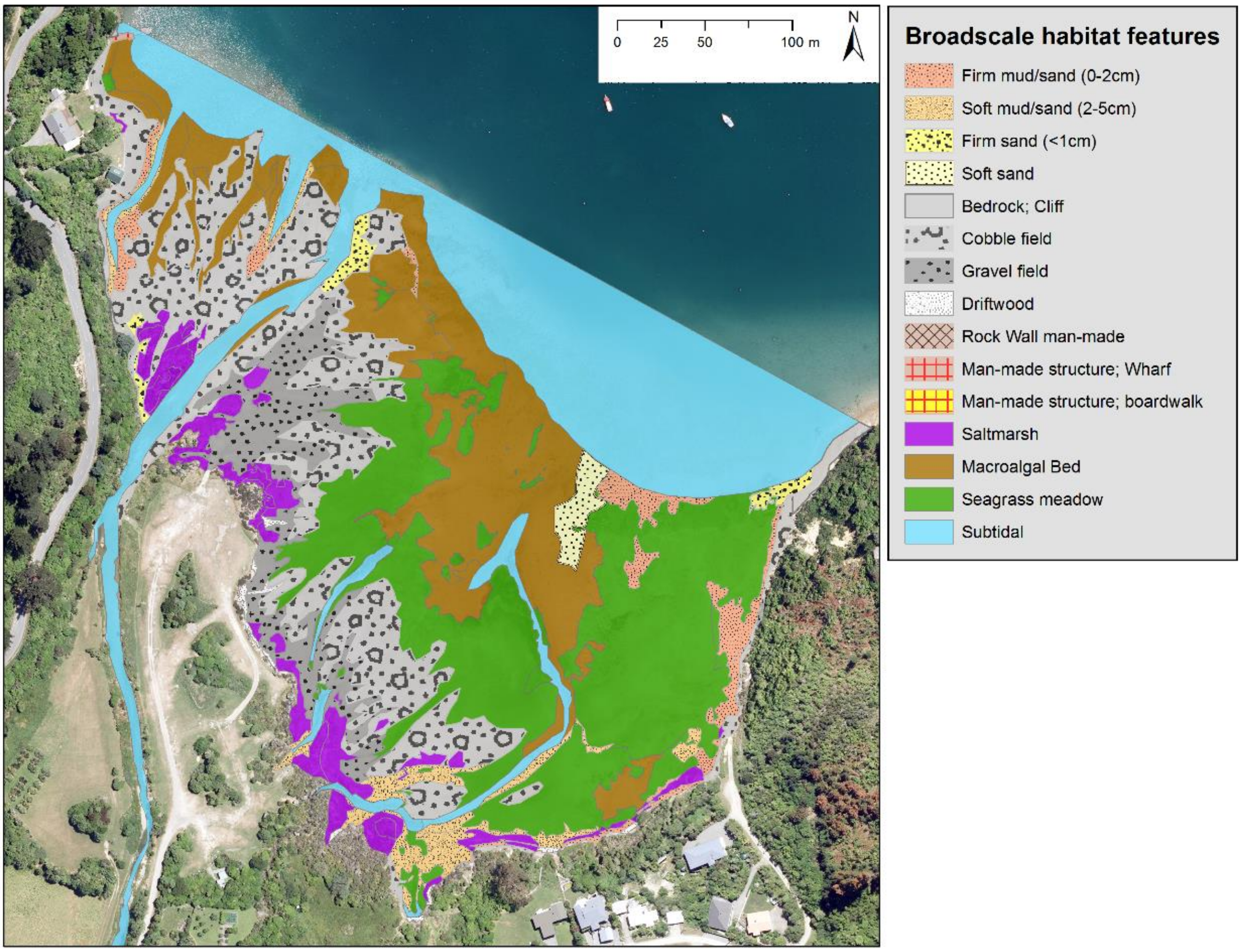

Figure 5. Aerial photograph of the Whatamango Bay estuary intertidal zone showing digitised broad-scale habitat characteristics, 2018.

Table 4. Survey results for trophic indicators and metrics (Ecological quality ratings -EQRs, bands and trophic status) used to calculate the final estuary trophic status EQR of the Whatamango Bay estuary, 2018. See Appendix 1 and Table 1 for description of indicators, and Table 2 for EQR bands.

Trophic indicators or metrics	EQR Value	EQR Band (if applicable)	Trophic Status (if applicable)
Opportunistic macroalgae (OMBT)	0.92	A	High
Percent estuary area of soft mud (%)	5.30	C	Medium
Redox Potential* (RP mV) (ha)	234.90	A	High
Gross Nuisance Area (GNA) (ha)	0.00	N/A	N/A
GNA/estuary area (%)	0.00	A	High
Final estuary trophic status	0.23	A	High

*The sediment aRPD was also measured although this was not required for the final trophic status of estuary EQR calculation. The aRPD was never 0 at the surface in any of our samples and therefore we considered it not to fall within Band D ('bad' trophic status) (see Table 2).

3.1.1. Unvegetated habitats

Unvegetated habitats were predominantly cobble/gravel fields and firm mud/sand. When compared against interim trophic indicator ratings, the proportion of soft mud/sand was large enough to be causing stress to aquatic organisms (Robertson et al. 2016b).

Dominant unvegetated habitats

When substrates underlying macroalgae and seagrass were excluded in area calculations (as per the EMP, Robertson et al. 2002), unvegetated habitats covered 40.2% of the Whatamango Bay estuary intertidal zone (Figure 5, Table 3). Cobble field (22.2%) and gravel field (7.6%) were the dominant unvegetated habitats (Figure 7), and were present in the high shore, as well as bordering the Graham River channel. The lack of finer sediments (e.g. mud and sand) either side of the channel was likely due to flushing/scouring of the seabed by the river. Firm mud/sand covered a relatively small proportion (3.5%) of the estuary. In comparison to other estuaries within the Marlborough/Nelson region, the proportion of cobble/gravel field was high and mud/sand low (Table 5).

However, firm mud/sand was the dominant substrate (53.6%) when substrates underlying macroalgae and seagrass were included in area calculations (Figure 6, Table 6). This substrate was present in the middle and eastern regions of the bay on the mid/low shore, as well as in patches on the western side. We note the substantial differences in substrate areas (both in absolute terms as well as proportional) resulting from the different reporting methodologies.

Table 5. Comparison of key habitats as a proportion of the intertidal zone (reported following the EMP, unless stated for seagrass), for a selection of Marlborough (A) and Nelson/Marlborough (B) estuaries. Values for unvegetated substrates from some surveys could not be added due to the deviation of reporting methodologies from the EMP. Where known, estuary typology based on the ETI classification system (Robertson et al. 2016b) is stated: Shallow Intertidal Dominated Estuary = SIDE, Shallow, Short Residence Time Tidal River Estuaries = SSRTRE. Total intertidal area excludes subtidal water.

A: Marlborough

	Whatamango Bay estuary 2018	Okiwa Bay 2012	Ngakuta Bay 2012	Havelock Estuary 2014	Wairau Estuary 2015	Shakespeare Bay estuary 2016	Waikawa Estuary 2016	Mahikapawa Estuary 2017
Reference	Current survey	Gillespie et al. 2012	Gillespie et al. 2012	Stevens & Robertson 2014	Berthelsen et al. 2015	Berthelsen et al. 2016	Stevens & Robertson 2016a	Skilton & Thompson 2017
Total intertidal area of estuary (ha)	**9.1**	**70.1**	**9.7**	**565.0**	**358.5**	**5.4**	**2.8**	**137.5**
Typology	SIDE	-	-	SIDE	-	SIDE	-	-
Habitat (%)								
Mud/sand habitats	7.0	78.4	28.5	-	45.0	35.1	-	-
Sand habitats	2.2	1.3	40.5	-	0.0	2.7	-	-
Gravel/cobble	29.8	7.0	4.4	-	0.5	21.0	-	-
Saltmarsh	6.4	9.6	12.5	36.0	46.3	7.8	0.7	25.2
Seagrass	31.7	2.4	7.4	2.7[13]	0.0	30.8	35.8[14]	0.01

[13] Includes seagrass cover > 50%.
[14] Includes seagrass cover > 50%.

B: Marlborough and Nelson

	Whatamango Bay estuary 2018	Ruataniwha 2002	Waimea Inlet 2006	Nelson Haven 2009	Delaware Inlet 2009	Kokorua Inlet 2015	Whangarae Estuary 2016	Kaiuma Bay estuary 2017
Reference	Current survey	Robertson et al. 2002	Clark et al. 2008	Gillespie et al. 2011a	Gillespie et al. 2011b	Stevens & Robertson 2015	Stevens & Robertson 2016b	Stevens & Robertson 2017
k	**9.1**	**726.2**	**2950.3**	**850.8**	**331.1**	**61.4**	**124.0**	**52.8**
Typology	SIDE	SSRTRE	SIDE	SIDE	SIDE	SIDE	-	-
Habitat (%)								
Mud/sand habitats	7.0	40.4	65.0	48.6	26.4	-	-	-
Sand habitats	2.2	29.5	12.2	22.2	31.8	-	-	-
Gravel/cobble	29.8	11.8	9.8	4.8	8.3	-	-	-
Saltmarsh	6.4	16.5	8.7	0.8	7.0	34.9	7.9	11.4
Seagrass	31.7	1.7	0.7	14.0	1.4	0[15]	1.6[16]	0.02[17]

[15] Includes seagrass cover > 50%.
[16] Includes all seagrass – this was present in two densities (40% and 100%).
[17] Includes seagrass cover > 20%.

Soft mud/sand

Soft mud/sand (i.e. soft mud) covered 5.3% of the intertidal zone if the soft mud/sand underlying seagrass and macroalgae was included (or 3.5% if the soft mud/sand underlying these vegetation types was excluded). Soft mud/sand was present near small channels along the high shore line in the middle of the estuary and to the west (Figure 6). If including the area of soft mud under macroalgae and seagrass, as has been done in other surveys utilising ETI indicators, the percent estuary area of soft mud EQR was within Band C ('medium' trophic status) (Table 4), indicating that soft mud was causing a moderate stress on some organisms, with a risk of sensitive macroinvertebrate species being lost (Robertson et al. 2016b). Increasing mud content can alter sediment characteristics and is a strong determinant of benthic community composition. However the proposed soft mud EQR bands are considered interim only and need further validation.

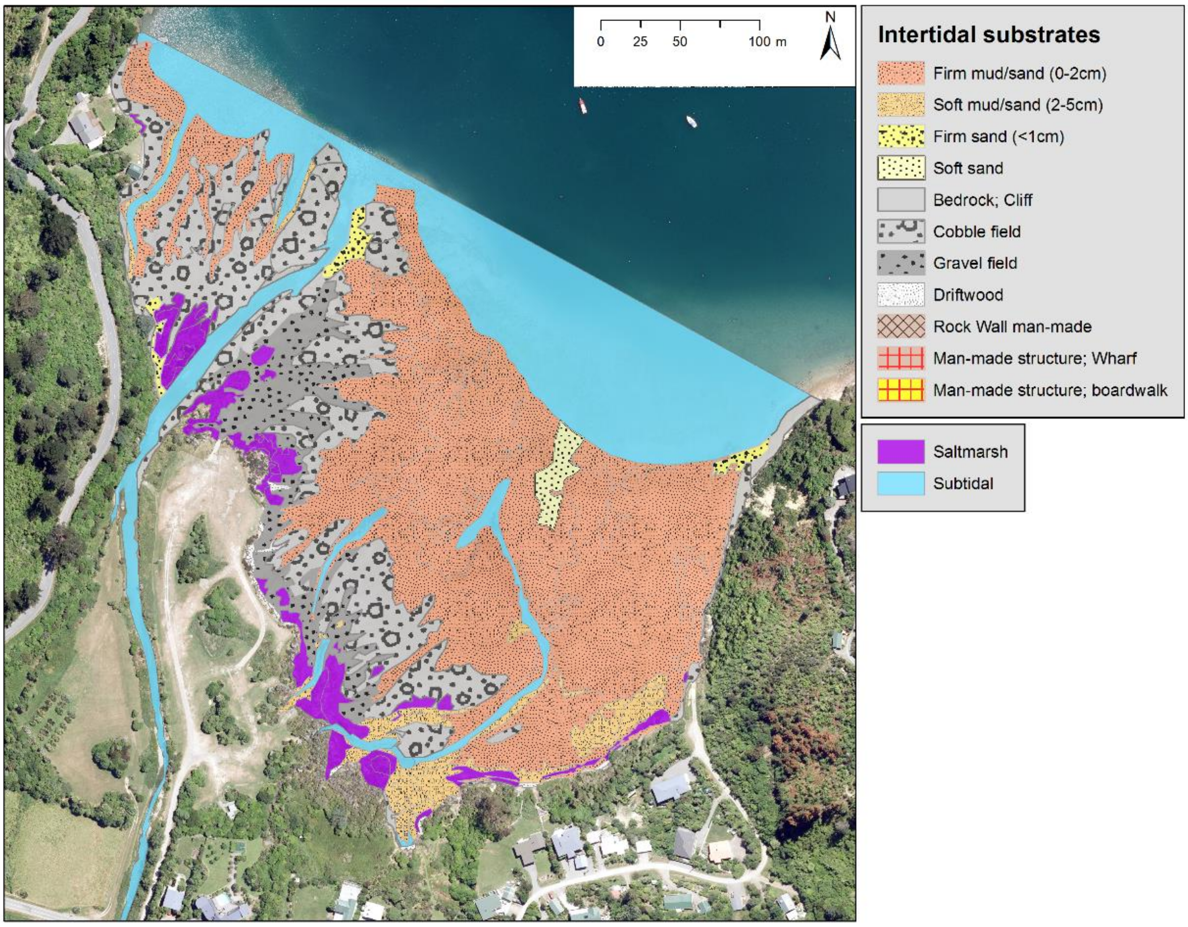

Figure 6. Unvegetated habitats, including those underlying macroalgae and seagrass, in the Whatamango Bay estuary intertidal zone, 2018. Saltmarsh is also shown.

Redox potential

The RP values from individual sites within firm mud/sand substrates (the most impacted substrate comprising at least ten percent of the estuary) were nearly all (15 out of 17) within EQR Band A ('high' trophic status), indicating that sediment oxygenation was generally not causing stress on aquatic organisms in these regions (Robertson et al. 2016b) (Table 4, Appendix 4). The average of all RP values from firm mud/sand was +234.9 mV ± +32.1 mV (± standard deviation)[18] (Table 4, Appendix 4). Cores were generally light brown near the surface and darker below the aRPD which, when present, ranged from approximately 2–8 cm depth (Figure 7, Appendix 4). As the aRPD in our cores was never at the surface, we considered these data not to be within EQR Band D ('bad' trophic status) (Table 4), indicating that this was unlikely to be causing a significant and persistent stress on aquatic organisms (Robertson et al. 2016b). Ecological quality rating thresholds for both RP and aRPD are also interim pending further research. For comparison, sediments in the nearby Waikawa Estuary were generally less oxygenated, with aRPDs ranging from 0–3 cm (Stevens & Robertson 2016a). In the Mahikapawa Estuary, aRPDs ranged from 2.7–10 cm, and average RPs from approximately +70mV to +180 mV (Skilton & Thompson 2017).

Other unvegetated habitats

Substrates containing cockles were present in the Whatamango Bay estuary, although cockle shells were never the dominant habitat. We recorded no oysters. There was human modification within the estuary in the form of a wharf, rock wall and other structures.

Table 6. Summary of unvegetated substrates (including those underlying seagrass and macroalgae but not saltmarsh) within the Whatamango Bay estuary intertidal zone, 2018. Subtidal water was excluded, and saltmarsh included, in the total intertidal area.

Unvegetated substrates	Area (ha)	Proportion of intertidal (%)
Firm mud/sand	4.89	53.56
Cobble field	2.17	23.82
Gravel field	0.69	7.57
Soft mud/sand	0.48	5.26
Firm sand	0.11	1.19
Soft sand	0.10	1.05
Bedrock	0.06	0.69
Driftwood	0.04	0.41
Wharf	0.00	0.05
Rock wall man-made	0.00	0.01
Man-made structure	0.00	0.00
Total	**9.13** (including 0.58 ha of saltmarsh)	**93.61** (excluding saltmarsh)

[18] This value, along with others, was used in the final estuary trophic state EQR calculation (Appendix 1).

Figure 7. Cobble field (top left), gravel field (top right) and firm mud/sand (bottom left) were the dominant unvegetated habitats within Whatamango Bay estuary intertidal zone, 2018. Sediment core collected from the estuary (bottom right).

3.1.2. Vegetated habitats

Vegetated habitats, comprising seagrass, macroalgae and saltmarsh, covered the majority (59.8%) of the intertidal zone (Figure 8, Table 3).

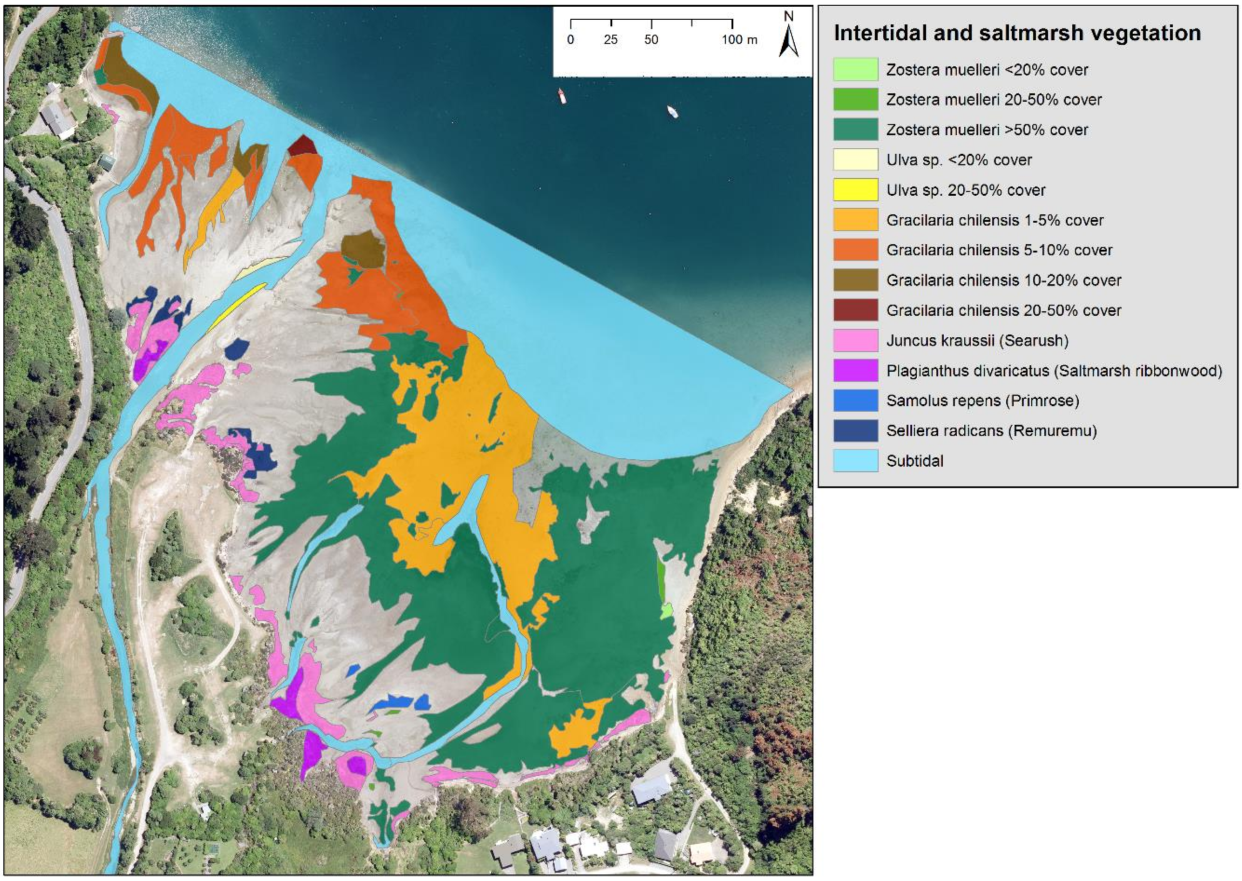

Figure 8. Vegetation coverage within the Whatamango Bay estuary intertidal zone, 2018.

Seagrass

Seagrass covered a relatively high proportion of the Whatamango Bay estuary and was likely performing key ecological functions. We suspected that the area of seagrass had reduced since 2015.

Seagrass covered 31.7% of the intertidal zone, and was generally very dense (> 50% cover) (Figure 8, Figure 9, Table 3). It was mostly found in the mid to low shore on firm mud/sand and was predominantly located in the mid and eastern side of the estuary. In comparison, seagrass was generally rare or absent in many other estuaries surveyed within the Marlborough/Nelson region (Table 5). Estuaries that do contain a relatively high proportion of seagrass within these regions include Nelson Haven (Gillespie et al. 2011a), Shakespeare Bay estuary (Berthelsen et al. 2016) and Waikawa Estuary (Stevens & Robertson 2016a), which ranged from 14%–36% seagrass cover. The extent of this ecologically important habitat within Whatamango Bay estuary was therefore one of the highest in the region.

Figure 9. Seagrass (*Zostera muelleri*) bed (left), and seagrass subject to physical disturbance probably caused by a vehicle (right) in the Whatamango Bay estuary, 2018.

Seagrass meadows are an important natural attribute of many New Zealand estuaries and have high ecological value (Matheson et al. 2009; van Houte-Howes et al. 2004). They provide a stable physical habitat and a localised food source to support a diverse community of animals including a variety of fish species (Matheson et al. 2009), as well as important foraging areas for certain shorebirds. They also help filter nutrients and trap sediments, thereby maintaining water quality (Turner & Schwarz 2006). As photosynthesising plants, they release oxygen from their leaves and roots that benefits other biota and stimulates nutrient cycling (Matheson et al. 2009).

Seagrass was largely absent from the western side of the estuary where coarser substrates (i.e. cobble and gravel) were present alongside the Graham River channel. It is likely that both the coarser substrates, and lower salinity of the river water, prohibited seagrass establishment in this region. Seagrass was also absent from a circular region in the mid-shore of the middle/eastern part of the estuary and probably extending into the unmapped subtidal. Darker regions within the 2015 aerial photo suggested that seagrass may have been more extensive (in comparison to the current survey and 2017 aerial image) in this general area, although we cannot be certain as no ground truthing was conducted in 2015. Seagrass can be naturally spatially and temporally variable (Turner & Schwarz 2006), although alternatively, seagrass habitat can be lost to due to other reasons, e.g. smothering by fine sediments or macroalgae.

We also observed apparent physical disturbance of seagrass in the estuary caused by vehicles (Figure 9), which has occurred in other estuaries within the Marlborough/Nelson region (e.g. Gillespie et al. 2011; Gillespie et al. 2012; Šunde et al. 2017). Vehicles can damage seagrass in localised areas (Turner & Schwarz 2006; McCrone 2001), and the seagrass could take several seasons to regenerate with repeated disturbances potentially resulting in long-term damage or mortality.

We were unable to calculate an EQR for seagrass as there were no known appropriate historical seagrass mapping data. However, the data collected during this survey provided a baseline value that could be combined with data from future surveys to assess this indicator.

Overall, the high proportion of seagrass in the Whatamango Bay estuary indicated that this habitat was performing key ecological functions and was unlikely subject to adversely high sediment deposition rates and/or excessive nutrients. However, suspected loss of seagrass in recent years, along with evidence of possible physical damage caused by vehicles, suggested that the seagrass was possibly suffering some stress.

Macroalgae

Macroalgal abundance within the Whatamango Bay estuary intertidal zone was low enough to indicate that the estuary was not subject to excessive nutrients. Macroalgae covered a relatively large proportion (21.7%) of the estuary intertidal zone, although its percent cover within these regions was generally low (mostly 1–5%, and never higher than 50%) (Figure 8, Table 3). *Gracilaria chilensis*[19], the dominant species, was predominantly found on firm mud/sand, and sometimes cobble field, on the low and/or mid-shore to the west and middle of the estuary (Figure 8, Figure 10).

Macroalgae can grow rapidly, particularly during summer, and opportunistic taxa such as *G. chilensis* can reach problem densities under enriched conditions. All individual sub-metrics of the OMBT (e.g. those relating to biomass, entrainment, % cover) were in the 'high' trophic status band, except for the affected area (AA) as a proportion of the available intertidal habitat (AIH), which was considered 'good' (Table 7, Appendix 5). We note that the AIH can be subjective depending on what habitats were considered appropriate for macroalgal growth and this can influence the OMBT sub-metric and overall results. The overall OMBT EQR value was in the 'high' band (0.92), suggesting that the macroalgae was not subject to excessive nutrients. We also note that there has been recent discussion regarding the appropriateness of applying the ETI EQR bands to New Zealand conditions, as they are based on those from the European Water Framework Directive (WFD) (Townsend & Jones 2018). The aerial image from December 2017 also showed what appeared to be green blooms of macroalgae in the lower intertidal/shallow subtidal region, although this could not be confirmed as we had no ground-truthing information from the month that the photograph was taken. More detailed assessment would be required to quantify any temporal changes in macroalgal coverage over the course of a summer season.

[19] It is likely that this is *G. chilensis*, although an introduced species that is morphologically identical has been found in the upper North Island (Nelson 2013).

Table 7. Survey results for the Opportunistic Macroalgal Blooming Tool (OMBT) and associated sub-metrics (actual/face value and ecological quality ratings [EQRs], bands and trophic status) for Whatamango Bay estuary, 2018. See Table 1 and Appendix 1 for description of indicator and sub-metrics. See Table 2 and Appendix 2 for EQR bands. The Available Intertidal Habitat (AIH) was calculated as 8.31 ha. See report glossary for definition of terms.

Overall description	**Trophic indicator or sub-metrics**	**Actual/Face value**	**EQR value**	**EQR Band**	**Trophic status**
OMBT sub-metrics	**Cover in AIH** (%)	0.82	0.97	N/A	High
	Biomass per m^2 AIH (wet weight g/m^2)	2.62	0.99	N/A	High
	Biomass per m^2 AA (wet weight g/m^2)	27.77	0.94	N/A	High
	Entrained in AA (%)	0.00	1.0	N/A	High (= lower limit)
	AA* (ha)	0.78	0.98	N/A	High
	AA/AIH* (%)	9.43	0.71	N/A	Good
Final EQR	**OMBT**	N/A	0.92	A	High

*The lowest EQR from AA and AA/AIH is used in the OMBT calculation.
Note: All metrics are equally weighted and combined within the multimetric index.

Ulva sp.[20] covered a much smaller area than *G. chilensis* and was found growing on cobbles (Figure 10). *Ulva* sp. was also growing amongst the *Gracilaria* beds but as a subdominant habitat. Although *Ulva* is considered to be bloom-forming, when it was the dominant taxa we excluded it from the OMBT as it was generally only growing on hard substrates and therefore not suitable for inclusion in this calculation (Wells et al. 2010).

Gelidium sp.[21] and *Codium* sp. were also present in the estuary, but were relatively sparse and are not primary bloom-forming taxa in New Zealand (Robertson et al. 2016b).

[20] Possibly *Ulva intestinalis.*
[21] Possibly *Gelidium caulacantheum.*

Figure 10. Low density macroalgae (*Gracilaria chilensis* 1–5% cover) (left) was the dominant vegetated habitat within the Whatamango Bay estuary intertidal zone, 2018. *Ulva* sp. was also present (right).

Saltmarsh

While the overall proportion of saltmarsh habitat was low compared to most other estuaries in the region, its upper shore location suggested saltmarsh was still performing key ecological functions.

Saltmarsh (estuarine shrub, rushland and herbfield) was growing within the high shore and covered 6.4% of the intertidal zone (Figure 8, Table 3, Figure 11). The dominant saltmarsh species were *Juncus kraussii* (searush), *Plagianthus divaricatus* (saltmarsh ribbonwood), *Samolus repens* (primrose), and *Selliera radicans* (remuremu). The proportion of saltmarsh within the estuary was on the low side compared to many other Marlborough/Nelson estuaries (Table 5). The herbfield species *Sarcocornia quinqueflora* (glasswort), common in other regional estuaries (e.g. Berthelsen et al. 2016; Stevens & Robertson 2016b), was relatively low in proportion (i.e. never the dominant habitat) in the Whatamango Bay estuary.

Saltmarsh species generally colonise areas of fine substrate, so this may be the limiting factor for saltmarsh expansion in this estuary. These upper intertidal habitats are functionally important in that they are areas of active primary production and decomposition (Gillespie & MacKenzie 1981). Saltmarsh habitats also act as a filter at the land sea interface and can assimilate inorganic nutrients and trap fine sediment from spreading into coastal areas.

Figure 11. Saltmarsh in the Whatamango Bay estuary intertidal zone, 2018.

Gross Nuisance Areas

There were no GNAs[10] present in the Whatamango Bay estuary. This indicator was therefore given a 'high' trophic status (Band A) (Table 4) (Stevens & Robertson 2017), indicating that excessive opportunistic macroalgae associated with anoxic sediment were absent.

3.1.3. Estuary margin

The estuary margin (from MHWS to 200 m) was covered largely by terrestrial scrub/shrub/forest, although more human-modified habitats were also common. The estuary margin was predominantly (64%) covered by terrestrial scrub/shrub/forest, which largely comprised of native scrub/shrub trees (58.7%) followed by exotic scrub/shrub/trees (4.4%) (Figure 12, Table 8). The exotic species *Ulex europaeus* (gorse) was also recorded as a component of the terrestrial scrub/shrub/forest habitat. Vegetated habitats within the estuary margin help protect estuarine habitats by serving as a buffer zone around the estuary edge. Saltmarsh (herbfield, reedland, rushland, estuarine shrub) was also present directly adjacent to the MHWS boundary around much of the estuary (0.8%). The high proportion of native vegetation surrounding the estuary indicated that the vegetation was likely performing key ecological functions.

The next two most dominant habitats in the margin, rural residential (comprising houses and associated structures and green spaces, e.g. gardens) and exotic pasture grass (including a campground), were both highly modified by humans. Other human-modified habitats included road, bridge and other man-made structures. These habitats, along with the presence of exotic species, have modified the natural state of the estuary margin.

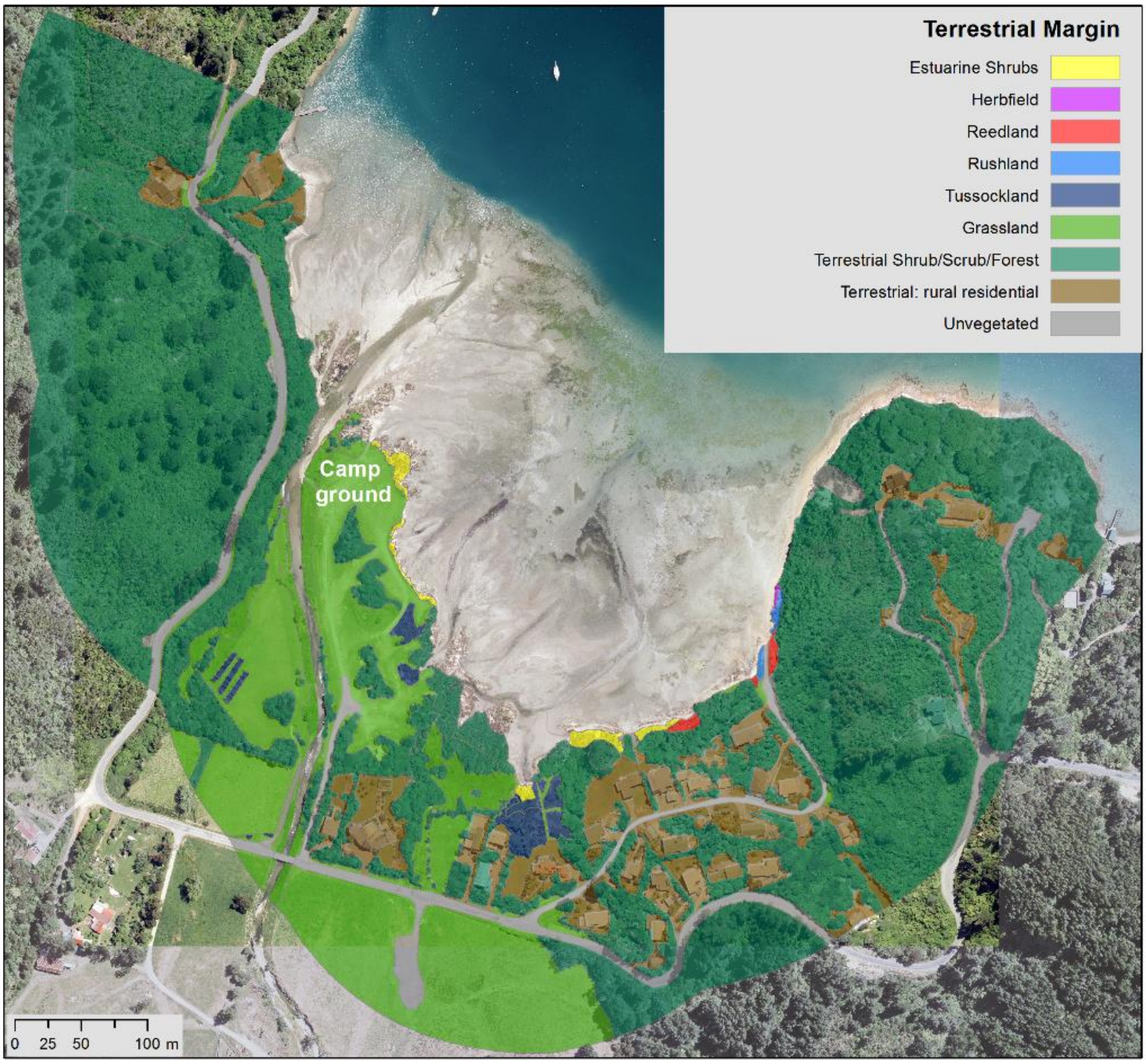

Figure 12. Key broad-scale habitats within the estuary margin (MHWS to 200 m) of Whatamango Bay estuary, 2018.

Table 8. Breakdown of dominant broad-scale habitats within the estuary margin (MHWS to 200 m) of Whatamango Bay estuary, 2018.

Class	Dominant Habitat	Area (ha)	Proportion of intertidal (%)
Terrestrial Shrub/Scrub/Forest		**17.49**	**64.21**
	Native scrub/shrub/trees	16.01	58.77
	Exotic scrub/shrub/trees	1.21	4.44
	Leptospermum scoparium (manuka) or *Kunzea ericoides* (kanuka)	0.24	0.88
	Ulex europaeus (gorse)	0.01	0.04
	Unidentified trees	0.01	0.04
Grassland		**5.17**	**18.98**
	Exotic pasture grass	2.31	8.48
	Grassland	1.95	7.16
	Unidentified grass	0.91	3.34
Terrestrial		**2.62**	**9.62**
	Rural residential	2.62	9.62
Unvegetated		**1.47**	**5.40**
	Road	1.21	4.44
	Unvegetated	0.17	0.62
	Cobble field	0.04	0.15
	Driftwood	0.04	0.15
	Bridge	0.01	0.04
	Boulder field	0.01	0.04
	Man-made structure	0.00	0.00
Tussockland		**0.28**	**1.03**
	Phormium tenax (New Zealand flax)	0.20	0.73
	Tussockland	0.08	0.29
Estuarine Shrubs		**0.13**	**0.48**
	Plagianthus divaricatus (saltmarsh ribbonwood)	0.12	0.44
	Muehlenbeckia complexa	0.01	0.04
Reedland		**0.04**	**0.15**
	Typha orientalis (raupo)	0.04	0.15
Rushland		**0.03**	**0.11**
	Juncus kraussii (searush)	0.01	0.04
	Leptocarpus similis (jointed wirerush)	0.01	0.04
Herbfield		**0.01**	**0.04**
	Selliera radicans (remuremu)	0.01	0.04
Total		**27.24**	**100.00**

3.1.4. Final estuary trophic status

The final estuary trophic status of the Whatamango Bay estuary was calculated as ‘high’ (Band A), indicating that the estuary was exhibiting minimal eutrophic symptoms (Table 4). This trophic indicator utilises a ‘weight of evidence approach’ by incorporating results from multiple trophic indicators within its equation. However, its robustness is weakened by the fact that most of the indicator EQR thresholds are interim, pending further validation.

3.1.5. Overall estuary health

Overall, we consider the Whatamango Bay estuary to be in generally good health. The proportion of key ecological habitats, including seagrass and firm mud/sand and other unvegetated substrates such as cobble and gravel fields, was relatively high. Sediments were generally well oxygenated. Saltmarsh habitats were also present, macroalgae was low in abundance, and the estuary margin was predominantly forested in native vegetation. The final estuary trophic status EQR of 'high' indicated that the estuary was exhibiting minimal eutrophic symptoms. From a broad-scale perspective, the estuary could therefore be used as a reference against which other estuaries with similar typology within Queen Charlotte Sound could be compared. For example, it could be used as a desirable baseline for restoration and management goals for estuaries in a poorer state of health.

However, following interim thresholds based on trophic status, the proportion of soft mud was considered high enough to be causing stress to sensitive aquatic organisms. Some modification of the estuary and its margin had occurred, and exotic plants were present in the margin. We also suspected that the area of seagrass had reduced since 2015.

4. MONITORING AND MANAGEMENT

We have based the following monitoring and management recommendations on any key issues/threats that were identified to be compromising the health of the estuary. We have also made suggestions regarding monitoring improvements.

Following the MDC Coastal Monitoring Strategy (2012), Whatamango Bay estuary is to be monitored at ten-year intervals by habitat and vegetation mapping only. For this future monitoring, we recommend the following actions:

- To ensure the most accurate and up-to-date habitat maps, current aerial images should be utilised. Higher resolution images can also increase the accuracy of habitat mapping. Estuary habitats within the Marlborough/Nelson region have been mapped successfully, and relatively cost-efficiently, using current and higher resolution images collected by drone (e.g. Berthelsen et al. 2015; Skilton and Thompson 2017; Šunde et al. 2017).
- To allow accurate comparison of broad-scale habitat mapping results, reporting methodologies need to be standardised. This issue is also likely to be reduced if original GIS files are accessible.

Additional monitoring and management recommendations include:

- For a more complete assessment of estuary health, we recommend carrying out fine-scale benthic assessments following EMP methodologies and timeframes. Relevant ETI indicators can also be used (for fine- as well as broad-scale surveys), keeping in mind that for many of these the bands defining trophic status are interim, pending further validation. Methodologies for calculating some ETI indicators may also need further standardisation.
- Due to the suspected recent loss of seagrass, we recommend more regular broad-scale monitoring of this ecologically valuable habitat using high resolution drone images. This could be undertaken at least every five years and would also be particularly important before and/or after any activities/events that may increase the amount of fine sediment entering the estuary (e.g. forestry harvesting in the catchment, flood events). It could also provide an opportunity to evaluate the extent of vehicle damage to the seagrass.
- As the proportion of soft mud was considered high enough to be causing stress to sensitive aquatic organisms, and as seagrass can be adversely affected by fine sediments, we recommend implementing strict sediment controls for any relevant activities in the catchment. Planting native vegetation in the estuary margin, and elsewhere in the catchment, may reduce the amount of sediment entering the estuary as well as provide other benefits.

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7. APPENDICES

Appendix 1. Data required for the calculation of the final estuary trophic status Ecological Quality Rating (EQR) of the Whatamango Bay estuary, 2018. The calculation was made using Zeldis et al. (2017).

Input data (trophic indicators/or metrics)	**Definition**
Percent estuary area of soft mud* (%)	Percentage of estuary intertidal area** with soft mud substrate* (i.e. sediment with > 25% mud content) as assessed using the EMP (Robertson et al. 2002)
Redox Potential (RP) (mV)	Mean of measured RP at 1 cm depth. Must represent the most impacted*** sediments* and at least 10% of estuary area**
Opportunistic macroalgae (OMBT)	Use seasonal worst case and calculate for whole estuary
Gross Nuisance Area (GNA) (ha)	Spatial measures of the macroalgal Gross Nuisance Area (GNA), measured in both ha and as a percent of the total estuary area** GNA = Area where opportunistic macroalgae exceed 50% cover and the underlying sediments exhibit aRPD at the surface (i.e. aRPD 0-0.5 cm) (often with muddy sediments i.e. >25% mud content)
GNA/estuary area** (%)	
Estuary type	Estuaries classified into DSDE, SIDE, SSRTRE
ICOE status	Whether an estuary is intermittently closed. Values are "TRUE" or "FALSE"
Final trophic status of estuary	**Values range from 0 to 1, with a value of 1 indicating a good trophic condition**

*we have included relevant substrates underlying macroalgae and seagrass (but not saltmarsh) in this value
**we have defined this as intertidal area minus subtidal water. It includes saltmarsh
***we have interpreted this as substrates assumed to comprise the highest percentage of mud

Appendix 2. Ecological Quality Rating (EQR) bands for sub-metrics used to calculate the Opportunistic Macroalgal Blooming Tool (OMBT). #The ETI does not define an upper limit that is distinct from the Poor/Bad threshold, therefore a default value from the WDF United Kingdom OMBT calculation template was used. See report glossary for definitions of relevant terms.

	Lower limit	**High/Good**	**Good/Medium**	**Medium /Poor**	**Poor/Bad**	**Upper limit**
Cover in AIH* (%)	0	5	15	25	75	100
Biomass per m^2 AIH** (wet weight g/m^2)	0	100	500	1000	3000	6000#
Biomass per m^2 AA*** (wet weight g/m^2)	0	100	500	1000	3000	6000#
Entrained in AA**** (%)	0	1	5	20	50	100
AA (ha)	0	10	50	100	250	6000#
AA/AIH***** (%)	0	5	15	50	75	100
Final OMBT EQR	1	0.8	0.6	0.4	0.2	0

Calculations:
*Cover in AIH = (Total % cover/AIH) X 100, where Total % cover = Sum of ((patch size)/100)x average % cover for patch.
**Biomass per m^2 AIH = Total biomass/AIH, where Total biomass = Sum of (patch size x average biomass for the patch).
*** Biomass per m^2 AA = Total biomass/AA, where Total biomass = Sum of (patch size x average biomass for the patch).
**** Entrained in AA = (No. quadrats with entrained algae/total no. quadrats) x 100 x patch size (average for all patches).
*****Size of AA in relation to AIH = (AA/AIH) x 100.
Note: all metrics are calculated per patch.

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Appendix 3. DVD-ROM file containing a working version of the 2018 broad-scale habitat maps of Whatamango Bay estuary (entitled 'Broad-scale intertidal habitat mapping for Whatamango Bay estuary: 2018') (see inside back cover).

Appendix 4. Redox Potential (RP) and apparent Redox Potential Discontinuity (aRPD) sample locations and values/descriptions for firm mud/sand substrates . N/A = not assessed. See report glossary for definitions of relevant terms.

NZTM_E	NZTM_N	RP (mV)	aRPD (cm)
1690138	5431078	190.2	6
1690146	5431073	208.4	5.5
1690130	5431125	224.7	No layer
1690107	5431063	288.7	~2
1690122	5431042	209.7	No layer
1690139	5431032	228.2	7-8
1690177	5430949	252.1	~2
1690186	5430957	270.9	No layer
1690179	5430986	262.2	No layer
1690082	5431149	238.1	N/A
1689970	5431203	260.5	Layer indistinct
1690001	5431148	298.8	No layer
1690307	5430869	197.1	N/A
1690313	5430874	224.5	N/A
1690212	5430844	217.8	N/A
1690216	5430841	208.3	N/A
1690225	5430826	213.7	N/A
Average ± st dev		**234.9 ± 32.1**	

Appendix 5. Macroalgal patch data values (dominant species, percent cover, biomass and area of patch) used to calculate the opportunistic macroalgal blooming tool (OMBT) in the Whatamango Bay estuary intertidal zone, 2018. Data for patches with percent cover 1–5% were excluded from the OMBT calculation (Robertson et al. 2016b).

Dominant macroalgal species and range of percent cover in patches (%)	Biomass (g/m^2)	Area of patch (ha)
Gracilaria chilensis 20-50%	101.65	0.02
Gracilaria chilensis 10-20%	41.16	0.02
Gracilaria chilensis 10-20%	41.16	0.00
Gracilaria chilensis 10-20%	61.25	0.06
Gracilaria chilensis 10-20%	27.45	0.05
Gracilaria chilensis 5-10%	24.40	0.01
Gracilaria chilensis 5-10%	24.40	0.02
Gracilaria chilensis 5-10%	35.00	0.19
Gracilaria chilensis 5-10%	16.05	0.39
Gracilaria chilensis 5-10%	24.40	0.02
Gracilaria chilensis 5-10%	29.20	0.03
Gracilaria chilensis 1-5%	10.35	0.02
Gracilaria chilensis 1-5%	11.10	1.01
Gracilaria chilensis 1-5%	10.35	0.06
Gracilaria chilensis 1-5%	10.35	0.05