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SHAKESPEARE BAY ESTUARY MONITORING 2016

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Prepared for Marlborough District Council

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EXECUTIVE SUMMARY

Cawthron Institute (Cawthron) was commissioned by the Marlborough District Council (MDC) to undertake state of the environment monitoring of the Shakespeare Bay estuary. This comprised an assessment of estuary condition or 'health' following the standardised Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) and involved one 'point in time' survey of the estuary based on:

- Broad-scale mapping of intertidal and estuary margin (i.e. supra-littoral fringe) habitats.
- Fine-scale benthic surveys of the intertidal seabed at two reference sites within the estuary.

The monitoring provided a reference point from which to compare the Shakespeare Bay estuary against other estuaries and national indicator ratings and to assess future 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.

Summary and recommendations

The Shakespeare Bay estuary is ecologically significant within the Marlborough region and is valued culturally, recreationally and commercially. This survey found the estuary to be subject to generally minor pressures from key environmental stressors and therefore in relatively **good health**.

High value habitats including seagrass and rushland comprised a high proportion of the estuary and were likely performing key functional roles.

The limited area of soft sediment habitats within the intertidal zone, and a relatively low percentage of mud within sediments, indicated that the estuary was unlikely to be threatened by high sedimentation.

Relatively low sediment nutrient and organic carbon concentrations, and lack of a strong redox discontinuity layer in sediment core profiles, suggested that excessive nutrients and eutrophication were not an issue. This was also indicated by the limited abundance of macro- and microalgae.

Sediment contaminants were below ISQG-Low guideline thresholds (metal/metalloids) and detection limits (SVOCs, organotin) and there was no evidence to suggest that they were having an adverse ecological effect.

However, the estuary was not unimpacted, as mud and nitrogen levels within the sediment were high enough (within indicator rating Band B) to potentially cause a minor stress on benthic animal communities. In addition, a proportion of the supra-littoral zone was modified from its natural state with the presence of exotic plant species and man-made structures.

Future recommendations include:

- Conducting broad-scale and fine-scale monitoring in at least five-yearly intervals to assess any future changes that might adversely affect the health of the estuary.
- The careful management of anthropogenic activities within the Shakespeare Bay and its catchment that could increase environmental stressors (with particular focus on fine sediment and nitrogen levels), and therefore compromise the good health of the estuary. This could be complemented by further targeted monitoring of ecological indicators (e.g. seagrass) or environmental stressors that may be influenced by future anthropogenic activity (e.g. monitoring of sediment deposition patterns in conjunction with commercial forestry activities within the catchment).
- Using the Shakespeare Bay estuary as a reference against which other estuaries with similar characteristics (e.g. typology) within Queen Charlotte Sound could be compared.
- The consideration of the incorporation of an iwi monitoring programme. State of the environment monitoring may align with iwi environmental management aims. An iwi monitoring programme could also support objectives of the MDC coastal monitoring strategy (2012).

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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. The MDC prioritised the Shakespeare Bay estuary (Figure 1) for monitoring in 2016 and Cawthron Institute (Cawthron) was commissioned to conduct this work. This comprised an assessment of estuary condition or 'health' following the standardised Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) and involved a 'point in time' survey of the estuary.

1.1. Background

1.1.1. Importance of estuaries

The intertidal[1] and supra-littoral[2] habitats associated with estuaries provide a link between terrestrial and marine environments. They are functionally important and provide a number of ecosystem services, including primary[3] and secondary[4] 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. Estuarine habitats are often of high ecological value and contain resources of significant cultural, recreational and commercial benefit.

1.1.2. Threats to estuary health

New Zealand estuaries are subject to a range of anthropogenic stressors that can compromise their health (Ellis et al. 2015). A summary of commonly occurring stressors is provided below.

High value habitats within estuaries (e.g. salt marsh, seagrass, tidal flats) contribute to estuary health by providing key functions such as enhanced decomposition and nutrient cycling processes, trapping of sediments and provision of food and habitat (Gillespie & MacKenzie 1981; Matheson et al. 2009). **Loss of these high value habitats,** caused directly by human activities (e.g. saltmarsh reduction through land reclamation) or indirectly through impacts from environmental stressors (e.g. seagrass vulnerability to sedimentation and eutrophication), can compromise important functions leading to a variety of adverse effects e.g. reduced productivity, biodiversity, increased sediment mobility.

[1] Area of seabed between Mean Low Water Springs and Mean High Water Springs.
[2] A 10 meter wide riparian strip above Mean High Water Springs.
[3] Primary production is 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.
[4] Secondary production is 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.

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. It can also adversely impact benthic animals, e.g. by smothering and clogging filter feeding apparatus, and is therefore a strong determinant of benthic community composition (Thrush et al. 2004).

Excessively high levels of nutrients (e.g. nitrogen, phosphorus) **and total organic carbon,** often derived from catchment runoff or point source discharges**,** can lead to enriched,and potentially eutrophic, conditions (Ferreira et al. 2011; Robertson et al. 2016). The process of eutrophication is indicated by a variety of symptoms (e.g. macroalgal or microalgal blooms, anoxic[5] sediment, sulphide toxicity), which can adversely impact animal communities (Paerl 2006) (e.g. by reducing available oxygen within the sediments, or smothering by macroalgae).

Contaminants, such as heavy metals/metalloids, semi-volatile organic compounds[6] (SVOCs) and organotin compounds[7], can result from a range of anthropogenic activities and be highly toxic to marine life (Bryan 1971; Mucha et al. 2003; Moore et al. 2002). Animals belonging to higher trophic levels can also be adversely impacted through bioaccumulation of particular contaminants within their tissues that may potentially affect reproductive success and/or immune-responses.

1.1.3. Estuary Monitoring Protocol

In 2002, a national set of standardised estuarine monitoring methodologies, termed the Estuarine Monitoring Protocol or EMP (Robertson et al. 2002), was created by Cawthron as a tool to assess the ecological condition of New Zealand estuaries. Use of this protocol ensures long-term consistancy of monitoring datasets, allowing comparisons of past monitoring efforts within an estuary as well as a means of cross-referencing with other estuaries that have been similarly assessed.

The EMP methodology includes three stages. The first is a general overview of background descriptive information and preparation of a preliminary decision matrix (DM), 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 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.

[5] Total absence of available oxygen.
[6] Any moderately volatile organic compound as defined according to specific analytical criteria.
[7] Chemical compounds based on tin with hydrocarbon substitutes.

1.2. Scope and objective

The aim of the survey was to use the EMP to provide a 'point in time' baseline of estuary characteristics with the purpose of indicating the current environmental condition or 'health' of the Shakespeare Bay estuary. This report focusses on stages two (broad-scale habitat mapping) and three (fine-scale benthic surveys) of the EMP with the following scope:

- Broad-scale habitat mapping of the intertidal zone and supra-littoral fringe based on EMP protocol
- Fine-scale benthic survey of two sites based on EMP protocol
- Summary of estuary condition and recommendations for ongoing monitoring and management

1.3. Study Area

1.3.1. General description

Shakespeare Bay is part of Queen Charlotte Sound, located to the west of Picton between Wedge Point and Kaipupu Point (Figure 1). The bay is approximately 1400 m long and 500 m wide and a large proportion of it is relatively deep (> 12 m). The tidal range within the bay is between 0.6–1.7 m (www.portmarlborough.co.nz). Except for its southern valley, the land rises steeply from the water's edge. The bay's catchment is approximately 325 hectares in size and largely covered by vegetation comprising native forest/shrub and exotic forest and grassland (Newcombe & Johnston 2016).

Shakespeare Bay's estuary is positioned at the head of the bay. It comprises an area of gently sloping beach that is exposed for approximately 200 m at low tide. The estuary salinity regime is largely dominated by the tidal flow of saltwater as only two small streams flow into the estuary from the nearby low-lying valley. The estuary is a coastal embayment according to the classification scheme proposed by Hume et al. (2007). Using a classification system designed for estuary response to eutrophication (Robertson et al. 2016), the intertidal estuary habitat could be described as a 'shallow intertidal dominated estuary' (SIDE).

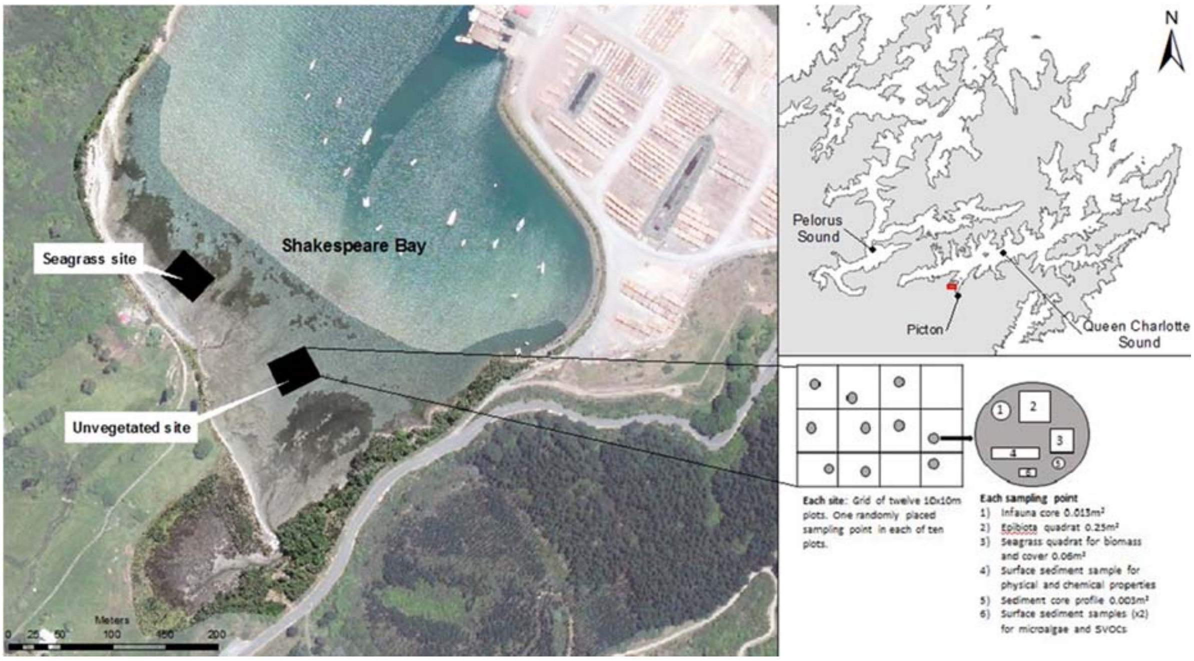

Figure 1. Location of Shakespeare Bay estuary within Queen Charlotte Sound in the Marlborough region (red rectangle), showing the locations of the fine-scale seagrass (SG) and unvegetated (UV) sites and the sampling layout (modified from Robertson et al. 2002).

1.3.2. Ecological and human significance

Shakespeare Bay estuary 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
- the area is visited by banded rail (*Gallirallus philippensis assimilis*), a significant bird species that is nationally classified as 'at risk' (Robertson et al. 2013) due to its declining population
- large areas of the lower intertidal flats support seagrass beds and the alga *Gracilaria* sp. is also common on tidal flats.

The Shakespeare Bay estuary is used recreationally for watercraft (moorings are present in the bay), although other land-based activities are restricted due to limited public access. The catchment area above the estuary contains the Queen Charlotte Drive, which is a popular scenic route appreciated for its aesthetic values. Culturally, the area includes various wāhi tapu[8] and underwater urupā[9] that are significant to Te Ātiawa o Te Waka-a-Māui (Te Tau Ihu Statutory Acknowledgments 2014). Shakespeare Bay was renowned for pipi, kopakopa[10] and being a good spawning

[8] Sacred place or site.
[9] Burial ground.
[10] A type of mussel.

area for mussels. It was also a Tauranga waka[11] and mahinga kai[12] site for Te Ātiawa o Te Waka-A-Māui (Te Tau Ihu Statutory Acknowledgments 2014). Commercially, Shakespeare Bay has a logging port and portions of the wider catchment are used for exotic forestry plantation.

1.3.3. Previous impacts

Environmental reports on Shakespeare Bay conducted by Wear & Haddon (1986), Knox and Bolton (1977), Bolton (1991) and Newcombe and Johnston (2016) contain details of human impacts. In general, Shakespeare Bay has been subject to a variety of human impacts over time including:

- The discharge of freezing works wastewater and by-products into the bay from 1900-1980 causing heavy bacterial pollution and enrichment within the receiving environment (Newcombe & Johnston 2016). Benthic communities are likely to have largely recovered since this time (e.g. Bolton 1991).
- The development in the 1990s of the Waimahara Wharf (Figure 1) including coastal reclamation and wharf construction (Bolton 1991). Stormwater from the port facilities discharges into Shakespeare Bay (Newcombe & Johnston 2016).
- Historical deforestation and subsequent planting and harvesting of exotic vegetation in the catchment (Newcombe & Johnston 2016), likely leading to increased sediment loads entering the bay at various times.

[11] Resting place.
[12] Food gathering.

2. METHODS

2.1. Broad-scale mapping of habitat areas

The broad-scale assessment uses field-verified habitat mapping of the intertidal environment as a key proxy for estuary condition (Robertson et al. 2002). High definition (up to 0.1 m), geo-referenced coloured aerial photographs were taken of Shakespeare Bay estuary on 17 February 2015. Using these ortho-rectified photographs of the bay, potential vegetation and substrate habitat boundaries were digitally pre-classified using image geoprocessing tools through ArcGIS 10.2.2 software prior to field validation. Supervised classification was used to train or 'teach' the classification process how to classify particular habitats based on certain pixel colour combinations as determined by the user. An interactive post-classification processing was then used to further filter and clean boundaries. This procedure created digital polygons of habitat features automatically and in significiantly less time than manual digitising. Copies of the resulting pre-classified habitat types and boundaries, overlying the aerial photos, were printed and laminated for verifiation and further validation in the field.

A field survey covering the majority of the estuary was undertaken on 29 February 2016 from the Mean High Water Spring (MHWS) to the approximate Mean Low Water Spring (MLWS). The supra-littoral fringe was also assessed visually to enable general comment on the type of habitat surrounding the edge of the estuary. Dominant substrate or biota with a spatial coverage greater than 2 m 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). The resulting habitat types were coded 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 different 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).

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' of the sediment 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. A calibration experiment in the Wairau Estuary has also shown that the substrate classes do not solely correlate with grain size (Berthelsen et al. 2015). In order to reduce subjectivity, Cawthron limited the number of soft sediment substrate categories by grouping together 'soft' and 'very soft'.

2.1.1. *Additional methods*

Due to the significance of seagrass and opportunistic macroalgae (i.e. those that respond quckly to increased nutrients) as ecological indicators of estuary health, methods additional to those of the EMP were used to survey these habitats. Seagrass was classified into three categories based on percentage cover (Figure 2). Where applicable, a visual evaluation was conducted to gather information used in the opportunistic macroalgal blooming tool (OMBT), proposed as part of an estuarine trophic index (ETI) to assess the trophic state of New Zealand estuaries (see Robertson et al. 2016 for details).

Figure 2. Percentage cover categories of seagrass: < 20%, 20–50% and > 50% (from left to right).

2.2. Fine-scale sampling design and analyses

Fine-scale sampling was carried out on 29 February 2016 according to EMP procedures (modified slightly; e.g. number of analysed replicates, site size). Two sites positioned at mid to low tide were chosen within the estuary while avoiding zones directly influenced by freshwater sources (Figure 1, Appendix 1). One site was situated on firm mud/sand tidal flats, a common intertidal habitat in Shakespeare Bay estuary and a representative intertidal habitat in most New Zealand estuaries (Robertson et al. 2002). The other site was positioned in seagrass, a common and ecologically significant intertidal habitat in the estuary.

At each site, a 30 m x 40 m area containing twelve 100 m^2 (10 x 10 m) grids was marked out to achieve 12 replicate plots per location (Figure 1). A 0.25 m^2 quadrat was placed randomly within 10 of 12 grid squares. All quadrats were photographed to provide a visual record and any obvious signs of pollution in the site location were noted. All remaining samples were collected adjacent to the quadrats.

2.2.1. Physical/chemical sediment properties

To measure salinity, interstitial water (water seeping into core holes) was collected as a single composite for each site, returned to the laboratory and analysed using an ATI Orion (model 162) salinity meter.

Cores for sediment profile descriptions were collected with 62 mm diameter Perspex tubes pushed to a depth of at least 150 mm into the seabed. Sediment colour, stratification and texture profiles were described. Particular attention was paid to any black (anoxic) zones. Where these occurred, the average depth of the lighter-coloured surface layer was recorded as the depth of the apparent redox discontinuity layer (RDL)—defined as the transitional zone between aerobic[13] (oxygenated) sediments and anaerobic (deoxygenated) sediments. Any noticeable sulphide odours were also noted as a further indicator of anoxic conditions.

Samples for physical and chemical analyses were scraped from the top 25 mm of sediment, returned to the laboratory and chilled until analysed for a range of physical and chemical indicators of estuary condition (Table 1). Three composite samples were prepared for analyses by mixing replicates numbered 1–3, 4–6 and 7–10. A single site composite of all 10 replicate plots was prepared for analyses of SVOCs and organotins. The individual replicates were retained for later analyses in the event that high variability amongst composites was encountered.

[13] Devoid of dissolved oxygen as opposed to 'oxic' indicating sufficient dissolved oxygen availability for animal life.

Table 1. Analytical methods and detection limits for sediment physical and chemical indicators (undertaken by Hill Laboratories).

Parameter	Method	Detection Limit
Grain size <2 mm, >/=63 um	Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt
Grain size <63 um	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt
Total Organic Carbon	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt
Total Nitrogen	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser]	0.05 g/100g dry wt
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt
Heavy metals As, Cd, Cr, Cu, Ni, Pb, Zn, Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Semi-volatile Organic Compounds (SVOC) Trace in soil by GC-MS	Sonication extraction, GPC cleanup, GC-MS FS analysis. Tested on as received sample.	0.1 - 6 mg/kg dry wt
Tributyl Tin Trace in soil samples by GCMS	Dried at 103°C for 4-22hr (removes 3-5% more water than air dry) , gravimetry. US EPA 3550. (Free water removed before analysis).	0.10 g/100g as rcvd

2.2.2. Epibiota

Any visible epifauna (including crab and polychaete burrows/cases) within the 0.25 m^2 quadrats were identified and recorded (Figure 3). The percentage cover of macroalgae and seagrass was also estimated within each quadrat. The number of grid intersections (including the outer frame) that overlapped vegetation were counted and the result converted to percentage cover (i.e. number of intersections x 2 = %). Epibiota data were described and compared against other estuaries.

Seagrass cover, biomass and disease

At the seagrass fine-scale site, seagrass above-ground biomass and cover was evaluated using an additional smaller (0.06 m^2) quadrat[14] placed randomly within each of the ten plots. To obtain a comparative estimate of biomass, all above-ground seagrass vegetation was harvested from each quadrat using scissors and returned to the laboratory. For dry-weight analysis, leaves were rinsed in low-salinity water (e.g. ~10% seawater) to remove sediment, debris and any rhizome material. Washed leaves were placed in aluminium trays in the drying oven at 60 C° until dry, transferred to a desiccator to cool and weighed to the nearest 0.1 g.

[14] A smaller quadrat was used to minimise seagrass destruction.

Samples of seagrass leaves with darker colouration (a potential sign of seagrass disease/infection or partial decay) were collected and preserved with 4% formaldehyde in filtered seawater for approximately 48 hours before transfer to 70% ethanol. Histological slides were prepared and observed under a microscope for signs of disease/infection.

Microalgae

Observations of the surrounding area at each site were made regarding the development of microalgal mats, described as patchy yellow/green colouration on the surface of the sediment. Samples were scraped off the sediment surface and diluted with seawater for microscopic examination.

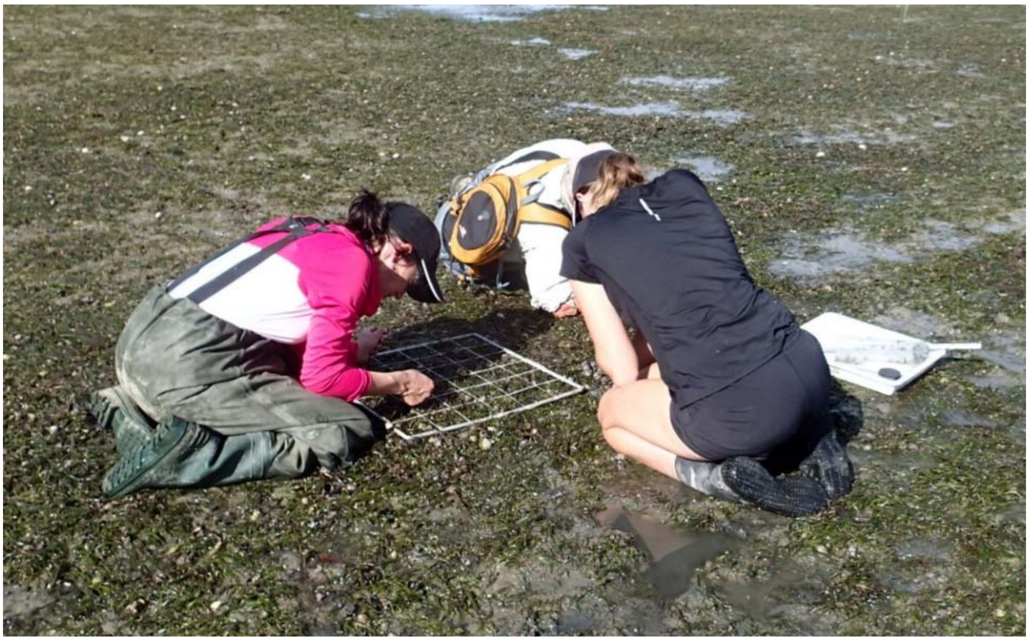

Figure 3. Cawthron scientists counting epibiota at a fine-scale seagrass monitoring site in Shakespeare Bay Estuary, 2016.

2.2.3. Infauna

Infauna were collected by inserting a 130 mm diameter core to a depth of 100 mm into the sediment. The core contents were gently washed through a 0.5 mm mesh sieve attached to one end of the core and the residual was preserved with 95% ethanol (plus 5% glyoxal) in seawater. All infauna were later sorted, counted and identified by Cawthron taxonomic staff following protocols in Hewitt et al. (2014).

The infauna data were evaluated according to a variety of statistical descriptors of community structure including the number of infauna taxa (richness), the number of infauna individuals (abundance) and diversity (H'). The AZTI Marine Biotic Index (AMBI) (Borja et al. 2000) was also calculated for the unvegetated site using New Zealand-specific eco-groups for tolerance to mud and organic content (Robertson et al. 2015) where possible, as recommended in Robertson et al. (2016). Individual taxa for which a New Zealand-specific mud-tolerant ecogroup was not available were assigned an ecological group from either Keeley et al. (2011), based on regional (Marlborough Sounds) specificity relating to enrichment, or from the globally applicable AZTI AMBI database.

A non-metric, multi-dimensional scaling (MDS) ordination procedure, based on Bray-Curtis similarities (Bray & Curtis 1957), was used to evaluate variations in the community structure of infauna. A square-root transformation was applied to the infauna data during this process to down-weigh the influence of the most dominant species (Clarke & Warwick 1994). A SIMPER analysis was used to determine within-site variability and major contributing taxa (Clarke & Warwick 1994). All multivariate analyses were conducted using the software package PRIMER v.6 (Clarke & Gorley 2006).

2.3. Region and national comparisons

To guide the assessment of the health of Shakespeare Bay estuary, broad- and fine-scale results were compared against those from other estuaries within the Marlborough region as well as nationwide. Historical comparisons were also made with previous Shakespeare Bay estuary surveys where feasible. The ANZECC (2000) Sediment Quality Guidelines were used to assess and interpret the contaminant status of the sediment. Where applicable, results were also compared against indicator threshold ratings developed as part of the Estuarine Trophic Index Tools Project to assess the trophic state of New Zealand estuaries (Robertson et al. 2016). The ratings are designed as bands (A, B, C and D), that represent recommended thresholds based on the ecological gradient of estuary trophic condition from a scale of minimal eutrophication (A) to very high eutrophication (D) (see Robertson et al. 2016 for details). Note that fine-scale results from seagrass-covered sites were not compared against the indicator threshold ratings as these were developed for unvegetated habitats.

3. RESULTS AND DISCUSSION

3.1. Estuary habitat characteristics

A total of 5.4 ha of intertidal estuary habitat was mapped within the Shakespeare Bay estuary (Table 2). A detailed map shows the estuary areas covered by the dominant habitat categories (Figure 4). The subtidal area[15] within the bay was not considered in this report. An additional 2.5 ha of supra-littoral fringe was also mapped (see Section 3.1.3). Individual GIS layers can be accessed and evaluated through the DVD-ROM in Appendix 6.

While the total intertidal zone of Shakespeare Bay is very small compared to other estuaries within the region, the proportion of vegetated and unvegetated habitats is comparable (Table 3). The estuary is dominated mainly by unvegetated habitats (60.5% versus 38.6% vegetated habitats) with minimal amounts of standing water (0.8%).

Table 2. Key broad-scale habitats within the Shakespeare Bay estuary intertidal zone, 2016.

Habitat Groups	Dominant Habitat		Area (ha)	% of Total
Unvegetated habitats			**3.28**	**60.5%**
	Mud/sand habitats		1.90	35.1%
		Firm mud/sand (0-2 cm)	1.58	29.2%
		Soft mud/sand (2-5 cm)	0.32	6.0%
	Gravel field		1.14	21.0%
	Sand habitats		0.14	2.7%
		Firm sand (< 1 cm)	0.10	1.8%
		Shell bank	0.03	0.6%
		Soft sand	0.01	0.2%
	Cobble field		0.06	1.2%
	Bedrock		0.02	0.4%
Vegetated habitats			**2.09**	**38.6%**
	Seagrass		1.67	30.8%
	Rushland		0.39	7.2%
	Herbfield		0.03	0.6%
Water			**0.04**	**0.8%**
Total Area of Intertidal			**5.41**	**100.0%**

[15] Area that is always covered by the sea.

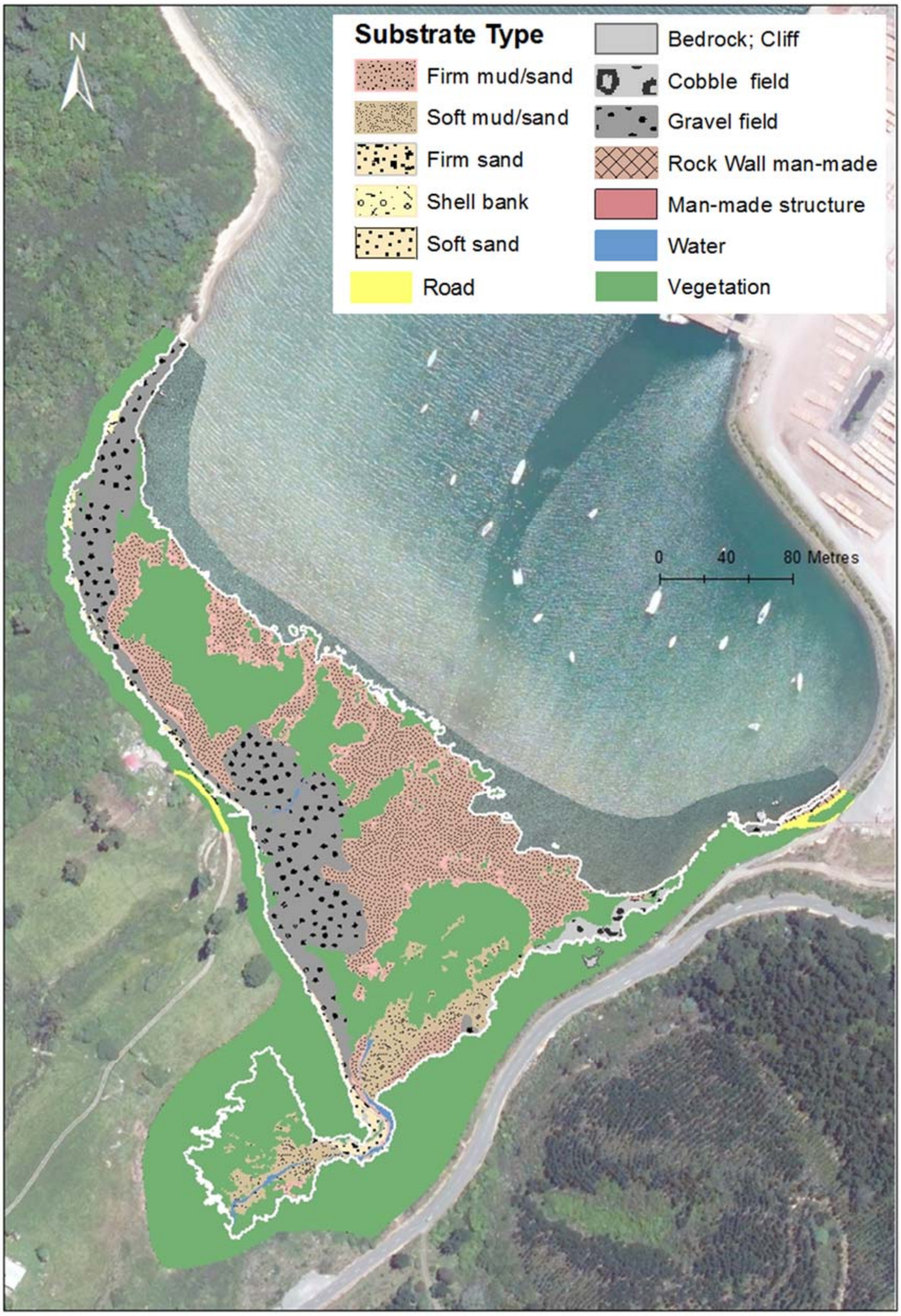

Figure 4. Aerial photograph of the Shakespeare Bay estuary showing digitised broad-scale habitat characteristics of the intertidal zone (distinguished by the white outline) and supra-littoral fringe, 2016.

Table 3. A comparison of the percentage coverage (of the intertidal zone only) of dominant habitats (vegetated and unvegetated) in the Shakespeare Bay estuary with other Nelson/Marlborough estuaries.

Habitat	Wairau Estuary 2015 [A]	Nelson Haven 2009 [B]	Delaware Inlet 2009 [C]	Waimea Inlet 2006 [D]	Ruataniwha 2002 [E]	Havelock Estuary 2014 [F]	Shakespeare Bay estuary 2016
Unvegetated (%)	**46.17**	**77.52**	**79.64**	**87.30**	**81.68**	**56.5**[16]	**60.5**
Mud/sand habitats	45.02	48.61	26.44	64.97	40.43	-	35.1
Sand habitats	0.00	22.19	31.77	12.24	29.49	-	2.7
Gravel/cobble	0.53	4.82	8.32	9.75	11.77	-	21.0
Vegetated	**53.83**	**22.48**	**20.36**	**12.59**	**18.31**	**43.5**[17]	**38.6**
Herbfield	43.74	0.73	1.92	5.22	0.48	1.38	0.6
Reedland	0.00	0.00	0.21	0.00	0.00	0.005	0.00
Rushland	2.51	0.07	4.80	3.51	15.93	33.98	7.2
Seagrass	0.00	14.01	1.39	0.68	1.66	2.7[18]	30.8
Sedgeland	0.00	0.00	0.05	0.01	0.00	0.018	0.0
Total intertidal area of estuary (ha)	**358.52**	**850.77**	**331.11**	**2950.29**	**726.20**	**565**	**5.4**

A Berthelsen et al. 2015
B Gillespie et al. 2011a
C Gillespie et al. 2011b
D Clark et al. 2008
E Robertson et al. 2002
F Stevens & Robertson 2014

16 Excludes seagrass and macroalgae where cover >50%.
17 Includes seagrass and macroalgae where cover >50%.
18 Includes seagrass cover >50%

3.1.1. Unvegetated habitats

A breakdown of unvegetated habitats in the Shakespeare Bay estuary intertidal zone is shown in Appendix 2. Firm mud/sand was the most extensive unvegetated habitat covering 48% (1.6 ha) followed by gravel field at 34% (1.1 ha) (Figure 4, Figure 5). Soft mud/sand areas were generally present only within the saltmarsh and stream discharge area in the southern region of the estuary and covered only 10% (0.3 ha) of the intertidal zone; a small area compared to other estuaries within the region (Table 3).

Increasing mud content can alter sediment characteristics and is a strong determinant of benthic community composition. The relatively high proportion of firm mud/sand and low proportion of soft mud/sand, likely due at least in part to the relatively small catchment size and low freshwater inflow rate, indicates the Shakespeare Bay estuary is currently not threatened by high sedimentation.

Figure 5. Firm mud/sand (left) and gravel field (right) were the dominant unvegetated habitats within Shakespeare Bay estuary, 2016.

3.1.2. Vegetated habitats

A break-down of vegetated habitats in the Shakespeare Bay estuary is shown in Appendix 3. Seagrass (*Zostera muelleri*) covered 80% (1.7 ha) of the vegetated habitat within the intertidal zone (Figure 6, Figure 7). It displayed some spatial patchiness, with a higher percentage cover of seagrass generally present lower down the shoreline. Seagrass was also observed within the estuary in 1986 and 1991 although its abundance was not quantified (see Wear & Haddon 1986; Bolton 1991). Seagrass was generally rare or absent in some other estuaries surveyed within the region (Table 3), with the exception of Nelson Haven (Gillespie et al. 2011a).

Seagrass beds have high ecological and biodiversity value (van Houte-Howes et al. 2004). Although their photosynthetic contribution can be relatively modest (Gillespie & MacKenzie 1981), they provide a stable physical habitat and a localised food source to support a diverse community of animals including a variety of fish species. Seagrass also helps filter nutrients and trap sediments, thereby maintaining water quality (Turner & Schwartz 2006). They are sensitive to macroalgal overgrowth, sediment deposition and reduced water quality conditions, therefore making them a good indicator of estuary health (Matheson et al. 2009). The high proportion of seagrass cover in the Shakespeare Bay estuary intertidal zone indicates this habitat likely performs key functions and that the estuary is unlikely subject to adversely high sediment deposition rates and/or excessive nutrients.

The second most abundant vegetated habitat was rushland, which covered 19% (0.4 ha) of the intertidal zone and was comprised largely of searush (*Juncus kraussii*) and jointed wirerush (*Apodasmia* syn. *Leptocarpus similis*). This was primarily present within the saltmarsh surrounding the small stream at the southern end of the estuary. This saltmarsh (and neighbouring supra-littoral fringe) has high ecological value and is subsequently protected by a conservation covenant (Wagenhoff & Newcombe 2016). The proportion of rushland within the Shakespeare Bay estuary was comparable to other Nelson/Marlborough estuaries (Table 3). These upper intertidal habitats are functionally important in that they are areas of active primary production and decomposition (Gillespie & MacKenzie 1981). They also act as a filter at the land sea interface and can assimilate inorganic nutrients and trap fine sediment.

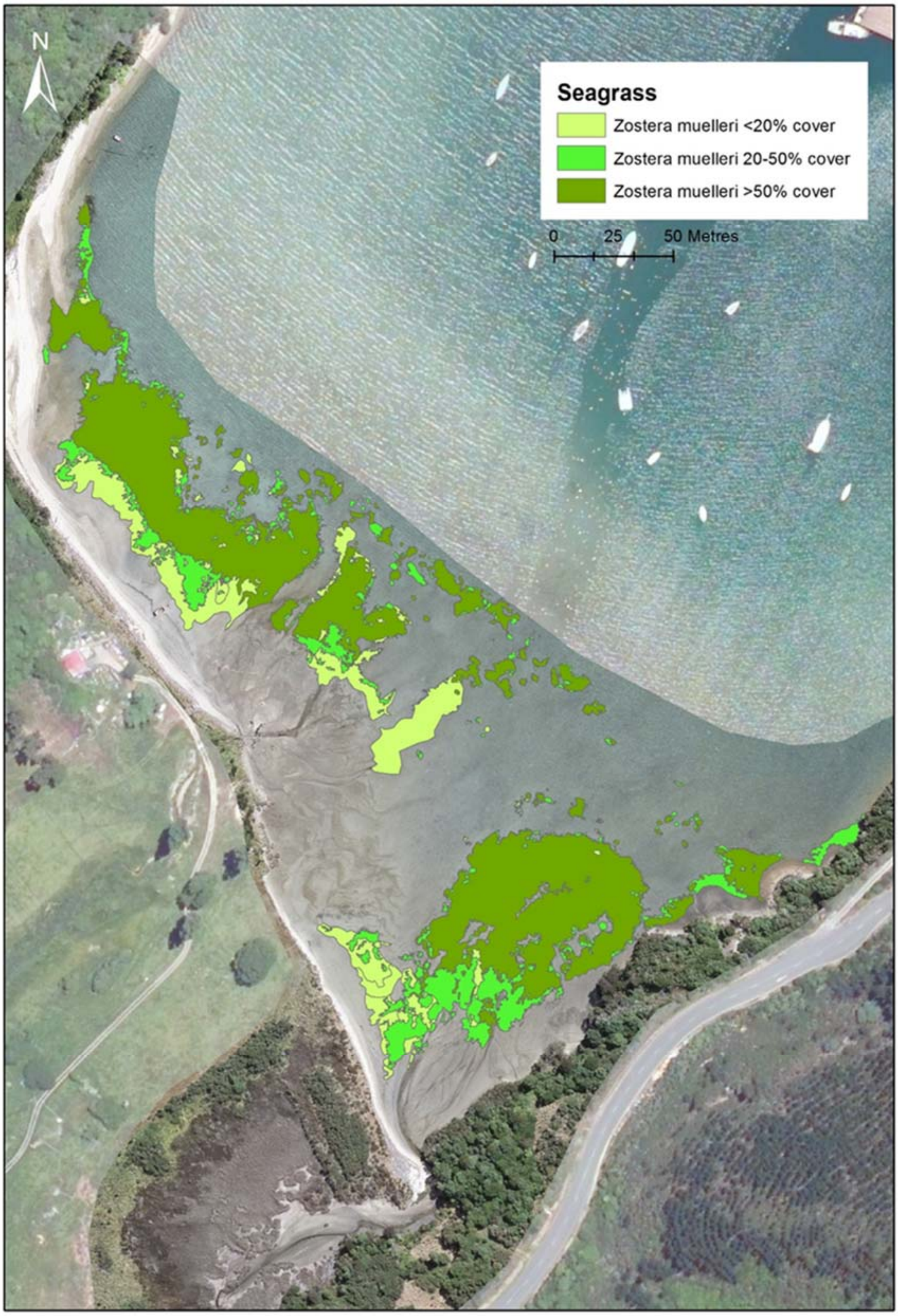

Figure 6. Seagrass coverage within the Shakespeare Bay estuary intertidal zone, 2016.

Figure 7. Seagrass and rushland were the dominant vegetated habitats within the Shakespeare Bay estuary intertidal zone, 2016.

Intertidal habitats containing macroalgae covered 1.7 ha, however, macroalgae was sparse enough that it was never more than the third or fourth subdominant category (and covered less than 5%) within any of the habitats. *Codium* sp.—likely *Codium fragile* and possibly subspecies *novae-zelandiae* or *fragile*[19] (Nelson 2013)—was the primary macroalgal taxon present (Figure 8). It was observed as beachcast only and was not seen growing within the intertidal zone. *Codium* is not considered to be one of the primary bloom-forming taxa in New Zealand estuaries (Robertson et al. 2016) and therefore, an indicator rating using the OMBT was not calculated. The native subspecies *C. fragile* subsp. *novae-zelandiae* is known to be widespread within the Marlborough region (Wendy Nelson pers. comm.). However, *Codium fragile* subsp. *fragile,* native to Japan, is considered invasive and has become widespread around the world. This subspecies has become established along some wave-protected rocky shores in New Zealand (Trowbridge 1995), although it is currently not known to be present in the top of the South Island (Wendy Nelson pers. comm.).

Gracilaria sp. was also present within the estuary, although it was scarce. *Gracilaria* sp. is a typical blooming macroalgal taxa in New Zealand estuaries, however, based on visual observations in the Shakespeare Bay estuary its scarcity placed it in Band A, the best ecological rating in the OMBT (Robertson et al. 2016).

Macroalgae can grow rapidly and are often dominant features of estuaries during summer months. Opportunistic species (e.g. *Ulva* spp.) can reach problem densities under enriched conditions. The limited abundance of macroalgae within the Shakespeare Bay estuary intertidal zone indicates the estuary is not subject to excessive nutrient inputs or, alternatively, that hydrodynamic conditions are not

[19] The two subspecies are difficult to tell apart using morphological characteristics (Trowbridge 1996).

conducive to an accumulation of macroalgal biomass. More detailed assessment would be required to quantify any temporal changes in macroalgal coverage.

Figure 8. *Codium* sp. washed ashore in the Shakespeare Bay estuary intertidal zone, 2016.

3.1.3. Supra-littoral fringe

The supra-littoral fringe covered 2.5 ha in total and was dominated by vegetated habitats (2.46 ha, 97.7%) (Table 4, Figure 4). A breakdown of vegetated and unvegetated habitats in the supra-littoral fringe are shown in Appendix 5 and Appendix 4. The area consisted largely of terrestrial vegetation (shrub/scrub/forest - predominantly native) (1.6 ha, 64.5%), grassland (0.5 ha, 20.8%) and estuarine shrubs (predominantly native) (0.2 ha, 8.6%) (Figure 9). Vegetated habitats within the supra-littoral fringe help protect estuarine habitats by serving as a buffer zone around the estuary edge. The high proportion of native vegetation within the supra-littoral fringe indicates it is likely performing such key functions.

However, grassland was dominated by the exotic species tall fescue (*Festuca arundinacea*) and terrestrial vegetation (shrub/scrub/forest) also contained exotic species (e.g. poplar *Populus* sp., gorse *Ulex europaeus*). Only a small amount of unvegetated habitat (0.06 ha, 2.4%) covered the supra-littoral fringe. This comprised mostly of man-made structures (e.g. road and rock wall). The presence of exotic plant species and man-made structures within the supra-littoral fringe has modified the natural state of this habitat.

Table 4. Key broad-scale habitats within the supra-littoral fringe areas of Shakespeare Bay estuary, 2016.

Habitat Groups	Dominant Habitat	Area (ha)	% of Total
Water		**0.000**	**0.0%**
Unvegetated habitats		**0.057**	**2.3%**
	Road	0.037	1.5%
	Rock wall man-made	0.013	0.5%
	Cliff	0.005	0.2%
	Man-made structure	0.001	0.0%
	Firm sand (<1cm)	0.001	0.0%
Vegetated habitats		**2.466**	**97.7%**
	Terrestrial shrub/scrub/orest	1.629	64.5%
	Grassland	0.525	20.8%
	Estuarine shrubs	0.217	8.6%
	Rushland	0.054	2.1%
	Tussockland	0.021	0.8%
	Sedgeland	0.021	0.8%
Total Area of Intertidal		**2.523**	**100%**

Figure 9. Terrestrial shrub/scrub/forest (mostly native) was the dominant habitat (left), and grassland (mostly exotic) was also present (right), within the Shakespeare Bay estuary supra-littoral fringe, 2016.

3.2. Fine-scale benthic characteristics

Salinity strongly influences estuarine ecology, therefore in order for fine-scale estuary monitoring results to be comparable among estuaries, the EMP recommends salinity to be over 20 ppt (Robertson et al. 2002). This criteria was met at the Shakespeare Bay estuary seagrass (34.6 ppt) and unvegetated (35.3 ppt) fine-scale sites. No obvious signs of pollution e.g. objectionable odours, visible scum from fats, oils or unnatural debris, were noted at any of the survey locations (Appendix 7, Appendix 8).

3.2.1. Sediment characteristics

No strong sulphide odour was detected in cores from either of the fine-scale survey sites. Cores were generally grey and commonly lighter brown at depths less than 5 cm (Appendix 9, Appendix 10). No distinct RDL was observed. These results indicate that excessive oxygen depletion was unlikely to be occurring within the sediments. Shell hash and gravel was usually present deeper than 10 cm and, at the seagrass site, seagrass rhizomes were also present to at least 15 cm.

Grain size

Sediment at both fine-scale sites was dominated by sand (grain size 63–2000 µm) ranging from 67–85%, while mud (grain size less than 63 µm) ranged between 8–24% overall at the sites (Figure 10, Appendix 11). The percentage of sand and mud in Shakespeare Bay estuary sediments was similar to many other sand-dominated estuaries within New Zealand (Table 5).

The percentage of mud was greater at the seagrass site (21.2 % ± 2.7 SE) compared to the unvegetated site (8.5 ± 0.5SE) (Figure 10), likely due to the ability of seagrass to trap fine sediment and prevent it from washing away (Matheson et al. 2009). Mud was also more prevalent in sediments from a seagrass-dominated site compared to two unvegetated sites in Nelson Haven (Table 5; Gillespie et al. 2012a). The percentage of mud in intertidal seagrass-covered sites in Shakespeare Bay estuary was comparable to that in a number of Northland estuaries (van Houte-Howes et al. 2004) as well as in Tauranga Harbour (unpublished data). The average percentage of mud at the unvegetated site was within threshold Band B proposed by Robertson et al. (2016), indicating the level of mud as a minor stress on sensitive organisms.

These results indicate that sedimentation in unvegetated sites is currently having a minor influence on the benthic community structure. Although the amount of fine sediment was higher at the seagrass site this was expected due to the sediment-trapping abilities of seagrass.

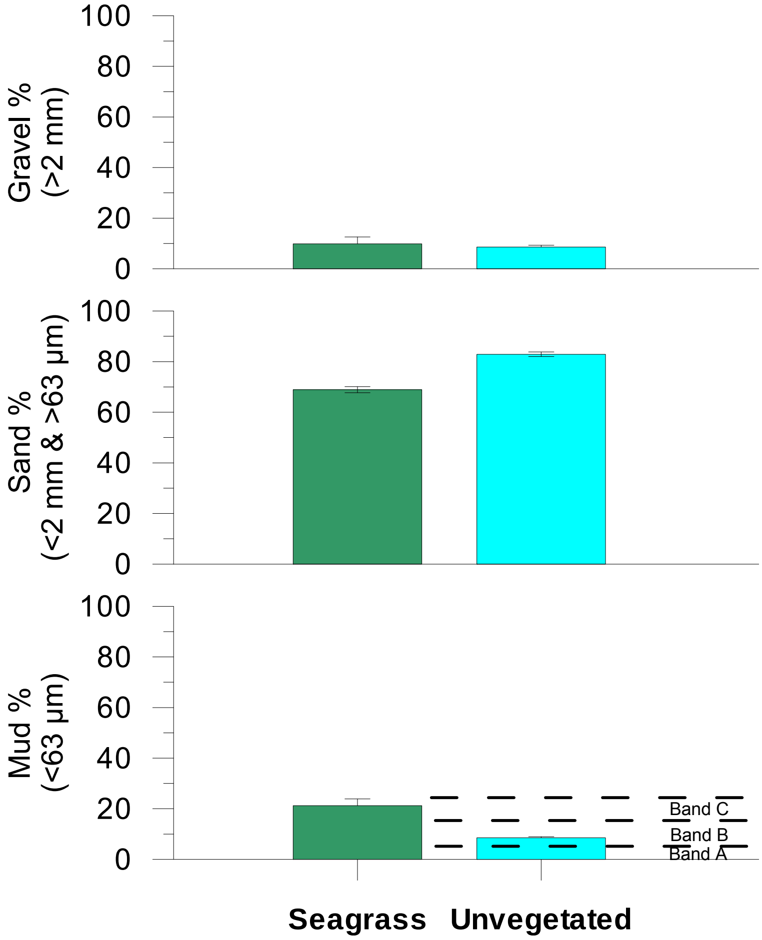

Figure 10. Sediment grain size from two intertidal fine-scale sites (seagrass and unvegetated) within Shakespeare Bay estuary, 2016. Dashed lines represents thresholds for New Zealand Estuary Trophic Index mud sensitivity indicator rating bands: Band A = no stress, Band B = minor stress on sensitive organisms, Band C = significant, persistant stress, on aquatic organisms (Robertson et al. 2016). N=3, error bars represent + 1 standard error.

Table 5. Comparison of average (n = 3) particle size and nutrient characteristics of sediments from intertidal sites in Shakespeare Bay estuary as well as previously reported values for other New Zealand estuaries. Sites where mud comprises a higher proportion of the sediment than sand are shaded. The described condition is based on the tabulated subset of indicators only.

Location	Sand	Mud	TN	TP	TN:TP	TOC	AFDW	Condition
Shakespeare Bay estuary (this study)	**%**	**%**	**mg kg-1**	**mg kg-1**	**Molar**	**%**	**%**	
Seagrass site	68.9	21.2	533.0	223.3	2.3	0.6	-	
Unvegetated site	82.9	8.5	250.0	185.7	1.3	0.3	-	
Other NZ estuaries								
Wairau Estuary (sites A, B, C) [a]	16.1	83.5	1166.7	667.7	3.5	0.8	3.8	Slightly enriched to enriched
Nelson Haven (2012) [b]	89.1	10.0	221.5	358.0	1.5		1.1	Relatively undisturbed, naturally productive
Nelson Haven (2012) [c]	82.0	16.1	383.0	300.0	2.8		1.9	Relatively undisturbed, naturally productive
Delaware Inlet (mud-dominated, site A) [d]	26.1	73.3	823.0	587.0	3.1		3.4	Relatively undisturbed, naturally productive
Delaware Inlet (sand-dominated, sites B, C) [e]	88.1	11.4	282.0	558.0	0.5		2.2	Relatively undisturbed, naturally productive
Moutere (sites A, B) [f]	88.0	12.0	339.0	530.0	1.4		1.6	Slight to moderately enriched
Orowaiti (sites A, B) [g]	42.0	53.0	529.0	938.0	1.9		3.2	Slight to moderately enriched
Kaipara (Otamatea Arm sites A, B) [h]	27.2	67.7	1850.0	503.0	8.1		6.3	Moderately enriched
Ohiwa (sites B, D) [h]	87.0	11.0	524.0	248.0	4.7		1.7	Slight to moderately enriched
Ruataniwha (sites A, B, C) [h]	86.0	9.0	263.0	458.0	1.3		1.2	Slightly enriched
Waimea (sites B, C) [h]	87.0	13.0	304.0	377.0	1.8		1.0	Slight to moderately enriched
Havelock (sites A-D) [i]	56.4	42.3	891.5	397.5	-	0.8	-	Slight to moderately enriched
Avon-Heathcote (sites A, B, C) [h]	94.0	5.0	301.0	327.0	2.0		1.8	Moderately enriched
Waimea [j]	NA	82.5	4340.0	1063.0	8.9		9.1	Highly enriched

a Mean of three sites collected in mud-dominated habitats in 2015 (Berthelsen et al. 2015)
b Mean of two sites collected in a sand-dominated habitat in 2012 (Gillespie et al. 2012a).
c Value from one seagrass habitat site in 2012 (Gillespie et al. 2012a)
d Mean of one mud-dominated site sampled in 2009 (Gillespie et al. 2009).
e Mean of two sand-dominated sites sampled in 2009 (Gillespie et al. 2009).
f Slightly modified estuary near Motueka, affected by food processing wastes and urban runoff in 2006 (Gillespie & Clark 2006).
g Slightly modified estuary near Westport (Gillespie & Clark 2007).
h Subset of mud-dominated sites from an inter-estuary comparison, 2001 (Robertson et al. 2002).
i Mean of four mud-dominated sites sampled in 2015 (Stevens & Robertson 2015).
j Mudflat affected by a freezing works effluent, 1981 (Gillespie & MacKenzie 1990).

Nutrient and organic composition

Phosphorus, nitrogen and total organic carbon (TOC) were all higher in sediments at the seagrass site compared to the unvegetated site (Figure 11). Total organic carbon and nitrogen were also higher within a seagrass site compared to two unvegetated sites in Nelson Haven (Gillespie et al. 2012a). The elevated TOC and nutrient concentrations in sediment at seagrass sites is likely derived from natural decomposition and detritus generated from the seagrass vegetation (Turner & Schwartz 2006). The higher proportion of fine sediment within the seagrass site also likely contributed to increased nutrient and organic carbon content as a strong positive relationship often exists between these two variables (e.g. Robertson et al. 2015). In comparison, average concentrations of nitrogen were higher, and phosphorous lower, in the seagrass site in Shakespeare Bay estuary compared to Nelson Haven (Table 5). At the unvegetated site average TOC was within threshold Band A (refer Figure 11), suggesting no stress caused by this variable, and average nitrogen was within threshold Band B (just above the Band A threshold), suggesting it was causing a minor stress on sensitive organisms (Robertson et al. 2016).

Compared to other estuaries within New Zealand, nutrient and organic carbon levels were relatively low within the Shakepseare Bay estuary sites (Table 5). Molar TN:TP ratios[20] in sediments from both sites were also similar to those from other estuaries and suggest that nitrogen was likely more limiting than phosphorus for photosynthetic production.

Excessively high levels of nutrients and organic carbon can lead to enriched (and potentially eutrophic) conditions that can adversely impact animal communities. The results from this survey indicate that nutrient and organic levels were generally low, and eutrophication was unlikely to be threatening the health of the estuary. However, based on the threshold bands in Robertson et al. (2016), nitrogen may be having a minor effect on benthic communities as it was in Band B (just above the Band A threshold). Further research is needed to confidently implement and interpret threshold bands, such as shown in Figure 11, with regard to ecological health. For example, the degree of stress due to elevated sediment TN and TOC concentrations will depend on the chemical composition of the organic material. If readily biologically available it may carry a significant oxygen demand whereas if largely recalcitrant (e.g. consisting of terrestrial woody debris) oxygen demand and related stress will be much lower.

[20] The stoichiometric atomic ration of nitrogen to phosphorus for phytoplankton is generally considered to be around 16:1. In estuarine sediment this ratio is seldom greater than 10:1 indicating that nitrogen is likely to be relatively more limiting than phosphorus for the growth of benthic microalgae.

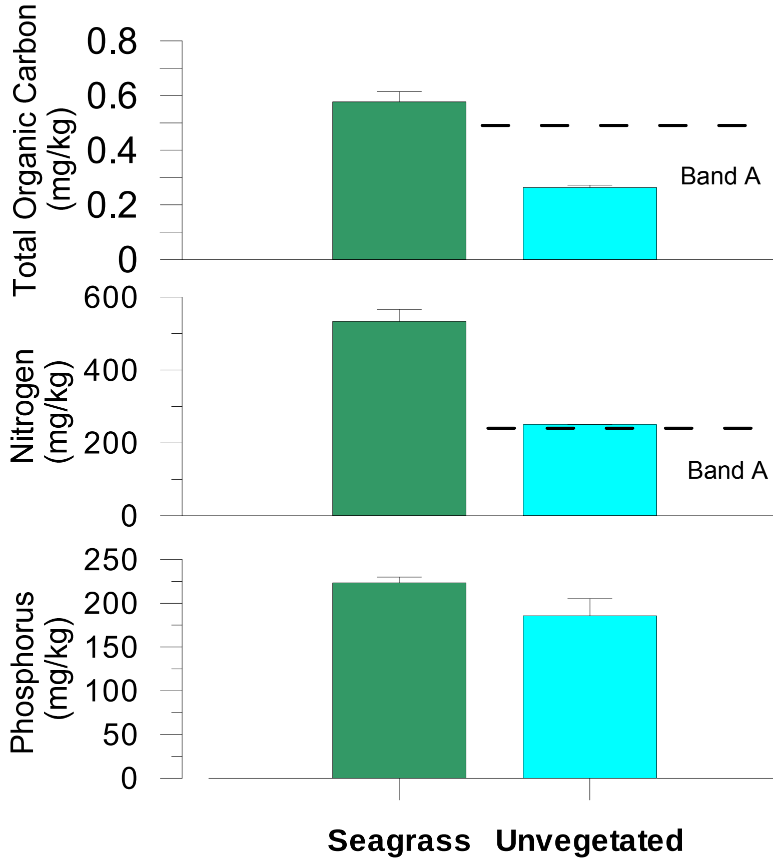

Figure 11. Nutrients and organic carbon concentrations in sediment from two intertidal fine-scale sites (seagrass and unvegetated) within Shakespeare Bay estuary, 2016. Dashed lines represent New Zealand Estuary Trophic Index threshold values for indicator rating bands: Band A = no stress, Band B = minor stress on sensitive organisms, Band C = significant, persistant stress, on aquatic organisms (Robertson et al. 2016). N=3, error bars represent + 1 standard error.

Contaminants

The concentrations of all metals/metalloids in sediments were well below ISQG-Low trigger levels and were similar at both the seagrass and unvegetated sites (Figure 12). These concentrations were also generally low compared to a range of other New Zealand and overseas estuaries (Table 6). There was no evidence that metals were at high enough levels to have an ecological effect in the Shakespeare Bay estuary.

The SVOC and organotin analysis suite targeted over 70 individual compounds of varying toxicity (Appendix 12). None of the SVOCs or organotins screened were detected within sediment at either of the two fine-scale sites in Shakespeare Bay estuary, suggesting that general levels of contamination were low.

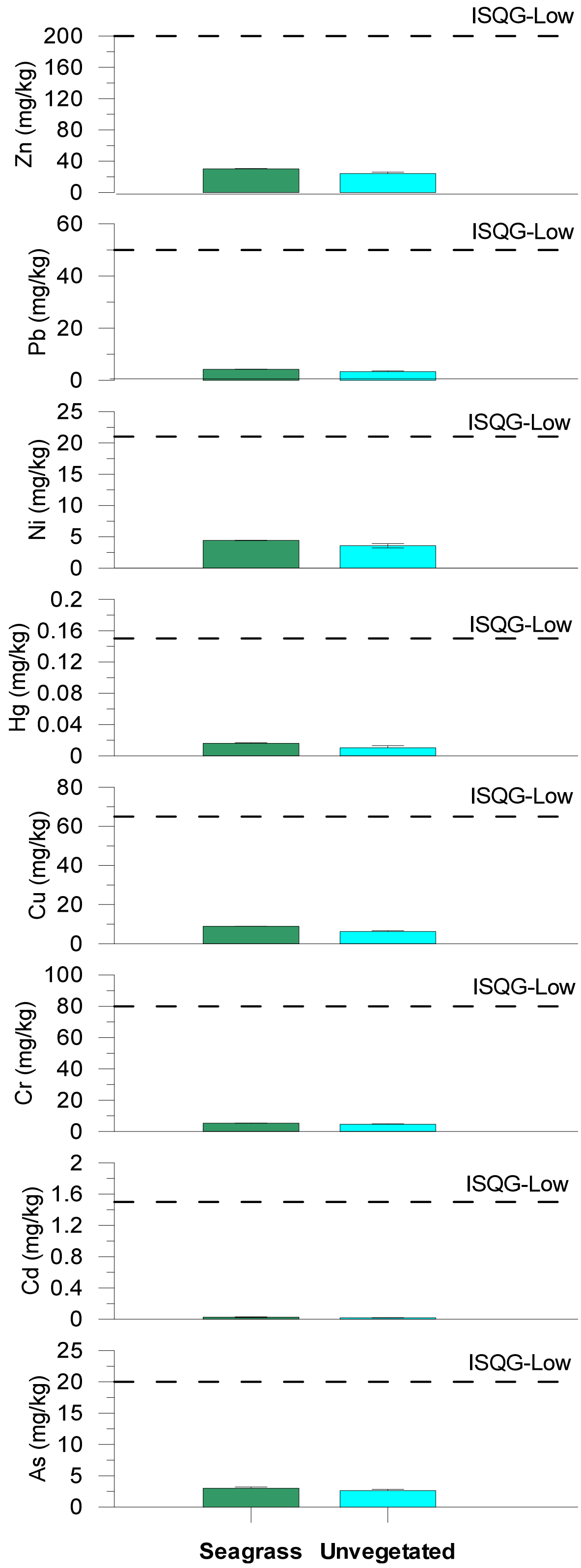

Figure 12. Concentrations of trace metals/metalloids in sediments from two intertidal fine-scale sites (seagrass and unvegetated) within Shakespeare Bay estuary, 2016. In one replicate sample mercury was below detection limit and where this occurred the detection limit value was halved and included in the average. ANZECC (2000) ISQG-Low thresholds (dashed lines) represent the concentration at which there is a 10% probability that significant toxicity will occur in sensitive species. N=3, bars represent + 1 standard error.

Table 6. Concentrations of trace metals/metalloids in sediments from Shakespeare Bay estuary and a selection of New Zealand and overseas estuaries that have been contaminated to varying degrees. Some values drawn from other studies are approximate as they were estimated from figures.

Location		**As** mg kg^{-1}	**Cd** mg kg^{-1}	**Cr** mg kg^{-1}	**Cu** mg kg^{-1}	**Pb** mg kg^{-1}	**Ni** mg kg^{-1}	**Zn** mg kg^{-1}
ANZECC (2000) ISQG-Low		*20*	*1.5*	*80*	*65*	*50*	*21*	*200*
ANZECC (2000) ISQG-High		*70*	*10*	*370*	*270*	*220*	*52*	*410*
Shakespeare Bay estuary (this study)	**Seagrass Site**	3	0.03	5.3	8.8	4.2	4.4	30.3
	Unvegetated Site	2.6	0.02	4.6	6.2	3.3	3.6	24.3
EMP development study	Otamatea Arm		0.4	20.5	13.8	11.4	9.4	54.5
	Ohiwa		0.1	7.4	4.0	3.4	3.9	27.7
	Ruataniwha		0.1	24.0	7.1	4.7	13.7	37.5
	Waimea		0.3	67.6	9.6	7.4	72.5	41.8
	Havelock		0.04	43.2	13.5	7.1	37.4	40.5
	Avon-Heathcote		0.1	15.6	3.2	6.3	6.6	38.3
	Kaikorai		0.1	48.4	16.8	45.3	15.6	184.2
	New River		0.1	11.1	3.8	0.7	5	17.1
Other NZ sites	Delaware Inlet		<0.1	42.9	11.0	3.8	17.1	45.3
	Moutere Inlet		<0.01	31.7	6.1	4.2	67.3	25.9
	Wairau Estuary	5.4	0.04	17.9	13.4	14	24.1	52.8
	Nelson Haven		<0.1	22.1	5.5	3.8	23.9	24.3
	Tamaki A (E1)			14.5	27.8	132.1	56.9	136.1
	Tamaki B (E2)			20.6	26.1	72.9	6.6	167
	Tamaki C (E3)			17.3	29.4	69.7	9.3	173
	Tamaki D (E4)			35.9	38.5	145.2	12.8	233
	Manukau (rural catch)		0.03		20	9	15	114
	Manukau (industrial catch)		0.25		90	58	14	285
	Waitemata Harbour		<0.5	52	60	65	28	161
	Lampton Harbour, Wellington			91	68	183	21	249
	Porirua Harbour, Wellington			20	48	93	20	259
	Aparima Estuary		0.067	15	12	11	10	49
	Mataura Estuary		0.024	7.1	6.6	6.2	6	27
Overseas sites	Delaware Bay, USA		0.24	27.8	8.3	15		49.7
	Lower Chesapeake Bay, USA		0.38	58.5	11.3	15.7		66.2
	San Diego Harbour, USA		0.99	178	218.7	51		327.7
	Salem Harbour, USA		5.87	2296.7	95.1	186.3		238
	Rio Tinto Estuary, Spain		4.1		1400	1600		3100
	Restronguet Estuary, UK		12.0	1060	4500	1620		3000
	Nervión Estuary, Spain		0.2-15	50-300	50-350	50-400	20-100	200-2000
	Sorfjord, Norway		850		12000	30500		118000

Sources: Robertson et al. (2002), Stevens & Robertson 2015, Glasby et al. (1988), Gillespie et al. (2009), Stoffers et al. (1986), Gillespie & Clark (2006), Glasby et al. (1990), Gillespie et al. (2012a), Robertson (1995), Thompson (1987), Kennish (1997), Roper et al. (1988), Jezus-Belzunce et al. (2001), Berthelsen et al. (2015).

3.2.2. Epibiota communities

Epifauna

Benthic invertebrates are commonly used as indicators of estuarine environmental status as they can respond predictably to many kinds of stress (Weisberg et al. 1997). Animal taxa were common on the sediment surface at both sites (Appendix 13). These represented a range of animal groups and were typical of those found in intertidal estuarine areas within New Zealand (Robertson et al. 2002) and the Nelson/Marlborough region (e.g. Gillespie et al. 2012a; Stevens & Robertson 2014). The most commonly occurring animal taxa in the Shakespeare Bay estuary were the mudflat topshell (*Diloma* sp.), the spire shell (*Zeacumantus* sp.) and the estuarine barnacle (*Austrominus modestus*) (Figure 13). The chiton *Notoplax violacea* and crab holes were only present at the seagrass site while the bubble shell (*Haminoea* sp.), pipi (*Paphies australis*) and *Gracilaria* sp. (a macroalga) were only present at the unvegetated site. Mean abundance was higher at the seagrass site, as was also observed within Nelson Haven (Gillespie et al. 2012a). Seagrass can provide a stable physical habitat and localised food source for animal communities (Turner & Schwartz 2006). These results suggest that epifauna communities were not subject to excessive environmental stressors.

Figure 13. Common epifauna taxa in the Shakespeare Bay estuary: *Diloma* sp., *Zeacumantus* sp. and *Austrominus modestus* (left to right respectively), 2016. Images not to scale.

Seagrass cover, biomass and disease

Seagrass cover in the larger quadrats (0.25m^2) within the seagrass fine-scale site was relatively high (ranging between 82–98 %) with a mean of 91.8% ± 1.7 SE) (Appendix 8, Appendix 13). Seagrass cover in the smaller quadrats (0.06 m^2), from which the biomass was evaluated, was more variable ranging from 35–100% (mean of 68.8% ± 7.9 SE) (Appendix 14, Appendix 15). Seagrass above-ground biomass per 0.06 m^2 ranged between 1.9–5.0 g/dry weight with a mean of 2.5 ± 0.5 SE. Both percent cover and above-ground biomass (when comparatively scaled to 0.25 m^2), were lower in comparison to results from a seagrass-covered site in Nelson Haven (Gillespie et al. 2012a) (Appendix 14).

Patches of darkened leaves, indicative of partial decay, were relatively common in seagrass within the Shakespeare Bay estuary (Figure 14, Figure 15). When observed under a microscope, fusiform[21] *Labyrinthula* cells were present in low to moderate numbers. Similar field observations were made in other estuaries within the region e.g. Waimea Inlet (Gillespie et al. 2012c), Nelson Haven (Gillespie et al. 2012a) and Grove Arm (Gillespie et al. 2012b). Such infestations, often referred to as 'fungal wasting disease', have been previously reported to have decimated over 90% of seagrass along the Atlantic coast of North America (Ralph & Short 2002). Although this 'disease' is seen as a growing global issue, the potential threats to seagrass habitats in New Zealand are unknown. *Labyrinthula* has also been detected in healthy New Zealand seagrass beds (Matheson et al. 2009), suggesting that the organism is often present and may be endemic. Nevertheless, *Labyrinthula* abundance and infection rates may increase when the seagrass becomes stressed (Matheson et al. 2009) or when general environmental conditions (e.g. temperature, salinity, etc.) favour its infection.

Figure 14. Seagrass in the Shakespeare Bay estuary with patches of darkened leaves, 2016.

[21] Tapering at both ends i.e. spindle-shaped.

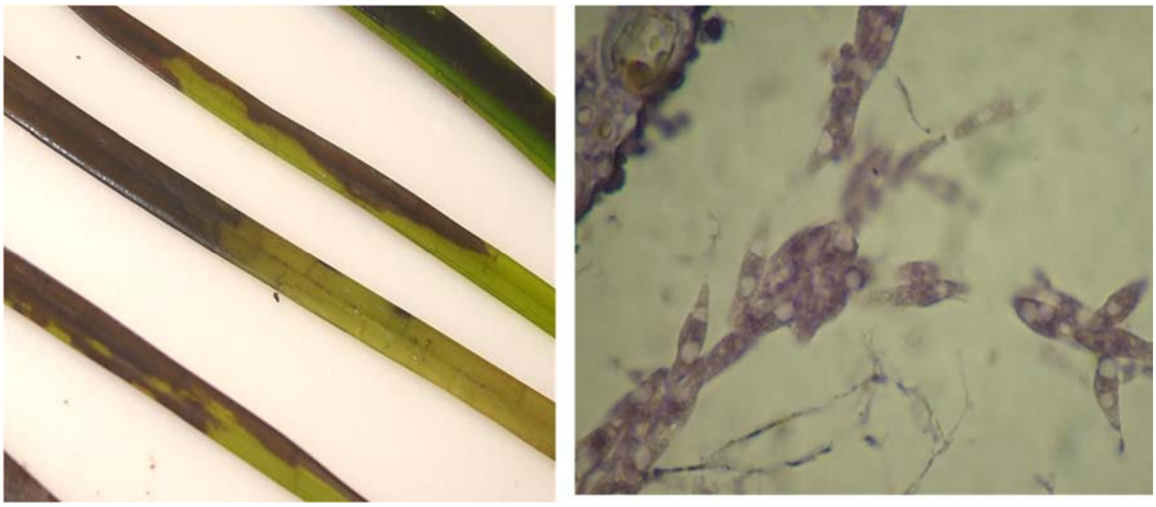

Figure 15. Blackened seagrass blades indicating *Labyrinthula* infection (left) and microscopic view of *Labyrinthula* cells (right). (Waimea Estuary survey results, P Gillespie, unpublished). Photo credit Steve Webb, Cawthron.

Macro- and microalgae

Gracilaria sp., the only macroalgal taxon within the fine-scale quadrats, was scarce (average cover of 1.4% ± 0.7 SE) within the unvegetated site and absent from the seagrass site (Appendix 13). The low percentage of macroalgae in summer within the Shakespeare Bay estuary fine-scale sites indicates that the estuary was not subject to excessive nutrient inputs.

A light green microalgal film was noted on the surface of open sand flat habitat inshore from the unvegetated fine-scale site in Shakespeare Bay estuary. This film was dominated by motile euglenoids[22] with low numbers of a variety of diatoms[23]. Cyanobacteria were also present and tentatively identified as *Oscillatoria* sp. These observations were typical of relatively unenriched intertidal sand flat habitats and similar to those at other estuaries within New Zealand (Robertson et al. 2002) and the Nelson/Marlborough region (e.g. Gillespie et al. 2012a; Gillespie et al. 2009). As visual observations of microalgal intensity within Shakespeare Bay estuary were not considered indicative of enriched conditions, further analysis of sediment chlorophyll *a* was not considered necessary.

3.2.3. Infauna

Overall, 68 infaunal taxa (52 at the seagrass site and 46 at the unvegetated site) were recorded at the two fine-scale sites (Appendix 16). The number of taxa was similar or higher compared to other estuaries within the region that represented health conditions from relatively pristine to compromised (e.g. Gillespie et al. 2012a; Gillespie et al. 2009; Berthelsen et al. 2015). Species richness, diversity and evenness were fairly similar between both the seagrass and unvegetated site (Figure

[22] Group of flagellates of the phylum Euglenophyta
[23] Group of unicellular algae

16). However, infauna communities within the seagrass site displayed more variability in composition (average similarity 48.4) compared to that displayed between infauna communities from the unvegetated site (average similarity 60.7) (Appendix 17).

The composition of infaunal communities from the seagrass and unvegetated sites were different, as evidenced by their separation in multivariate space (Figure 17). The most abundant taxa at the seagrass site were the cockle (*Austrovenus stutchburyi*), and the polychaetes *Heteromastus filiformis* and *Prionospio aucklandica* (Appendix 17, Figure 18). At the unvegetated site, the most common taxa were *H. filiformis*, Oligochaeta and *P. aucklandica* (Figure 18). Both *H. filiformis* and Oligochaeta belong to the mud sensitivity ecological grouping III and *Prionospio* spp. and cockles belong to ecological group II (Robertson et al. 2015), indicating that the dominant taxa were relatively mud-tolerant. Infaunal communities dominated by polychaetes and bivalves are typical in many New Zealand estuaries (Robertson et al. 2002) and were also historically typical within the Shakespeare Bay estuary (Wear & Haddon 1986; Bolton 1991).

The average AMBI score for the unvegetated site (AMBI 2.3 ± 0.2 SE) fell within the Band B threshold for screening estuaries, indicating minor to moderate stress on benthic fauna and community tolerance of slight organic enrichment and a moderate amount of mud (Robertson et al. 2016). Combined, these results indicate that infauna communities were not subject to excessive sedimentation, nutrient and toxic contaminant inputs. However, sedimentation and organic content levels were likely having a minor stress on benthic communities.

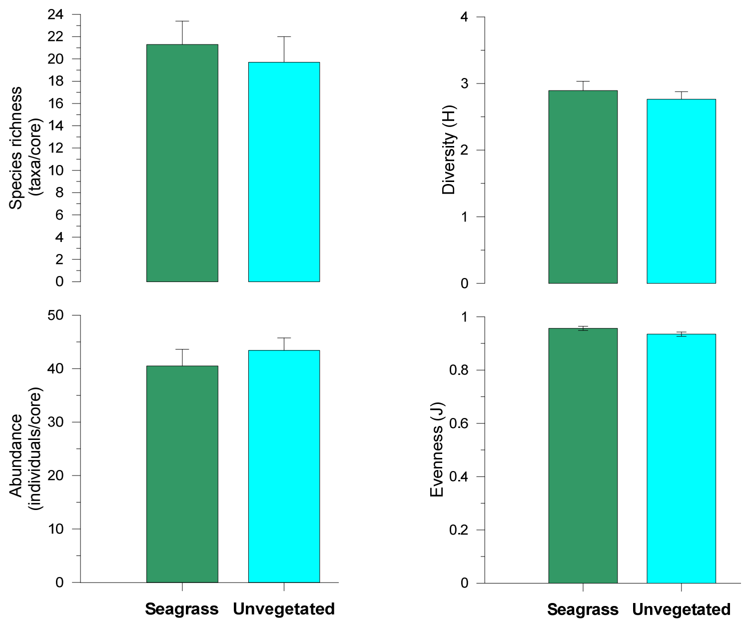

Figure 16. Infauna abundance and species richness (left) and diversity and evenness (right) at two intertidal fine-scale sites (seagrass and unvegetated) within Shakespeare Bay estuary, 2016. N = 10, error bars represent + 1 standard error.

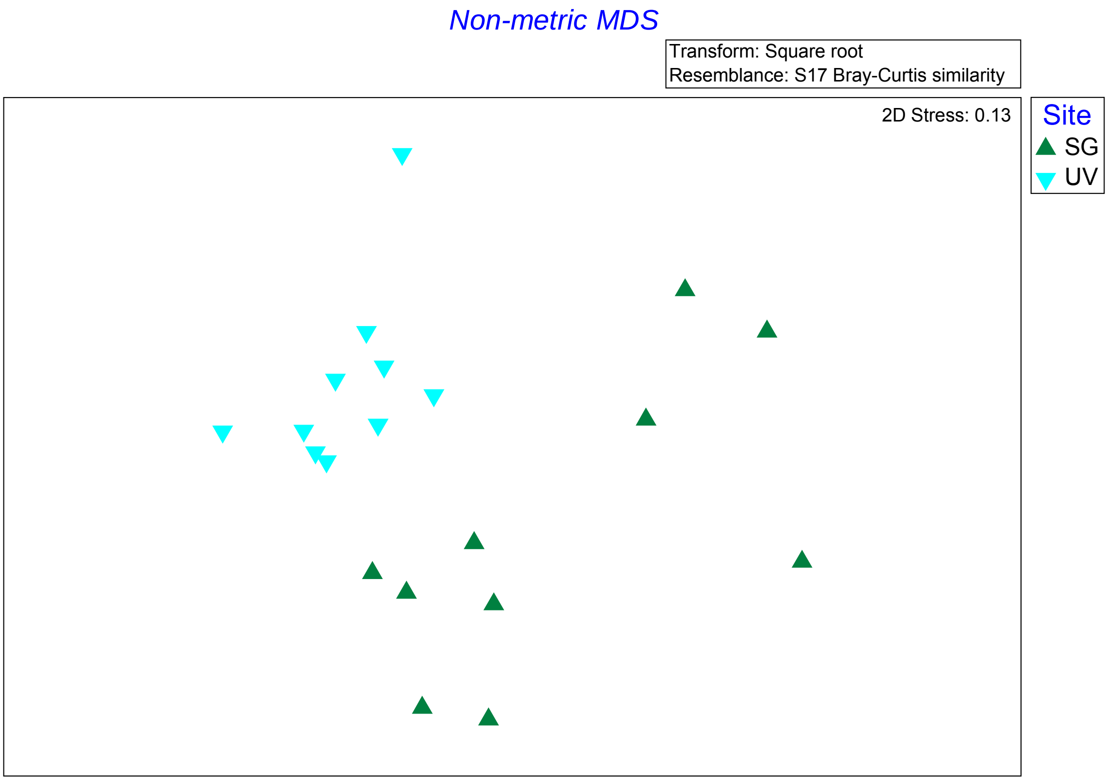

Figure 17. Non-metric MDS of intertidal infauna communities in Shakespeare Bay stuary, 2016. Blue symbols represent communities at an unvegetated site and green symbols represent communities at a seagrass-covered site.

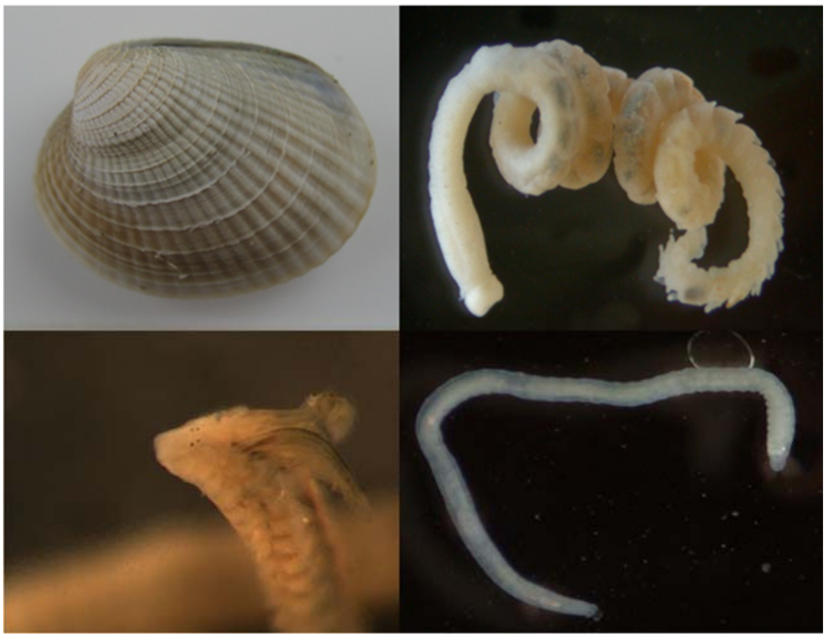

Figure 18. Common infaunal taxa from the intertidal zone in Shakespeare Bay estuary: cockles (top left), the polychaetes *Heteromastus filiformis* (top right) and *Prionospio aucklandica* (bottom left) and Oligochaeta (bottom right). Images not to scale.

4. SUMMARY AND RECOMMENDATIONS

The results indicate that the Shakespeare Bay estuary was subjected to generally minor pressures from key environmental stressors and was therefore in relatively **good health**. The relatively high proportion of seagrass, firm mud/sand and rushland in the intertidal zone, along with vegetation in the supra-littoral fringe, suggests that **high value habitats were present** and likely playing key functional roles within the estuary. However, a portion of the supra-littoral zone was modified from its natural state, with the presence of exotic plant species and man-made structures.

The low proportion of soft mud/sand habitat in the intertidal zone, and relatively low percentage of mud within sediments, indicates that the estuary was **unlikely being threatened by high sedimentation.** The **low nutrient and organic carbon levels** within the sediment, and lack of a strong RDL in core sediment profiles, suggest that excessive nutrients were not an issue within this estuary and that, although relatively productive, it has not been subject to the potentially adverse effects of eutrophication. The limited abundance of macro- and microalgae also support this conclusion. However, it was possible that mud and nitrogen levels within the sediment were high enough to be having a minor stress on benthic animal communities.

Concentrations of contaminants were below low guideline thresholds (metal/metalloids) and detection limits (SVOCs, organotin compounds) within the sediment and there was no evidence to suggest that they were having an adverse ecological effect.

4.1. Monitoring and management recommendations

- To assess any on-going or future changes that might adversely affect the health of this estuary, it is important to continue at least 5-yearly fine-scale and broad-scale monitoring intervals (next due in February-March 2021), as recommended in the EMP (Robertson et al. 2002).
- To maintain the current good health of this estuary, it is necessary to carefully manage human activities occuring in the catchment (e.g. commercial forestry harvesting) and and bay (e.g. dredging) that could potentially increase environmental stressors within the estuary. Particular focus should be applied to fine sediment and nitrogen levels as these stressors are already likely having a minor impact on benthic communities. This could be complemented by further targeted-monitoring of ecological indicators (e.g. seagrass) or stressors that may be influenced by future anthropogenic activity (e.g. monitoring of sediment deposition patterns in conjunction with commercial forestry activities within the catchment).
- The Shakespeare Bay estuary could be used as a reference against which other estuaries with similar characteristics (e.g. 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.

- Consider incorporating an iwi monitoring programme. For example, state of the environment monitoring may align with the aims of Te Ātiawa's iwi environmental management plan (Te Ātiawa o Te Waka-a-Māui 2014). A monitoring programme and set of protocols based on cultural health indicators has been developed for estuaries within the Nelson region (e.g. Walker 2009). Incorporating an iwi monitoring programme could support objectives of the MDC coastal monitoring strategy (2012), which include exploring opportunities to involve iwi in the implementation of the strategy and ensuring cultural values of the marine environment are not compromised.

5. ACKNOWLEDGMENTS

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7. APPENDICES

Appendix 1. Corner positions of two intertidal fine-scale sites in Shakespeare Bay estuary, 2016.

Corners	1	2	3	4
Seagrass site	41 16'46.5 S 173 59'42.6 E	41 16'45.7 S 173 59'43.5 E	41 16'46.6 S 173 59'44.8 E	41 16'47.3 S 173 59'43.9 E
Unvegetated site	173 59'48.5 41 16'48.7	41 16'49.6 173 59'49.2	41 16'50.2 173 59'47.6	41 16'49.2 173 59'47.0

Appendix 2. Breakdown of unvegetated habitats within the Shakespeare Bay estuary intertidal zone, 2016.

Class	Dominant Species	Primary Sub-dom	Area (Ha) Intertidal	% of Total
Bedrock			**0.02**	**1%**
	Bedrock		0.01	
		Cliff	0.00	
		Cobble field	0.00	
		Firm sand (<1cm)	0.00	
Cobble field			**0.06**	**2%**
	Cobble field	Gravel field	0.06	
Firm mud/sand (0-2cm)			**1.58**	**48%**
	Firm mud/sand (0-2cm)		0.00	
		Gravel field	0.38	
		Shell bank	1.20	
Firm sand (<1cm)			**0.10**	**3%**
	Firm sand (<1cm)	Gravel field	0.03	
		Shell bank	0.07	
Gravel field			**1.14**	**34%**
	Gravel field	Cobble Field	0.39	
		Firm mud and sand	0.27	
		Firm Sand	0.26	
		Shell bank	0.22	
Man-Made Structures			**0.00**	**0%**
	Man-Made Structures		0.00	
Rock wall man-made			**0.01**	**0%**
	Rock wall man-made		0.01	
Shell bank			**0.03**	**1%**
	Shell bank	Driftwood	0.02	
		Firm sand (<1cm)	0.02	
Soft mud/sand (2-5cm)			**0.32**	**10%**
	Soft mud/sand (2-5cm)		0.07	
		Gravel field	0.06	
		Shell bank	0.18	
		Driftwood	0.01	
Soft Sand			**0.01**	**0%**
	Soft Sand	Shell bank	0.01	
Water			**0.04**	**1%**
	Water		0.04	
Total			**3.32**	**100%**

Overall Summary	
Water	0.04
Unvegetated Substrata	3.28
Estuarine Vegetation	2.09
Grand Total	**5.41**

Appendix 3. Breakdown of vegetated habitats within the Shakespeare Bay estuary intertidal zone, 2016.

Class	Dominant Species	Primary Sub-dominant	Area (Ha)	% of Total
Herbfield			**0.033**	**2%**
	Samolus repens (Primrose)	*Selliera radicans* (Remuremu)	0.004	
	Sarcocornia quinqueflora (Glasswort)	Firm sand (<1cm)	0.004	
		Gravel field	0.013	
		Juncus kraussii (Searush)	0.011	
Rushland			**0.389**	**19%**
	Juncus kraussii (Searush)		0.158	
		Driftwood	0.015	
		Gravel field	0.015	
		Leptocarpus similis (Jointed wirerush)	0.074	
		Muehlenbeckia complexa	0.024	
	Leptocarpus similis (Jointed wirerush)	*Juncus kraussii* (Searush)	0.104	
Seagrass			**1.668**	**80%**
	Zostera muelleri (Seagrass)	Firm mud/sand (0-2cm)	1.619	
		Firm sand (<1cm)	0.026	
		Soft mud/sand (2-5cm)	0.023	
Total			**2.090**	**100%**

Appendix 4. Breakdown of vegetated habitats within the Shakespeare Bay estuary supra-littoral fringe, 2016.

Class	Dominant Species	Primary Sub-dominant	Area (Ha)	% of Total
Estuarine Shrubs			**0.217**	**9%**
	Muehlenbeckia complexa	*Festuca arundinacea* (Tall fescue)	0.027	
	Muehlenbeckia complexa	*Juncus kraussii* (Searush)	0.179	
	Muehlenbeckia complexa	*Leptocarpus similis* (Jointed wirerush)	0.010	
	Plagianthus divaricatus (Saltmarsh ribbonwood)		0.001	
Grassland			**0.525**	**21%**
	Festuca arundinacea (Tall fescue)	Atriplex prostrata	0.107	
	Festuca arundinacea (Tall fescue)	Exotic scrub/shrub/trees	0.012	
	Festuca arundinacea (Tall fescue)	*Juncus kraussii* (Searush)	0.024	
	Festuca arundinacea (Tall fescue)	*Muehlenbeckia complexa*	0.093	
	Festuca arundinacea (Tall fescue)	Unidentified grass	0.077	
	Unidentified grass	*Festuca arundinacea* (Tall fescue)	0.212	
Rushland			**0.054**	**2%**
	Juncus kraussii (Searush)	*Muehlenbeckia complexa*	0.054	
Sedgeland			**0.021**	**1%**
	Carex geminata (Cutty grass)		0.021	
Terrestrial Shrub/Scrub/Forest			**1.629**	**66%**
	Cyathea dealbata (Silver fern)	*Pseudopanax arboreus (Five finger)*	0.075	
	Exotic scrub/shrub/trees	*Atriplex prostrata*	0.002	
	Native scrub/shrub/trees	Exotic scrub/shrub/trees	1.178	
	Populus sp. (Poplar trees)		0.004	
	Salix cinerea (Grey willow)		0.002	
	Salix cinerea (Grey willow)	Native trees	0.003	
	Ulex europaeus (Gorse)	*Cordyline australis* (Cabbage tree)	0.157	
	Ulex europaeus (Gorse)	*Cytisus scoparius* (Broom)	0.070	
	Ulex europaeus (Gorse)	Exotic scrub/shrub/trees	0.065	
	Ulex europaeus (Gorse)	*Muehlenbeckia complexa*	0.035	
	Ulex europaeus (Gorse)	Native scrub/shrub/trees	0.038	
Tussockland			**0.021**	**1%**
	Phormium tenax (New Zealand flax)		0.000	
	Phormium tenax (New Zealand flax)	*Exotic scrub/shrub/trees*	0.018	
	Phormium tenax (New Zealand flax)	*Festuca arundinacea* (Tall fescue)	0.003	
Total			**2.466**	**100%**

Appendix 5. Breakdown of unvegetated habitats within the Shakespeare Bay estuary supra-littoral fringe, 2016.

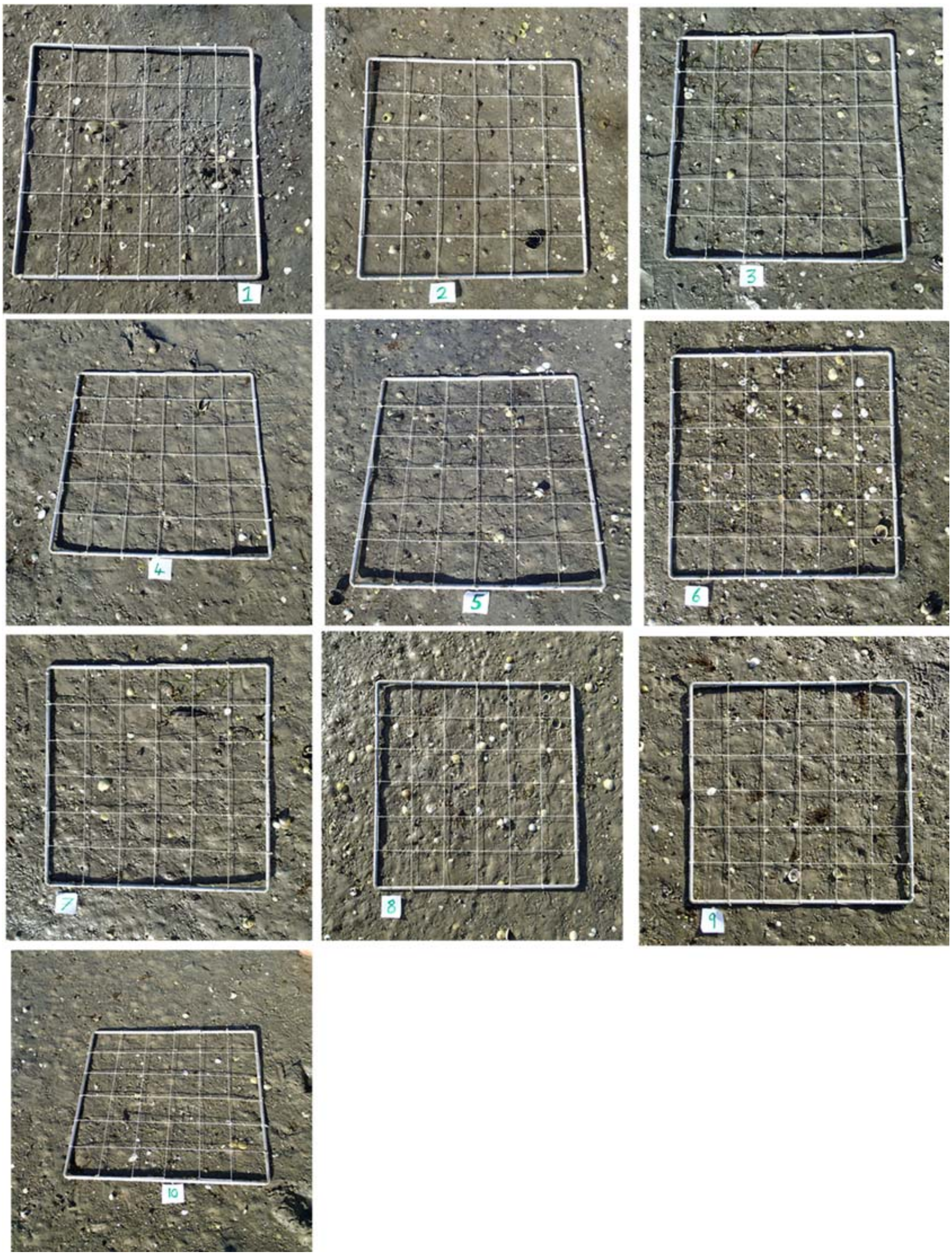
Class	Dominant Species	Primary Sub-dom	Area (Ha) Intertidal	% of Total
Cliff			**0.005**	**9%**
	Cliff		0.005	
Firm sand (<1cm)			**0.001**	**2%**
	Firm sand (<1cm)	*Festuca arundinacea* (Tall fescue)	0.001	
Man-Made Structures			**0.001**	**2%**
	Man-Made Structures		0.001	
Road			**0.037**	**65%**
	Road		0.037	
Rock wall man-made			**0.013**	**23%**
	Rock wall man-made		0.013	
Total			**0.057**	**100%**

Overall Summary	
Water	0.000
Unvegetated Substrata	0.057
Estuarine Vegetation	2.466
Grand Total	**2.523**

Appendix 6. DVD-ROM file containing a working version of the 2016 broad-scale habitat maps of Shakespeare Bay estuary (entitled ‘Broad-scale intertidal habitat mapping for Shakespeare Bay estuary: 2016’). This DVD-ROM also contains results from the Shakespeare Bay estuary 2016 fine-scale surveys (entitled ‘Fine-scale indicators results for Shakespeare Bay estuary:2016’).

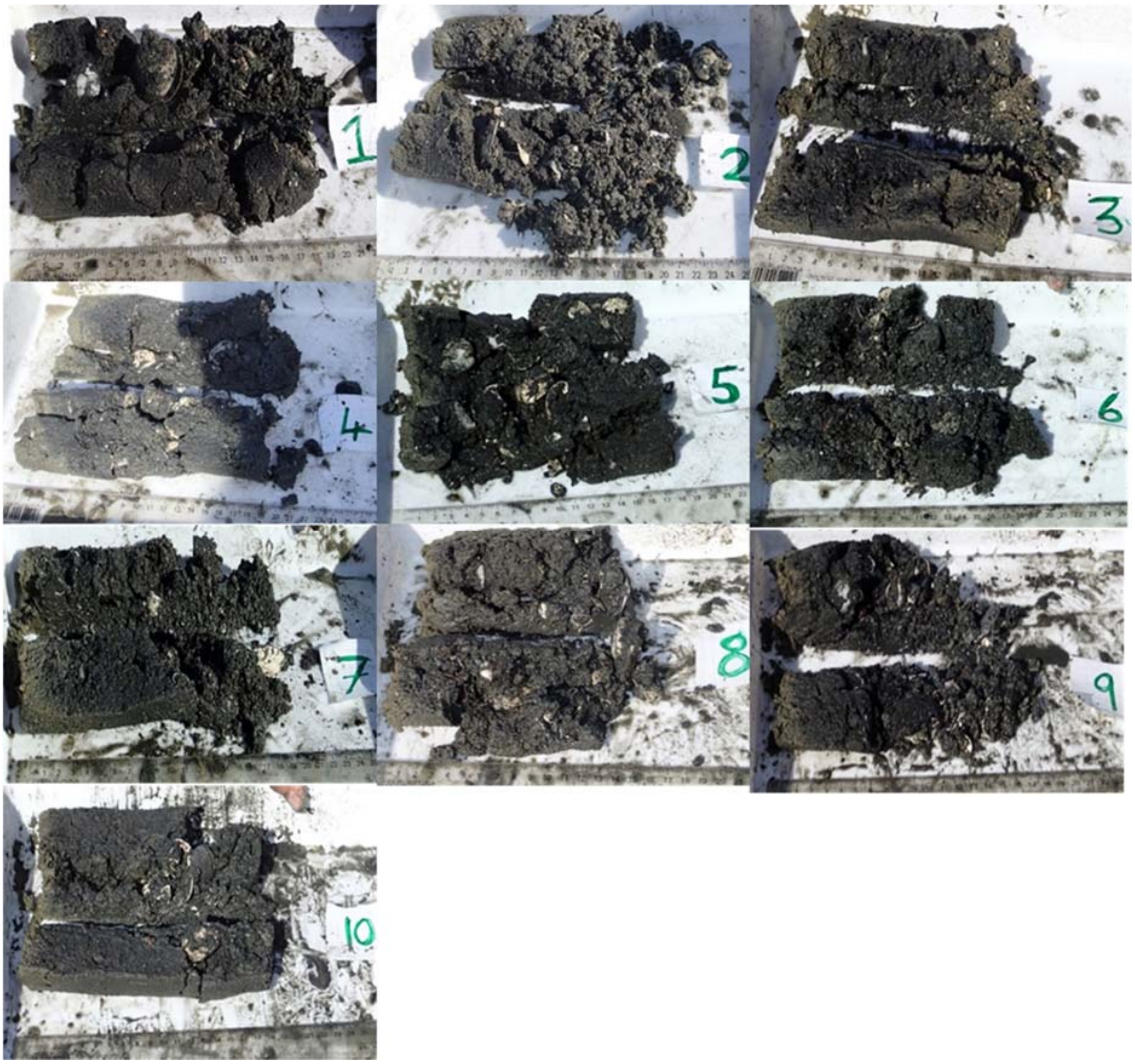
(see inside back cover)

Appendix 7. Epibiota quadrats (size 0.25m²) from an unvegetated (UV) intertidal fine-scale sampling site in Shakespeare Bay estuary, 2016.

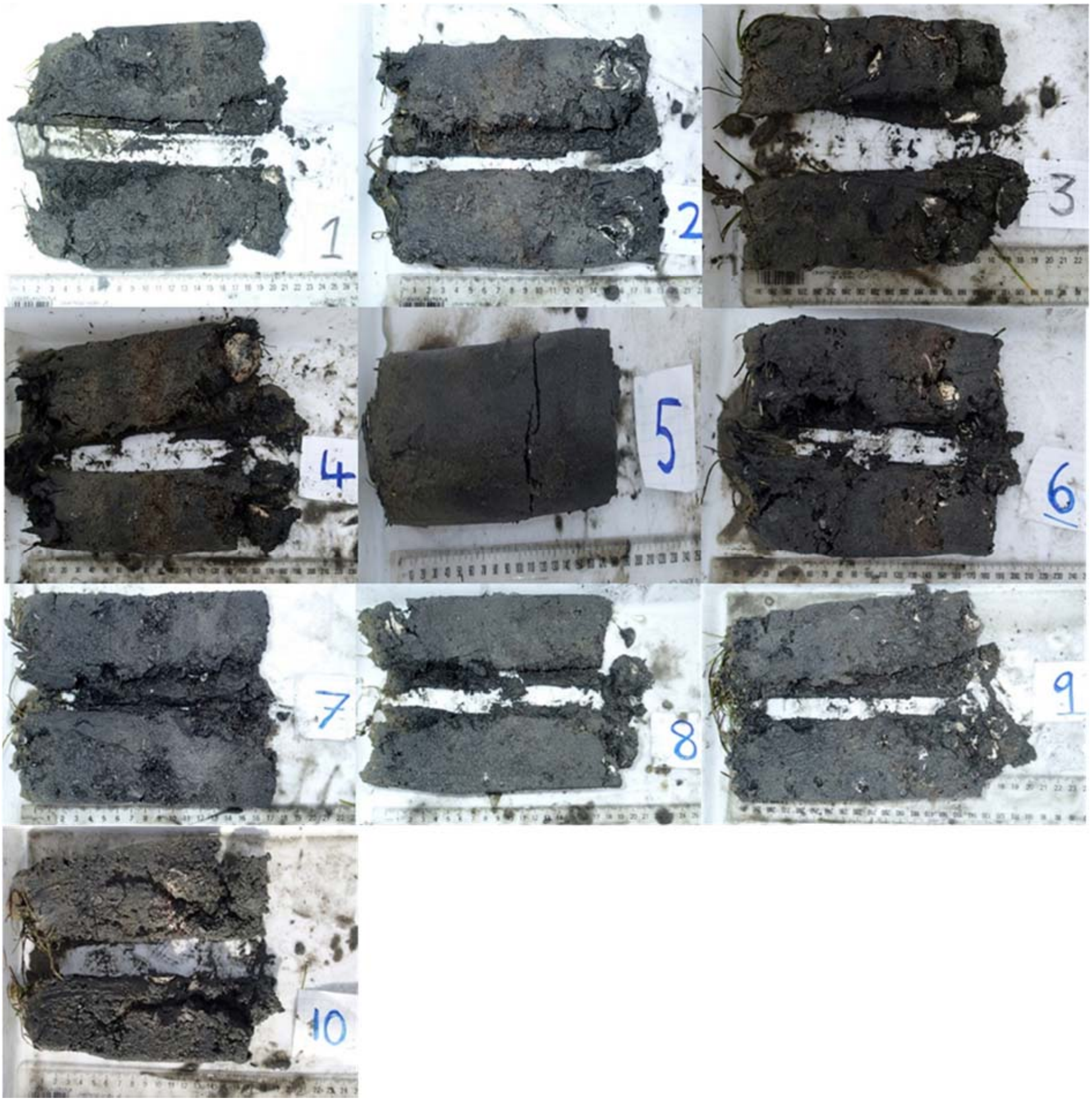


Appendix 8. Epibiota quadrats (size 0.25m²) from a seagrass (SG) intertidal fine-scale sampling site in Shakespeare Bay estuary, 2016.

Appendix 9. Sediment cores from an unvegetated (UV) intertidal fine-scale site in Shakespeare Bay estuary, 2016.



Appendix 10. Sediment cores from a seagrass (SG) intertidal fine-scale site in Shakespeare Bay estuary, 2016.



Appendix 11. Physical and chemical properties of sediment from two intertidal fine-scale unvegetated (UV) and seagrass (SG) sites in Shakespeare Bay estuary, 2016. Each sample is a composite from 3 or 4 replicates (listed in the main table heading).

Phys/chem variable	**Units**	**UV 1-3**	**UV 4-6**	**UV 7-10**	**SG 1-3**	**SG 4-6**	**SG 7-10**
Total Recoverable Phosphorus	mg/kg dry wt	147	210	200	210	230	230
Total Nitrogen	mg/kg dry wt	250	250	250	500	600	500
Total Organic Carbon	g/100g dry wt	0.25	0.26	0.28	0.64	0.58	0.51
Total Recoverable Arsenic	mg/kg dry wt	2.3	3	2.6	2.9	2.7	3.4
Total Recoverable Cadmium	mg/kg dry wt	0.019	0.021	0.015	0.035	0.024	0.02
Total Recoverable Chromium	mg/kg dry wt	4	5.2	4.6	5.2	5.3	5.3
Total Recoverable Copper	mg/kg dry wt	6	7	5.6	8.7	9.1	8.7
Total Recoverable Lead	mg/kg dry wt	2.8	3.8	3.4	4	4.2	4.4
Total Recoverable Mercury	mg/kg dry wt	0.013	0.013	0.005	0.017	0.015	< 0.010
Total Recoverable Nickel	mg/kg dry wt	3.1	4.2	3.4	4.5	4.4	4.4
Total Recoverable Zinc	mg/kg dry wt	25	27	21	30	30	31
Fraction >/= 2 mm	g/100g dry wt	8.8	9.7	7.3	5.3	9.6	14.7
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	81.7	82.3	84.7	70.7	66.6	69.5
Fraction < 63 µm	g/100g dry wt	9.5	8	8	24	23.8	15.8

Appendix 12. Analytical results (mg/kg dry wt.) for Semivolatile Organic Compounds and organotin compounds within sediments from two intertidal fine-scale (unvegetated and seagrass) sites in Shakespeare Bay estuary, 2016. Each sample is composited from 10 replicates.

	Units	Unvegetated	Seagrass
Dry Matter	g/100g as rcvd	74	63
Haloethers			
Bis(2-chloroethoxy) methane	mg/kg dry wt	< 0.10	< 0.10
Bis(2-chloroethyl)ether	mg/kg dry wt	< 0.10	< 0.10
Bis(2-chloroisopropyl)ether	mg/kg dry wt	< 0.10	< 0.10
4-Bromophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.10
4-Chlorophenyl phenyl ether	mg/kg dry wt	< 0.10	< 0.10
Nitrogen containing compounds			
N-Nitrosodiphenylamine + Diphenylamine	mg/kg dry wt	< 0.10	< 0.10
2,4-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.2
2,6-Dinitrotoluene	mg/kg dry wt	< 0.2	< 0.2
Nitrobenzene	mg/kg dry wt	< 0.10	< 0.10
N-Nitrosodi-n-propylamine	mg/kg dry wt	< 0.10	< 0.10
Organochlorine Pesticides			
Aldrin	mg/kg dry wt	< 0.10	< 0.10
alpha-BHC	mg/kg dry wt	< 0.10	< 0.10
beta-BHC	mg/kg dry wt	< 0.10	< 0.10
delta-BHC	mg/kg dry wt	< 0.10	< 0.10
gamma-BHC (Lindane)	mg/kg dry wt	< 0.10	< 0.10
4,4'-DDD	mg/kg dry wt	< 0.10	< 0.10
4,4'-DDE	mg/kg dry wt	< 0.10	< 0.10
4,4'-DDT	mg/kg dry wt	< 0.2	< 0.2
Dieldrin	mg/kg dry wt	< 0.10	< 0.10
Endosulfan I	mg/kg dry wt	< 0.2	< 0.2
Endosulfan II	mg/kg dry wt	< 0.5	< 0.5
Endosulfan sulphate	mg/kg dry wt	< 0.2	< 0.2
Endrin	mg/kg dry wt	< 0.10	< 0.10
Endrin ketone	mg/kg dry wt	< 0.2	< 0.2
Heptachlor	mg/kg dry wt	< 0.10	< 0.10
Heptachlor epoxide	mg/kg dry wt	< 0.10	< 0.10
Hexachlorobenzene	mg/kg dry wt	< 0.10	< 0.10

Appendix 12 continued.

	Units	Unvegetated	Seagrass
Polycyclic Aromatic Hydrocarbons			
Acenaphthene	mg/kg dry wt	< 0.10	< 0.10
Acenaphthylene	mg/kg dry wt	< 0.10	< 0.10
Anthracene	mg/kg dry wt	< 0.10	< 0.10
Benzo[a]anthracene	mg/kg dry wt	< 0.10	< 0.10
Benzo[a]pyrene (BAP)	mg/kg dry wt	< 0.10	< 0.10
Benzo[b]fluoranthene + Benzo[j]fluoranthene	mg/kg dry wt	< 0.10	< 0.10
Benzo[g,h,i]perylene	mg/kg dry wt	< 0.10	< 0.10
Benzo[k]fluoranthene	mg/kg dry wt	< 0.10	< 0.10
1&2-Chloronaphthalene	mg/kg dry wt	< 0.10	< 0.10
Chrysene	mg/kg dry wt	< 0.10	< 0.10
Dibenzo[a,h]anthracene	mg/kg dry wt	< 0.10	< 0.10
Fluoranthene	mg/kg dry wt	< 0.10	< 0.10
Fluorene	mg/kg dry wt	< 0.10	< 0.10
Indeno(1,2,3-c,d)pyrene	mg/kg dry wt	< 0.10	< 0.10
2-Methylnaphthalene	mg/kg dry wt	< 0.10	< 0.10
Naphthalene	mg/kg dry wt	< 0.10	< 0.10
Phenanthrene	mg/kg dry wt	< 0.10	< 0.10
Pyrene	mg/kg dry wt	< 0.10	< 0.10
Phenols			
4-Chloro-3-methylphenol	mg/kg dry wt	< 0.5	< 0.5
2-Chlorophenol	mg/kg dry wt	< 0.2	< 0.2
2,4-Dichlorophenol	mg/kg dry wt	< 0.2	< 0.2
2,4-Dimethylphenol	mg/kg dry wt	< 0.4	< 0.4
3 & 4-Methylphenol (m- + p-cresol)	mg/kg dry wt	< 0.4	< 0.4
2-Methylphenol (o-Cresol)	mg/kg dry wt	< 0.2	< 0.2
2-Nitrophenol	mg/kg dry wt	< 0.4	< 0.4
Pentachlorophenol (PCP)	mg/kg dry wt	< 6	< 6
Phenol	mg/kg dry wt	< 0.2	< 0.2
2,4,5-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.2
2,4,6-Trichlorophenol	mg/kg dry wt	< 0.2	< 0.2

Appendix 12 continued.

	Units	Unvegetated	Seagrass
Plasticisers			
Bis(2-ethylhexyl)phthalate	mg/kg dry wt	< 0.5	< 0.5
Butylbenzylphthalate	mg/kg dry wt	< 0.2	< 0.2
Di(2-ethylhexyl)adipate	mg/kg dry wt	< 0.2	< 0.2
Diethylphthalate	mg/kg dry wt	< 0.2	< 0.2
Dimethylphthalate	mg/kg dry wt	< 0.2	< 0.2
Di-n-butylphthalate	mg/kg dry wt	< 0.2	< 0.2
Di-n-octylphthalate	mg/kg dry wt	< 0.2	< 0.2
Other Halogenated compounds			
1,2-Dichlorobenzene	mg/kg dry wt	< 0.10	< 0.10
1,3-Dichlorobenzene	mg/kg dry wt	< 0.10	< 0.10
1,4-Dichlorobenzene	mg/kg dry wt	< 0.10	< 0.10
Hexachlorobutadiene	mg/kg dry wt	< 0.10	< 0.10
Hexachloroethane	mg/kg dry wt	< 0.10	< 0.10
1,2,4-Trichlorobenzene	mg/kg dry wt	< 0.10	< 0.10
Other SVOC			
Benzyl alcohol	mg/kg dry wt	< 1.0	< 1.0
Carbazole	mg/kg dry wt	< 0.10	< 0.10
Dibenzofuran	mg/kg dry wt	< 0.10	< 0.10
Isophorone	mg/kg dry wt	< 0.10	< 0.10
Tributyl Tin Trace			
Dibutyltin (as Sn)	mg/kg dry wt	< 0.005	< 0.005
Monobutyltin (as Sn)	mg/kg dry wt	< 0.007	< 0.007
Tributyltin (as Sn)	mg/kg dry wt	< 0.004	< 0.004
Triphenyltin (as Sn)	mg/kg dry wt	< 0.003	< 0.003

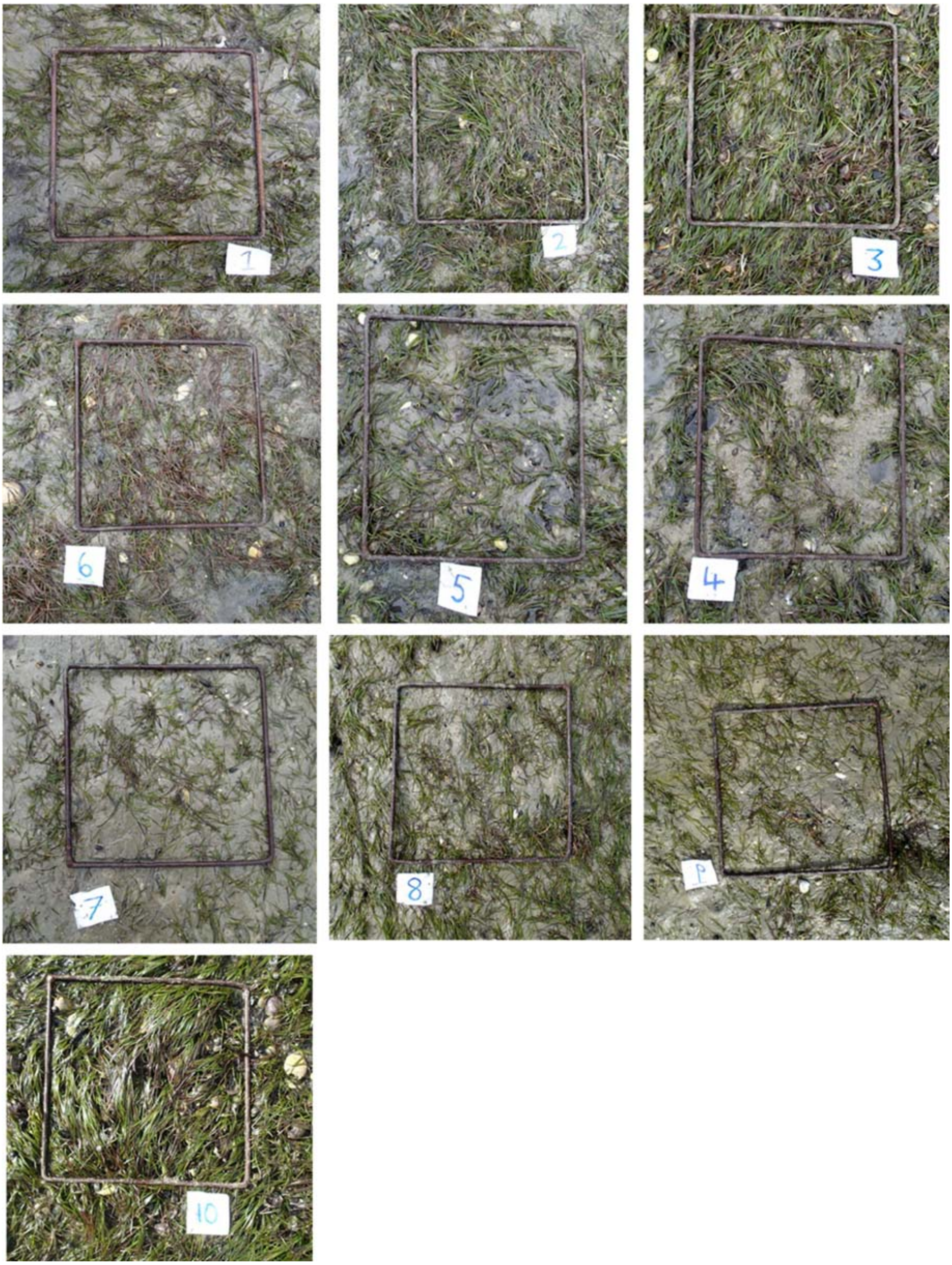
Appendix 13. Abundance of Shakespeare Bay estuary epibiota from two intertidal fine-scale sites (unvegetated and seagrass), 2016.

Shakespeare Bay Estuary Epibiota		Unvegetated Quadrats (0.25m²)										Seagrass Quadrats (0.25m²)									
Taxa	**Common name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chiton Glaucus		0	0	0	0	0	0	1	0	0	0	0	1	2	0	1	1	0	0	0	32
Notoplax violacea		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Cominella glandiformis	Mudflat whelk	10	8	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0
Diloma sp.	Mudflat topshell	5	23	11	7	14	24	11	11	13	17	4	39	24	6	19	12	17	8	10	37
Zeacumantus sp.	Spire shell	6	9	2	2	4	10	4	4	4	7	9	16	0	6	15	8	9	7	6	2
Notoacmea helmsi	Estuarine limpet	1	0	0	0	0	3	0	2	0	7	0	0	0	0	0	2	0	3	0	0
Haminoea sp.		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lunella smaragdus		0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Austrovenus stutchburyi	Cockle	0	5	3	0	1	1	0	3	1	2	0	4	11	0	1	0	0	0	0	0
Paphies australis	Pipi	0	0	1	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0
Crab holes		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	2	0
Helice crassa	Burrowing mud crab	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
Worm hole		0	0	0	0	1	0	15	0	47	0	0	0	0	0	0	0	0	0	38	0
Austrominius modestus	Estuarine barnacle	0	8	11	0	7	32	0	1	0	0	1	0	0	0	0	1	16	9	0	329
Gracilaria sp.		2%	0%	0%	6%	0%	0%	4%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Zostera muelleri	Seagrass	0%	0%	4%	0%	0%	0%	0%	0%	0%	0%	82%	96%	98%	92%	90%	94%	94%	84%	90%	98%

Appendix 14. Percentage cover and biomass of seagrass in an intertidal fine-scale sampling site in Shakespeare Bay estuary 2016 (current study) and Nelson Haven 2012 (Gillespie et al. 2012a).

Seagrass	**Shakespeare Bay Estuary 2016**		**Nelson Haven 2012**	
Quadrat	**% cover**	**Above-ground biomass** (scaled to g/dryweight per 0.25m^2)	**% cover**	**Above-ground biomass** (g/dryweight per 0.25 m^2)
1	65	9.5	66	13.9
2	98	20.7	78	21.9
3	95	20.3	78	16.5
4	50	8.8	92	25.1
5	60	7.4	92	29.3
6	90	8.1	80	17.4
7	40	2.8	80	14.3
8	55	6.1	66	16.9
9	35	2.7	58	11.1
10	100	18.3	68	12.6
Average ± Error	68.8 ± 7.9 (SE)	10.5 ± 2.2 (SE)	75.8 ± 11.3 (SD)	17.9 ± 5.8 (SD)

Appendix 15. Smaller quadrats (0.06m^2) from a seagrass (SG) fine-scale sampling site in Shakespeare Bay estuary, 2016.



Appendix 16. Abundance (per core) of infauna from two intertidal fine-scale seagrass (SG) and unvegetated (UV) sites in Shakespeare Bay estuary, 2016.

Taxa	Ecological Group	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	UV1	UV2	UV3	UV4	UV5	UV6	UV7	UV8	UV9	UV10
Edwardsia sp.	II	0	0	0	0	0	0	0	0	0	0	1	1	1	2	0	1	0	2	4	5
Nemertea	III	1	0	1	1	2	2	0	0	2	2	6	3	3	5	3	1	0	3	3	0
Nematoda	II	3	0	0	3	0	0	3	0	0	0	19	0	1	1	0	0	0	5	0	0
Chiton glaucus	II	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda Unid. Juv.	NA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lunella smaragdus	NA	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cominella glandiformis	III	0	0	0	0	3	2	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Diloma subrostrata	II	0	0	6	8	6	0	0	2	0	4	0	3	0	0	0	0	1	1	1	1
Diloma zelandica	NA	0	1	5	5	0	0	1	3	1	4	0	0	0	0	0	0	0	0	0	0
Neoguraleus sinclairi	NA	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Notoacmea sp.	NA	2	0	7	2	1	1	1	0	1	1	0	0	0	0	0	0	0	1	0	0
Potamopyrgus estuarinus	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Zeacumantus lutulentus	II	0	3	2	3	3	2	0	0	0	13	3	2	1	0	1	0	1	1	0	0
Zeacumantus subcarinatus	I	3	8	8	5	1	1	1	0	0	0	3	0	1	2	0	0	0	0	0	3
Haminoea zelandiae	I	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Arthritica bifurca	IV	0	8	2	7	6	2	0	3	0	7	0	4	1	0	0	0	1	1	0	0
Austrovenus stutchburyi	II	11	17	33	13	24	10	2	10	10	26	9	7	2	7	6	2	6	17	0	16
Linucula hartvigiana	II	0	0	4	1	2	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
Macomona liliana	II	4	5	1	0	1	0	4	4	4	4	7	5	3	6	8	3	7	4	7	3
Paphies australis	II	1	0	0	0	0	14	1	15	2	0	1	1	0	3	1	3	3	11	3	6
Soletellina sp.	I	0	0	0	0	0	0	0	0	0	0	2	0	2	3	0	0	0	7	0	0
Oligochaeta	III	1	9	0	1	7	62	0	6	21	42	30	24	14	11	0	23	29	22	39	35
Polychaeta Unid.	NA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Polydorid	NA	0	1	3	29	4	3	0	0	0	5	1	8	8	5	2	3	3	3	1	4
Orbiniidae	I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Leitoscoloplos spp.	NA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orbinia papillosa	I	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Scoloplos cylindrifer	I	4	1	0	1	0	2	0	7	0	0	0	0	0	0	0	0	0	0	0	0
Paraonidae	III	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aonides trifida	I	1	4	2	0	7	3	2	1	1	7	0	1	3	2	0	18	0	22	4	10
Prionospio aucklandica	II	3	20	10	9	19	17	2	1	0	21	23	31	22	32	2	11	30	12	9	5
Prionospio sp.	II	0	3	8	6	7	2	1	0	1	5	18	16	11	14	0	7	0	7	1	5
Scolecolepides benhami	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Scolelepis sp.	I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Capitellidae	V	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Taxa	Ecological Group	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	UV1	UV2	UV3	UV4	UV5	UV6	UV7	UV8	UV9	UV10
Barantolla lepte	V	0	0	0	1	0	0	0	0	0	5	5	0	0	2	0	2	1	0	1	1
Capitella capitata	IV	3	3	2	7	3	17	0	0	0	2	7	7	4	1	1	1	16	0	2	1
Heteromastus filiformis	III	13	11	7	10	18	16	6	0	1	49	66	54	48	61	6	24	20	22	30	17
Maldanidae	I	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia maculata	III	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Scalibregma inflatum	III	0	1	0	3	0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Phyllodocidae	II	0	0	0	0	0	0	0	0	0	0	2	2	1	3	0	0	0	3	0	1
Hesionidae	I	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Syllidae	II	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
Sphaerosyllis sp.	III	0	0	0	1	1	0	0	0	0	4	59	15	8	21	7	1	5	7	4	1
Nereididae	III	2	0	0	1	0	0	0	0	1	2	0	0	0	2	0	1	0	0	0	1
Perinereis vallata	II	0	1	0	0	3	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Glyceridae	II	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Goniadidae	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Dorvilleidae	II	0	0	0	1	1	5	1	0	0	3	0	0	0	0	0	0	0	0	0	0
Pectinaria australis	III	0	0	0	0	1	0	0	0	3	3	0	0	0	1	0	0	0	0	0	1
Collembola	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Mysidacea	I	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Isocladus armatus	II	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Corophiidae	II	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lysianassidae	II	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	II	1	2	0	0	0	0	0	0	0	2	0	2	0	0	0	1	1	0	1	0
Austrohelice crassa	V	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus sp.	III	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus whitei	III	1	2	3	1	2	3	1	2	1	4	0	0	0	1	0	0	0	0	0	0
Hemigrapsus crenulatus	NA	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Hemiplax hirtipes	V	0	2	0	4	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0
Brachyura indet.	NA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decapoda (larvae unid.)	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Diasterope grisea	I	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Austrominius modestus	II	0	0	1	5	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Dolichopodidae	II	1	0	0	0	0	0	2	1	3	0	0	0	0	0	0	0	0	1	1	1
Asteroidea	I	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 17. SIMPER analysis of infauna communities from two intertidal fine-scale sites (unvegetated and seagrass) in Shakespeare Bay estuary, 2016.

Site: **Unvegetated**					
Average similarity: 60.69					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Heteromastus filiformis	5.63	10.36	4.55	17.06	17.06
Oligochaeta	4.45	7.78	1.73	12.82	29.89
Prionospio aucklandica	3.96	6.97	3.03	11.49	41.37
Macomona liliana	2.26	4.8	3.49	7.92	49.29
Sphaerosyllis sp.	3.05	4.59	2.34	7.57	56.85
Austrovenus stutchburyi	2.41	3.93	1.61	6.47	63.33
Polydorid	1.85	3.49	3.12	5.76	69.09
Prionospio sp.	2.38	3.05	1.11	5.03	74.12

Site: **Seagrass**					
Average similarity: 48.44					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Austrovenus stutchburyi	3.77	7.6	3.67	15.69	15.69
Heteromastus filiformis	3.14	4.91	1.59	10.14	25.83
Prionospio aucklandica	2.78	4.1	1.53	8.47	34.3
Oligochaeta	2.9	3.2	0.92	6.61	40.91
Halicarcinus whitei	1.37	2.97	4.26	6.13	47.04
Macomona liliana	1.42	2.81	0.97	5.8	52.85
Aonides trifida	1.49	2.63	1.76	5.44	58.29
Prionospio sp.	1.53	2.08	1.17	4.29	62.57
Arthritica bifurca	1.51	1.77	0.88	3.66	66.24
Notoacmea sp.	1.05	1.65	1.15	3.41	69.64
Capitella capitata	1.48	1.6	0.88	3.31	72.95