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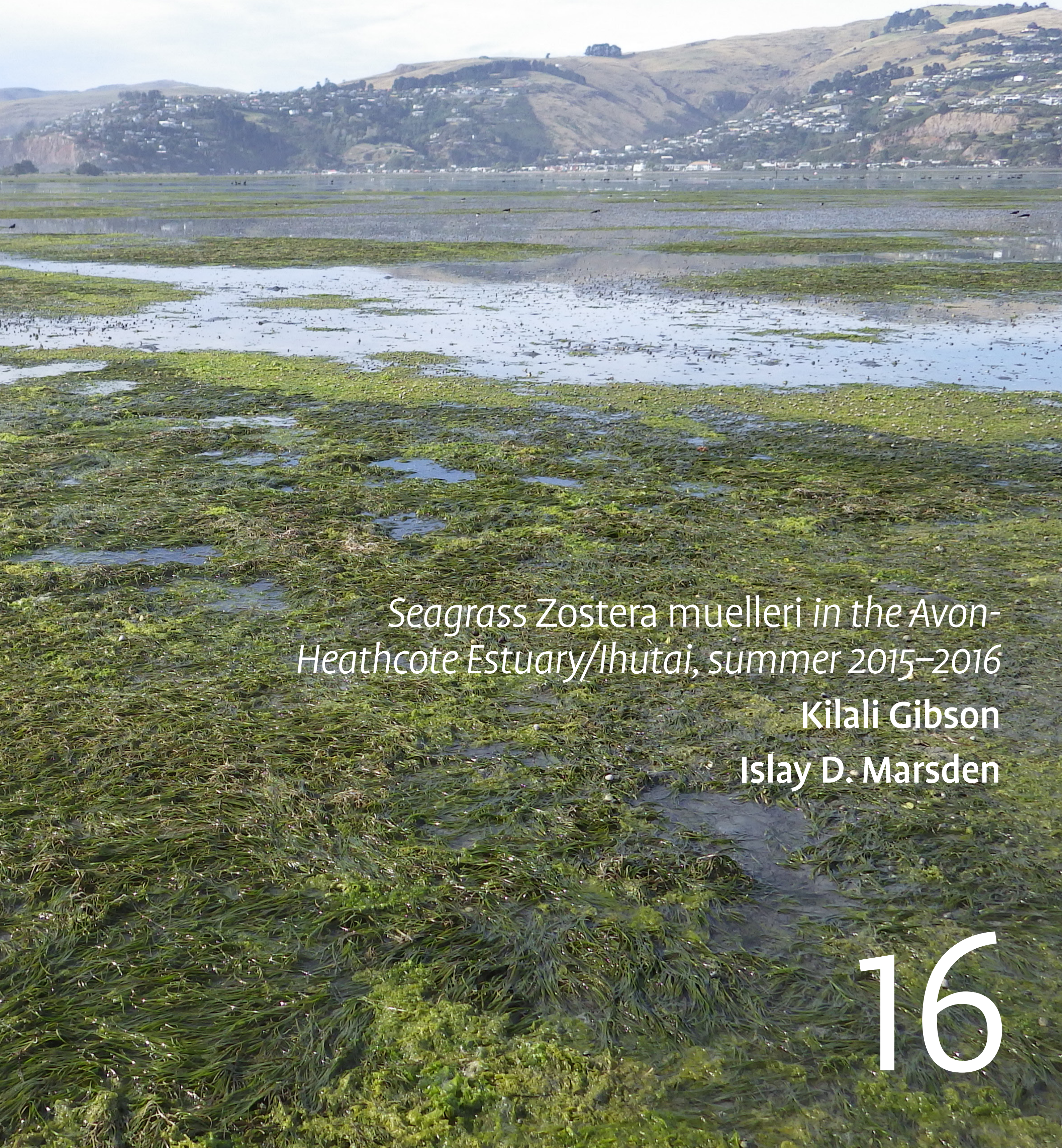
Estuarine Research Report 44



Seagrass Zostera muelleri *in the Avon-Heathcote Estuary/Ihutai, summer 2015–2016*

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16

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Cover Photo:
Northern patchy part of the seagrass bed facing towards the Port Hills

Prepared for:
Ihutai Trust and the University of Canterbury

Executive Summary

1. Seagrass was mapped in December 2015 within the Avon-Heathcote Estuary/Ihutai. Since 2003, the main seagrass bed has increased from 0.29 km^2 to 0.52 km^2 with evidence of eastern and northern expansion.
2. Transects across the Estuary found seagrass mainly on the eastern side. All transects had snails, and majority of the eastern sides of transects had sea lettuce. The distributions were similar to those of Maclaren and Marsden (2005). Anoxic sediment was consistently found within the seagrass bed.
3. Benthic samples were dug to 15cm depth using 15cm x 15cm quadrats within the seagrass bed. Seagrass and root biomass were highest in the centre of the seagrass bed at the low tide zone and southern mid tide zone of the bed. Organic matter biomass was highest in the southern mid tide zone. *Ulva* biomass was most dominant in the south mid tide zone.
4. Average seagrass shoot length was significantly higher in the mid-tide area compared with the low tide. The densest patches of seagrass shoots were found in the centre region in the low tidal zone and southern area in the mid tide zone.
5. Larger cockles were found in the middle low-tide zone and southern mid -tide zone. The small top shell *Micrelenchus tenebrosus.* and the polychaete *Nicon* sp. were the most abundant invertebrates found.
6. A new seagrass recruitment area was located within McCormack's Bay near the causeway. This was made up of small isolated patches on the north-eastern edge of the bay near the causeway.
7. Transplanted plots of healthy seagrass patches were placed in bare areas close to the main seagrass bed the estuary. After three months transplants in the southern and western part of the bed had either been bleached or had been swept away. The northern transplants that were not covered by sea lettuce were healthy and show potential for establishment.
8. The main recommendations were to regularly resurvey the seagrass beds, consider alternative mapping techniques and develop the transplant techniques for use elsewhere in the Estuary.

Contents

1.General Background

A brief history of the Estuary

The 8 km^2 estuary is a connecting link between the fresh water flowing from the northern Avon river and the southern Heathcote river out to the ocean by Sumner beach (Knox et al. 1973, Marsden and Knox 2008). It resembles a large triangular enclosed area that is almost completely drained of water at low tide making it easily accessible to walk on. Prior to the 2010 removal of treated sewage, the estuary endured over a 100 years of contamination from human wastes including output from engineering works, glue factories, and surrounding gas companies (Knox et al. 1973, Robb 1988, Bolton-Ritchie, 2010). In 1950 the city council began using the Estuary as a discharging point for the city sewage after receiving primary treatment. Kilner and colleagues (1973) described the sewage filled wetland as 'noxious and filthy with the bottom covered by a deep layer of glutinous black mud which, when disturbed, released hydrogen sulphide.' In March 2010 a new sewerage system was constructed to carry the treated waste 3 km out to sea where it would be taken away by the currents (Bolton-Ritchie 2012).

The 2011 earthquakes struck Christchurch and broke the main city sewage pipelines. With the excess of waste spilling out from the broken pipes, much untreated sewage was released into the Avon-Heathcote Estuary (Bolton-Ritchie 2012). The surplus of nutrients triggered mass growth of algal sea lettuce which smothered much of the seagrass beds; a habitat used by many species of sea snails and fish (Ren et al 2014). Organisms, such as shellfish, that did survive were considered too contaminated for people to consume (McMurtrie 2012). Liquefaction from the quake caused ancient sediment to bubble up from below the surface as sand volcanoes and cover the mudflats and the seagrass beds. These events have been largely influential on the current state of the estuary ecosystem.

Seagrass

Seagrass, also known as eel grass or *Zostera muelleri*, is a New Zealand endemic species found within intertidal zones. It often inhabits areas that are exposed during low tide and fully submerged at high tide (Matheson et al. 2009). Seagrass plays an important role in marine ecosystems for a variety of reasons. Beds of seagrass have high in primary productivity (Waycott et al. 2009) and have been shown to exceed many similar cultivated terrestrial ecosystem's primary production (Duarte and Chiscano 1999). Being the only marine plants with roots and rhizomes, they hold and stabilize sediment (Spalding et al. 2003) which aides in increasing sedimentation rates, alters water flow, filters nutrients (Hemminga and Duarte 2000) and increases water clarity (Van der Heide et al. 2007). A variety of marine fauna benefit from seagrass. Numerous fish, often juveniles, and shellfish depend on seagrass beds as a nursery; many that are commercial species (Watson et al. 1993, Short and Neckles 1999, Heck et al. 2003, Unsworth et al. 2008). It is also a popular spot for many seabirds (Kilner et al. 1973). Lastly, seagrass meadows have been termed as 'marine carbon sinks,' a highly valuable asset for organisms (Samper-Villarreal et al. 2016). Benthic fauna can benefit from the carbon provided by seagrass for their own resource use (Suchanek et al. 1985). Unfortunately, seagrass meadows are highly vulnerable to a variety of threats and face a global crisis due to their rapid reduction (Spalding et al. 2003). The dependency on seagrass directly and indirectly by other organisms and animals has led for a strong interest in their protection (Borsje et al. 2011).

Worldwide, seagrass meadows have been decreasing with an estimated 2-5% loss each year (Duarte et al. 2010). According to historical notes, seagrass used to be very abundant within the Avon-Heathcote Estuary creating homes for eels and small shrimp. Māori used the rhizome as a source of food and leaves as decoration for clothing (Inglis 2003). People use the Estuary for recreation, walking their dogs at low tide, sailing, kayaking swimming, and enjoying the scenic views. Within the Avon-Heathcote Estuary, there is currently one large bed of seagrass hugging the eastern edge. In this study we aim to provide recent mapping of the seagrass, identify present organisms and sediment type through transects, examine samples taken within the bed, and lastly begin an experiment on transplanting the seagrass. The information provided within this report can be used as a baseline survey for future studies to actively monitor the overall seagrass health.

Summer scholarship student Kilali Gibson working in the estuary.

2. Seagrass mapping

Introduction

The seagrass bed in the Avon-Heathcote Estuary has been of great interest to students, scientists, and community members. Congdon and Marsden's 2004 report gave an in depth comparison of 10 maps between 1951 and 2002 showing the fluctuation of size in the seagrass bed over time. Their 2004 report displayed the growth of seagrass size from 2002 at 0.17 km^2 to roughly 0.29 km^2 in 2004. In 2005, Maclaren and Marsden (2005) found the seagrass bed size to be about 0.21 km^2. Since the 2005 report, there is no record of other seagrass bed monitoring studies.

The 2011 Christchurch earthquakes had a considerable influence on the estuary's marine ecosystem (Bolton-Ritchie 2012, Zeldis et al. 2011). The earthquakes brought sediment from liquefaction and translocated sewage which polluted the wetland with organic matter (McMurtrie 2012). The health of the seagrass after the earthquakes is unknown and reduced health could be attributed to a variety of factors such as temperature, pollutants, and ability of the tides to flush out the organic matter. Unfortunately, because of the 10-year gap between surveys it is difficult to see the size difference directly after the earthquakes. In this study, we aim to provide the current location and size of the seagrass bed using methodology based off of Congdon and Marsden's (2004) report.

On the west side of the Estuary, McCormacks Bay was a potential site for seagrass recruitment. Initially the Bay was connected to the Avon Heathcote Estuary and served as a hot spot for bird diversity and aquatic life. Because of the development in Sumner, a route was created to connect the suburb to the city as seen in Photo 1. It is one of the potentially more contaminated areas within the estuary, due to a lack of tidal flushing. Here a variety of species struggle to survive in the highly anoxic environment (Flanagan 1997). There are no current records of seagrass mapping undergone within McCormacks Bay, however seagrass has been recorded in recent sea lettuce monitoring reports and its presence confirmed by local botanist Dr Trevor Partridge. This study will act as a baseline survey which can be used for future comparisons.

Methods

Avon-Heathcote Estuary/Ihutai

The eastern seagrass bed was mapped out in December 2015 by walking, and plotting points using a GPS system (Garmin Montana 650t) every 30 m around the edge of the seagrass bed which included all seagrass connected to the main patch by less than 5 m. For areas where the seabed changed direction, or if an indent in the bed (of more than 20 m) was found, points were plotted more frequently to accurately represent its shape. Patches of seagrass isolated from the main bed were only recorded if they were over 10 m in length. Channels and gaps within the bed were noted as well if the length/circumference was over 20 m. The data were analysed and plotted on the base camp programme and google maps where a line was created to connect the points.

McCormack's Bay

The mudflats within McCormack's Bay were inaccessible by walking due the extremely soft nature of the sediment and the possibility of sinking. The seagrass was mapped by walking around the edge of the Bay, recording the presence or absence of seagrass every 30 m, using the same GPS machine as was used in the main part of the estuary. All seagrass 10 m left and right of the 30 m point was recorded (Table 1). Where seagrass was present, the density of the seagrass from 1-4 (1 being sparse, 4 being very thick), and overall size of seagrass relative to the biggest patch in the estuary (1 being small, 5 being the largest patch found). Mapping took place in January 2016.

Photo 1. McCormacks Bay looking towards the causeway showing clumps of seagrass

Table 1. Sampling points used in McCormacks Bay survey

A	S43° 33.484' E172° 43.618'	**B**	S43° 33.470' E172° 43.630'	**C**	S43° 33.455' E172° 43.639'
D	S43° 33.453' E172° 43.681'	**E**	S43° 33.448' E172° 43.701'	**F**	S43° 33.447' E172° 43.723'
G	S43° 33.457' E172° 43.741'	**H**	S43° 33.428' E172° 43.805'	**I**	S43° 33.417' E172° 43.821'
J	S43° 33.407' E172° 43.843'	**K**	S43° 33.389' E172° 43.833'	**L**	S43° 33.388' E172° 43.811'
M	S43° 33.387' E172° 43.787'	**N**	S43° 33.385' E172° 43.764'	**O**	S43° 33.384' E172° 43.742'
P	S43° 33.382' E172° 43.720'	**Q**	S43° 33.380' E172° 43.699'	**R**	S43° 33.378' E172° 43.656'
S	S43° 33.376' E172° 43.633'	**T**	S43° 33.375' E172° 43.612'	**U**	S43° 33.374' E172° 43.591'
V	S43° 33.372' E172° 43.568'	**W**	S43° 33.371' E172° 43.546'	**X**	S43° 33.369' E172° 43.521'
Y	S43° 33.367' E172° 43.477'				

Results

The seagrass bed within the Avon Heathcote Estuary is visible from the surrounding road about two hours before and two hours after the predicted time of low tide. The GPS coordinates describe an irregular shaped bed with patches forming outside of the main bed (Figure 1).

Compared to Maclaren and Marsden's (2005) seagrass map, the seagrass bed has increased from 0.29 km^2 to about 0.40 km^2 in the south east region with about 0.12 km^2 of patchy seagrass in the north eastern area totalling at 0.52 km^2. The current seagrass bed has stretched as far north as the edge of the end of the wooden path off of Ebbtide St. and extended towards eastern margin of the estuary. The southern limit is close to Tern St

Figure 1. Seagrass bed in the Avon-Heathcote Estuary. Magenta coloured patch represents the main bed; the yellow represents the patchy seagrass area separated from the main bed.

In McCormacks Bay the largest grouping of seagrass was between A-B, I, K, L, and R-W. The densest patches of seagrass tended to be the smaller sized ones such as E, Q, and X and varied in location. Seagrass often occurred on higher level ground and was not present elsewhere in the Bay.

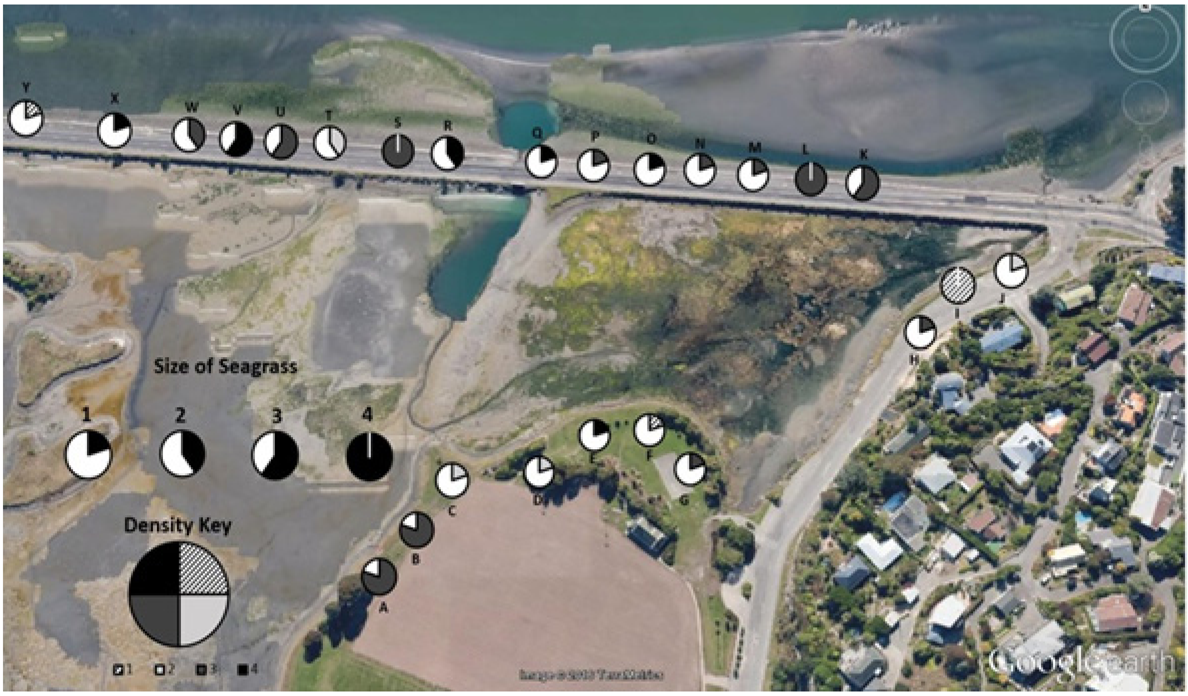

Figure 2. McCormacks Bay with pie charts showing sampling sites A-Y. The key shows the size of the patch size of the patch from1 (small) to 4 (large). Patch density is shown as sparse (diagonal lines), dense (light grey), thick (dark grey) and very thick (black).

Discussion

Compared to Maclaren and Marsden's (2005) map, the seagrass bed has expanded and stretched further east towards the estuary margin. It was common to see patches of sea lettuce between the seagrass bed and the edge, especially at the northern end. The seagrass has also moved further north since the 2003/4 mapping. It is speculated that the seagrass favours the northern part of the bed as the patchiness on the northern most end indicates new growth. This is also closer to where the rivers discharge. The absence of seagrass south of Tern St., where it used to cover in 2004 (Congdon and Marsden 2004), suggests that the southern region is no longer optimal for seagrass growth. As a personal observation, it was one of the first and last areas to be covered by the incoming tide. Overexposure to sunlight can cause harm to seagrass so it could be a potential factor as to the shift northward. Because of the lack of maps provided after 2005, it's difficult to say if the seagrass bed has been continuously growing or if it has fluctuating each year.

As seagrass mapping is a partly subjective exercise, the results of the present study   will not be perfectly comparable to Maclaren and Marsden's (2005) maps. A more thorough approach might include a combination of both aerial mapping and ground mapping to integrate two different perspectives (Alexander et al. 2008). Updated maps should be done annually to accurately follow the trend of the seagrass bed movement. Future research might look into potential factors for causing the seagrass to travel further north and east.

Seagrass patches in McCormack's Bay were scattered throughout the northern end in various sizes and densities. The largest connected patch sat on the north eastern side of the estuary near the drainage opening, and on the coast of the eastern side of the park. The densest patches were generally the smaller sized ones and found on raised surface sediment mounds. If transplantation of seagrass were to occur, the north eastern part of the estuary (labelled H-L on Fig. 2) might be the most suitable area because of the current large and sparse seagrass already successfully grown there and is slightly more raised than other surfaces around the Bay.

3. Estuary transects

Introduction

The small Avon-Heathcote Estuary/Ihutai is rich in biodiversity with a variety of plants, algae, invertebrates, fish and birds. The wetland endured over 100 years of industrial contamination from both the Avon and Heathcote rivers, treated and untreated sewage effluent (Robb 1988). Since 2011, there has been improved sewage treatment and the disposal of contaminants is more regulated. The estuary still gets a considerable amount of pollutants from runoff that enters both rivers from the northern and south eastern point (Owen 1992). As a result, there are a range of sediments and the distribution of organisms varies throughout the estuary.

Maclaren and Marsden (2005) created a series of transects along the east and west sides of the Avon-Heathcote Estuary to provide an overview of the benthic diversity and abundance. In this current study, the aim was to follow the same transacts and record presence and absence of chosen organisms and habitat type. The species of interest were *Ulva* spp., also known as sea lettuce, which acts as a nuisance opportunist algae and *Zostera muelleri,* also known as seagrass, which supports a range of benthic invertebrates. Presence or absence of snails was also recorded for *Amphibola crenata, Diloma subrostrata*, and *Micrelenchus tenebrosus* (Jones et al. 2005).

Methods

The coordinates, provided by Maclaren and Marsden (2005), represented the estuary edge with the consecutive numbers representing the distance from the coordinate point to the high, mid, and low tide mark. Using the Garmin 650t GPS system, the coordinates and points were located and using the map if the coordinates were unclear. At each location, observations were mde of the presence of seagrass, snails, sea lettuce, and anoxic sediment were recorded. It was determined if the sediment was anoxic by digging about 5-10 cm. If it was dominantly black/dark grey it was considered anoxic and anything lighter was considered not anoxic.

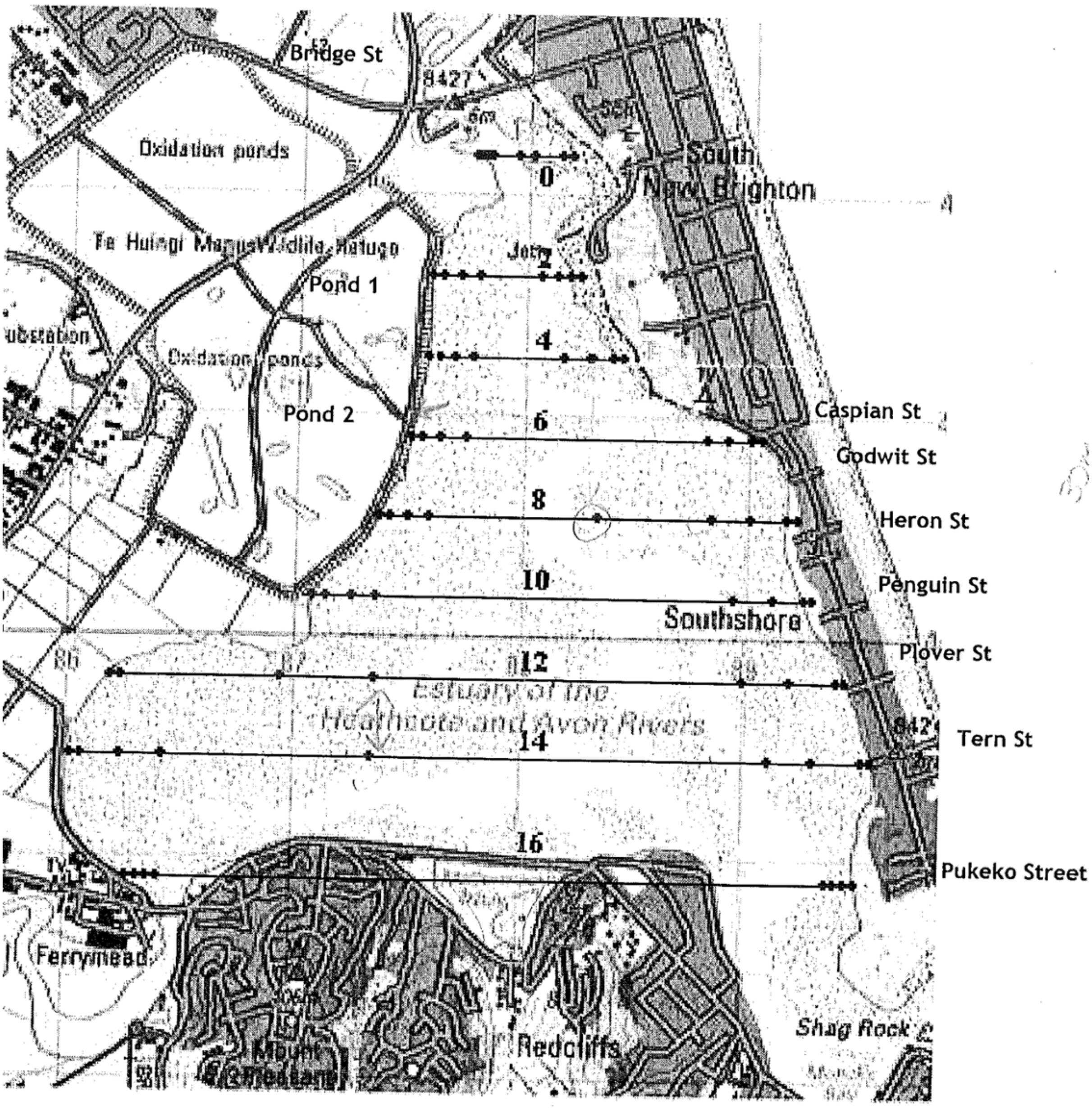

Figure 3. Map of transects followed in the Avon-Heathcote estuary (Maclaren & Marsden 2005).

Table 2. The GPS locations used for this project, inclusive of the distances (m) of the edge point to the three tidal levels. T represents the transect number and direction found on Figure 3.

T	Transect name	Estuary edge	High tide	Mid tide	Low tide
0W	Avon mouth	S43° 31.700, E172° 43.538	7m	31m	47m
E	Avon mouth	S43°31.611, E172°43.802	10m	216m	253m
2W	Oxidation Pond 1	S43° 31.964, E172° 43.344	10m	47m	119m
E	S. Brighton jetty	S43°31.952, E172°43.891	10m	101m	145m
4W	Outlet 1	S43° 32.173, E172° 43.325	10m	42m	98m
E	S. Brighton wetland	S43°32.173, E172°44.046	12m	115m	185m
6W	Outlet 2	S43° 32.335, E172° 43.289	10m	91m	149m
E	Capsian St.	S43°32.336, E172°44.437	20m	115m	185m
8W	Oxidation pond 2	S43° 32.538, E172° 43.179	12m	69m	11m
E	Heron St.	S43°32.532, E172°44.558	35m	156m	256m
10W	Sandy Point	S43° 32.736, E172° 42.971	10m	172m	361m
E	Penguin St.	S43°32.747, E172°44.624	40m	140m	236m
12W	Linwood Paddocks	S43° 32.925, E172° 42.310	10m	809m	1362m
E	Plover St.	S43°32.953, E172°44.753	30m	129m	280m
14W	Humphrey's Drive	S43° 33.090, E172° 42.193	10m	123m	280m
E	Tern St.	S43°33.136, E172°44.800	15m	192m	330m
16W	Heathcote mouth	S43° 33.470, E172° 42.469	10m	32m	49m
E	Estuary mouth	S43°33.448, E172°44.774	12m	165m	374m

Results
The main area of seagrass was found on the eastern part of the Estuary (Table 3).

Table 3. Presence (Y) or absence (N) of seagrass, anoxic sediment, snails, and sea lettuce on the A eastern and B western side of the estuary. Areas that were inaccessible are labelled as N/A.

		EAST		
Location A	**Seagrass**	**Anoxic**	**Snails**	**Sea Lettuce**
E East Mouth (16)	N	N	N	N
12 m	N	N	Y	N
165 m	N	N	N	N
364 m	N	N	N	N
E Tern St. (14)	N	N	N	N
15 m	N	N	N	N
192 m	Y	Y	Y	Y
330 m	N	N	N	Y
Plover St. (12)	N	N	Y	N
30 m	N	N	Y	N
129 m	Y	N	Y	Y
280 m	N	Y	Y	Y
Penguin St. (10)	N	N	Y	N
40 m	Y	Y	Y	N
140 m	Y	Y	Y	Y
236 m	N	Y	Y	N
Heron St. (8)	N	Y	N	Y
35 m	Y	Y	Y	Y
156 m	Y	Y	Y	Y
256 m	Y	Y	Y	Y
Capsian St. (6)	N	N	N	N
20 m	Y	Y	Y	Y
115 m	N	N	Y	N
185 m	N	Y	Y	Y
S Brighton Wetland (4)	N	N	N	N
12 m	N	Y	Y	Y
115 m	N	Y	Y	Y
185 m	N	Y	Y	Y
South Brighton Jetty (2)	N	N	N	Y
10 m	N	N	Y	Y
101 m	N	N	Y	Y
145 m	N	Y	Y	Y
Avon Mouth (0)	N	Y	Y	Y
10 m	N	Y	Y	Y
216 m	N	Y	Y	Y
253 m	N	Y	Y	Y

		WEST		
Location B	**Seagrass**	**Anoxic**	**Snails**	**Sea Lettuce**
Heathcote Mouth (16)	N	N	Y	N
10 m	N	N	Y	N
32 m	N	N	Y	N
49 m	N	N	Y	N
Humphrey's Drive (14)	N	N	Y	N
10 m	N	N	Y	N
123 m	N	N	Y	N
280 m	N	N	Y	N
Extra Point	N	N	Y	Y
Linwood Paddocks (12)	N	N	N	N
10 m	N	N	Y	N
809 m	N	N	Y	Y
1362 m	N	N	Y	Y
Sandy Point (10)	N	Y	N	N
10 m	N	Y	N	N
172 m	N	N	Y	N
361 m	N	N	Y	N
Oxidation Pond 2 (8)	N	N	N	N
12 m	N	N	Y	N
69 m	N	N	Y	N
111 m	N	Y	N	N
Outlet 2 (6)	N	N	Y	Y
10 m	N	N	Y	N
91 m	N	N	Y	N
149 m	N	Y	Y	N
Outlet 1 (4)	N	N	Y	Y
10 m	N	N	Y	Y
42 m	N	Y	Y	N
98 m	N	N/A	Y	N
Oxidation Pond 1 (2)	N	N	N	N
10 m	N	N	Y	N
47 m	N	N	Y	N
119 m	N	Y	Y	N
Avon Mouth (0)	N	N	N	Y
7 m	N	N	Y	Y
31 m	N	N/A	Y	N
47 m	N	N/A	Y	N

The seagrass beds were exclusively found on the eastern part of the Estuary between Tern St. and Caspian St. Seagrass was never found to occupy the high tide area but extended as far as the low tide mark out from Heron St. Every single transect included snails. *Amphibola crenata, Diloma substrata* and *Micrelenchus tenebrosus,* mostly at the mid and lower tidal levels. Sea lettuce was present in most of the eastern transects, with the exception of the southern end near the East Mouth. The western transects had the occasional sea lettuce at a variety of tide levels.

Anoxic sediment was sporadically found throughout the Estuary, but was more common on the eastern than the western site. Sediments from transects on the eastern side of the Avon Mouth, Penguin, and Heron St were all predominantly anoxic.

Discussion

The organisms and sediment type within the estuary differed with tidal level as well as with the distance from the Estuary mouth. The results from the present study are generally similar to those reported by Maclaren and Marsden (2005). Their study also found sea snails in almost every transect as well as sea lettuce residing at the high tide mark. The large dense 0.4-0.52 km^2 seagrass bed extended to the estuary edge of the mudflats on eastern side of the estuary. In the Avon-Heathcote Estuary, flowering shoots are rare. It is thought that recolonization is due to vegetative growth. Ramage and Schiel's (1998) found that flowering shoots were more likely to grow in the low intertidal zone than the upper areas. If the seagrass were to continue to expand, it's likely that it will stretch either further north or south and continue to border the edge with potential to be successful on the western side.

Snails were present throughout the estuary, and in some areas were very abundant and formed dense patches. The lack of snails at the high tide mark suggests that conditions were not optimal. Since the earthquake there has been increased deposition of coarse sediment at the higher tidal levels and this may not be suitable for snails which graze on microorganisms on the sediment surface. The results are consistent with other studies that have found snails on similar transects throughout the estuary (Marsden 1998; Maclaren & Marsden 2005).

Sea lettuce was found irregularly on the transects. Depending on temperature, nitrogen levels, and maximum availability of carbon, macro-algal blooms can range in biomass within a single year. Summer is the most ideal time for growth of sea lettuce due to the warm temperatures (Ren et al. 2014). A large portion of the eastern side of the estuary, especially the mid to southern end, had sea lettuce present. The western part of the estuary had the occasional sea lettuce but it could have appeared by drifting along from the abundant patches on the eastern side. The results collected in this report are representative of summer algal locations, but different locations and abundance are to be expected throughout the year.

Anoxic sediment mainly occurred on the eastern transects in the northern half of the estuary. This might be because of its close proximity to the Avon River Mouth which brings in contaminants from the City's storm water drains. More research into correlations between other physical variables and location of anoxic sediment would be beneficial.

The results from our study suggest that the majority of the seagrass, sea lettuce and anoxic sediment are found on the north eastern side of the estuary. Research of the flow direction of the rivers into the estuary might be beneficial in understanding where certain communities of organisms might inhabit.

One of the limitations of the present study was the inability to find certain transects according to the given coordinates from Maclaren and Marsden (2005). Locations that didn't match up were attempted using the road map and estimating the location with the GPS. Checking whether the sediment was anoxic or not was also objective as it was based on the darkness of the colour and might not be an accurate representation of whether it was truly considered anoxic or not.

4.Seagrass biomass

Introduction

The health of seagrass plants in the Avon-Heathcote Estuary/Ihutai was last measured in 2004 (Congdon & Marsden). Since then, the seagrass bed has shifted and changed over time especially due to the 2011 earthquakes which disrupted the established surface structure and resulted in excessive effluent inputs. Quantifying seagrass health can be based on a variety of characteristics such as weight and height of seagrass blades in randomly pre-selected areas. The size and presence of invertebrates can also assist in the understanding of the ecological values of the habitat.

This study compared seagrass biomass at different locations along the South Brighton spit. The methods for the study are based on unpublished previous research by Congdon and Marsden (2004). The study will also determine potential donor sites for transplanting healthy seagrass to other parts of the Estuary.

Methods

Six 30 m x 30 m sites were chosen along the seagrass bed. Three sites were 50 m from the seagrass edge to represent the high tide levels. Two were chosen 150 m and one 200 m from the edge of the seagrass bed to represent the mid and low tidal levels. The sites were placed in the northern, southern, and middle part of the seagrass bed (Figure 4). The Garmin Montana 650t was used to plot the sites as well as a navigation tool to find the coordinates of each location. At each site, a 30 m measuring tape was laid out parallel to the shore, starting from the corresponding coordinates from table 1 and running the tape south. By using excel to generate two random numbers (up to 30), six samples were taken per site and found by taking the first random number in meters on the measuring tape and walking the length in meters of the second number using the GPS system for accuracy.

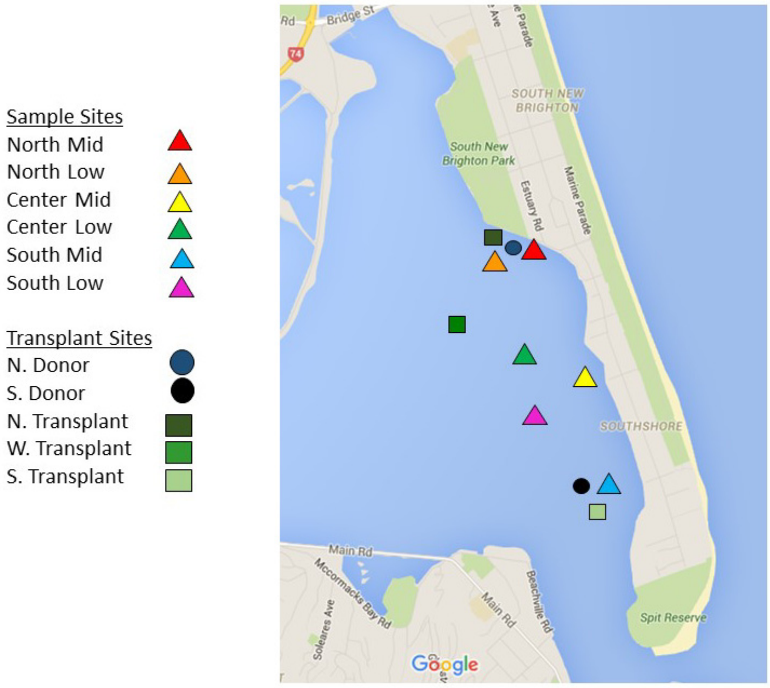

Figure 4. Map of locations where samples were collected and transplant donor and sites in the north (N) west (W) and southern (S) part of the seagrass bed.

For each sample, a 15 x 15cm plot was dug out, inclusive of all matter up to 10 cm depth, using a quadrat of equal size and a shovel with tape labelling the 10 cm depth line. Each sample was placed in a 2 mm sieve and washed out in nearby channels. All organisms retained by the mesh and organic matter were placed in a bag and evaluated in the lab.

After rewashing each sample in the lab through a 2 mm mesh sieve, the invertebrates, seagrass, sea lettuce (*Ulva*), organic matter, and empty seashells were separated. The sea snails and worms were identified and counted and empty seashells disposed of. The cockles were counted and measured from middle of the widest part of the shell, which is the top edge, to the smallest part of the shell, the bottom edge.

The seagrass and sea lettuce were carefully separated into containers to avoid breakage of the blades to their roots. Each root was counted for the number of shoots attached to it with disconnected seagrass blades each counting as one. 5 random blades were then selected to be measured to generate an average length for each sample, measuring from the start of part of the blade with the most consistent green colour to the tip of the blade.

The remaining organic matter, roots, seagrass, and sea lettuce were placed into small tins, weighed and put into an oven to dry at 60^{o} C for over a week. The samples were re-weighed to get their final dry weight. An ANOVA analysis was run to compare the average weight of seagrass, organic matter, roots, sea lettuce, shoot size and cockle size in relation to their location. A Poisson chi square test was used to determine significance of the total shoots and benthic invertebrates found in the various locations.

Photo 2. Equipment laid out in preparation for sample collections.

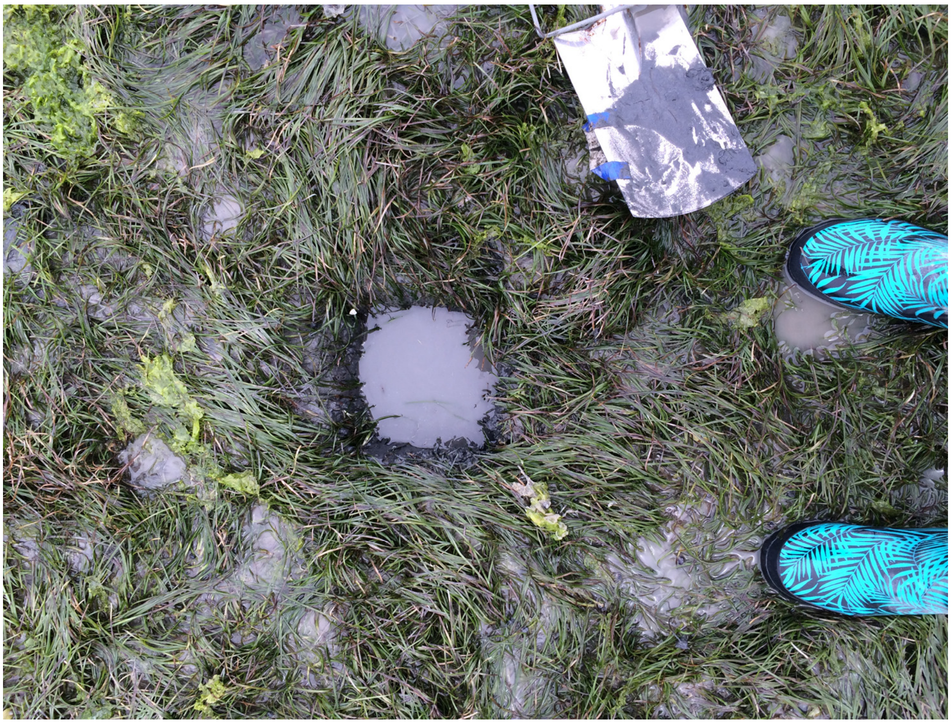

Photo 3. Hole left from retrieving the seagrass showing anoxic sediment.

Table 4. Coordinates of the first point for each 30m x 30m plot.

	North	Center	South
Low Tide	S43° 32.368' E172° 44.277'	S43° 32.635' E172° 44.397'	S43° 32.908' E172° 44.480'
Mid Tide	S43° 32.338' E172° 44.341'	S43° 32.749' E172° 44.547'	S43° 33.101' E172° 44.712'

Results

Weight Relationships

Seagrass and Organic matter

The highest seagrass biomass (>100g m^{-2}) was found in the mid tide level of the southern part of the seagrass bed close to Tern St (Figure 5). There were significant effects of location on seagrass biomass (F(2,3)=4.38, p=0.02). Weight of seagrass was dependent on location (F(2,30)=3.5, p=0.04) and interaction between location and tidal zone (F(2,30)=22.4, p<0.05). Biomass values were consistently lower for low tide from the north and south sites, and the centre mid tide. As noted in the mapping project, the northern part was very patchy and appeared to be expanding in that direction.

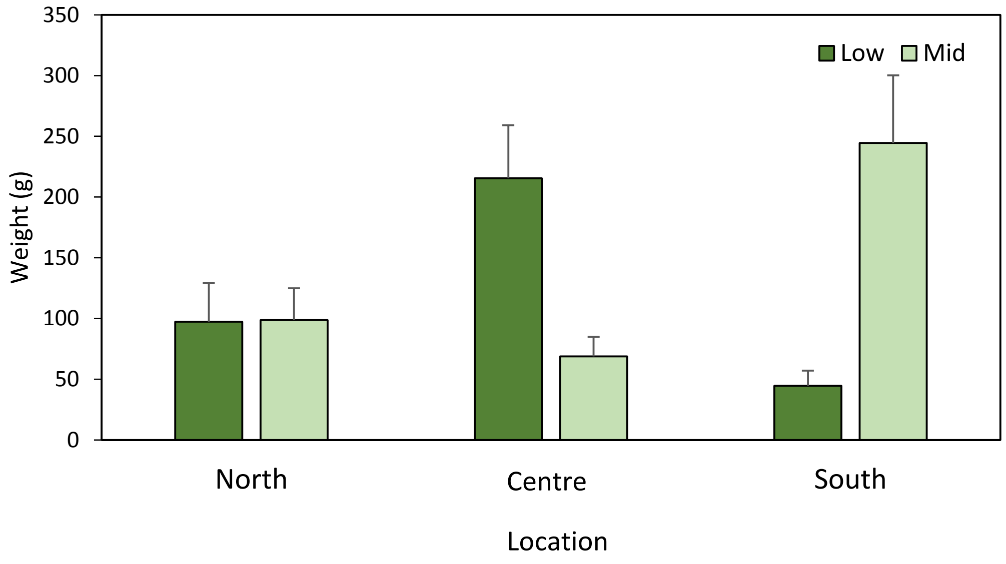

Figure 5. Average dry weight (g) of seagrass m^{-2} (± SE) at mid and low tide locations along the eastern part of the Estuary.

The average dry weight of organic matter was highly variable ranging from 100-300g m^{-2} (Figure 6). The highest values were recorded at the mid tide level in the southern part of the seagrass bed. There were significant differences depending on location and tidal level (F(2,30)=12.77,p<0.05

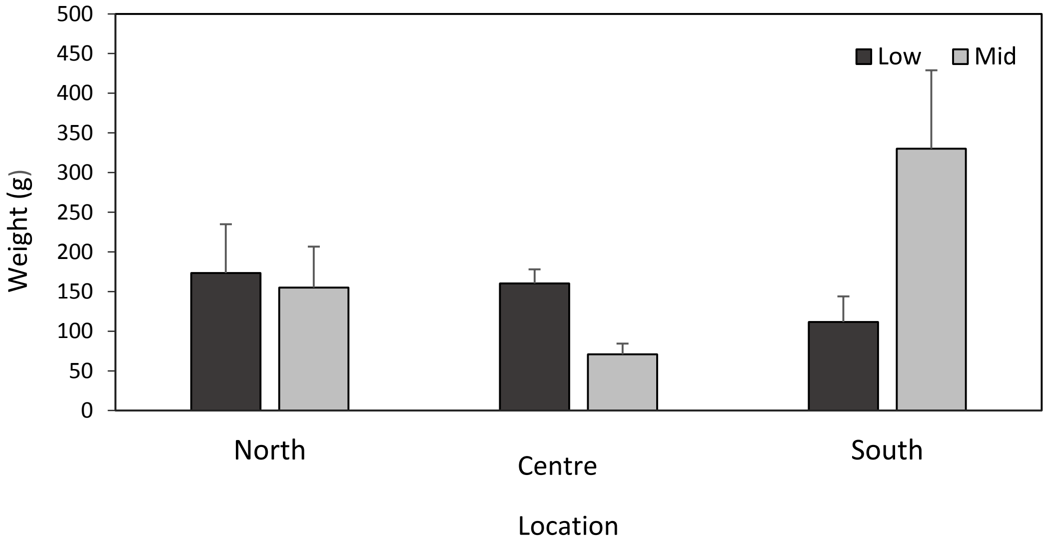

Figure 6. Average weight of organic matter m^{-2} (± SE) found from the various parts of the seagrass bed at the low and mid tide level.

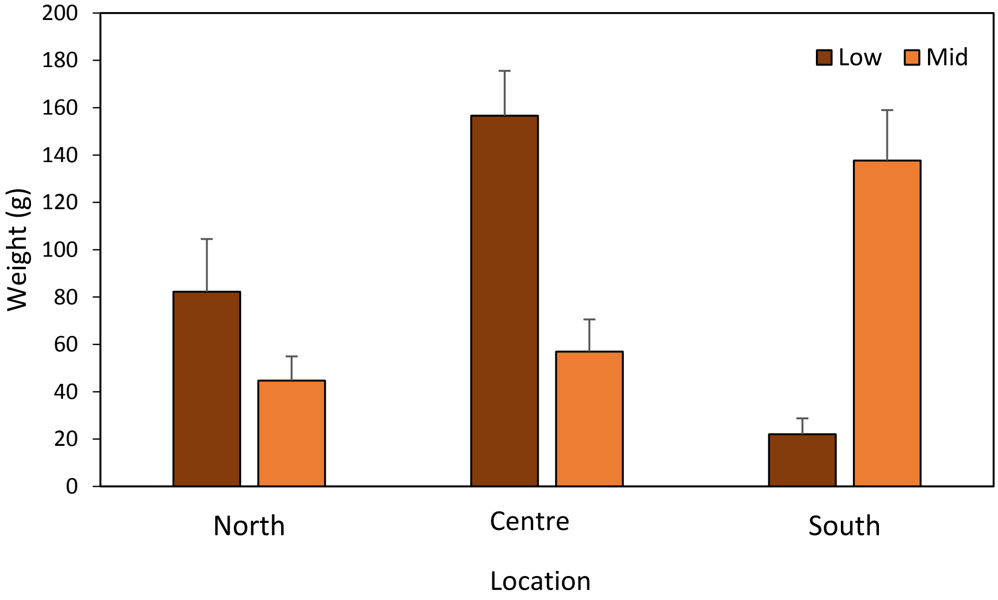

Figure 7. Average dry weight of collected roots m^{-2} (± SE) at different locations along the seagrass location in the seagrass bed.

Highest root biomass values (>140g m^2) were found in the centre section of the seagrass bed at the low tide area and also in the southern part at the mid tide level (Figure 7). Root biomass was dependent on both location and tidal level (F(2,30)=22.4, $p<0.05$).

Sea Lettuce Biomass

Sea lettuce *Ulva* sp. was mostly found on the north and southern area within the seagrass bed at the mid tide level (Figure 8). Only few sites had *Ulva* present, but, where it was found, it was in mats that had been pushed past the seagrass bed towards the estuary margin where it piled up and was slowly rotting, potentially smothering organisms underneath it.

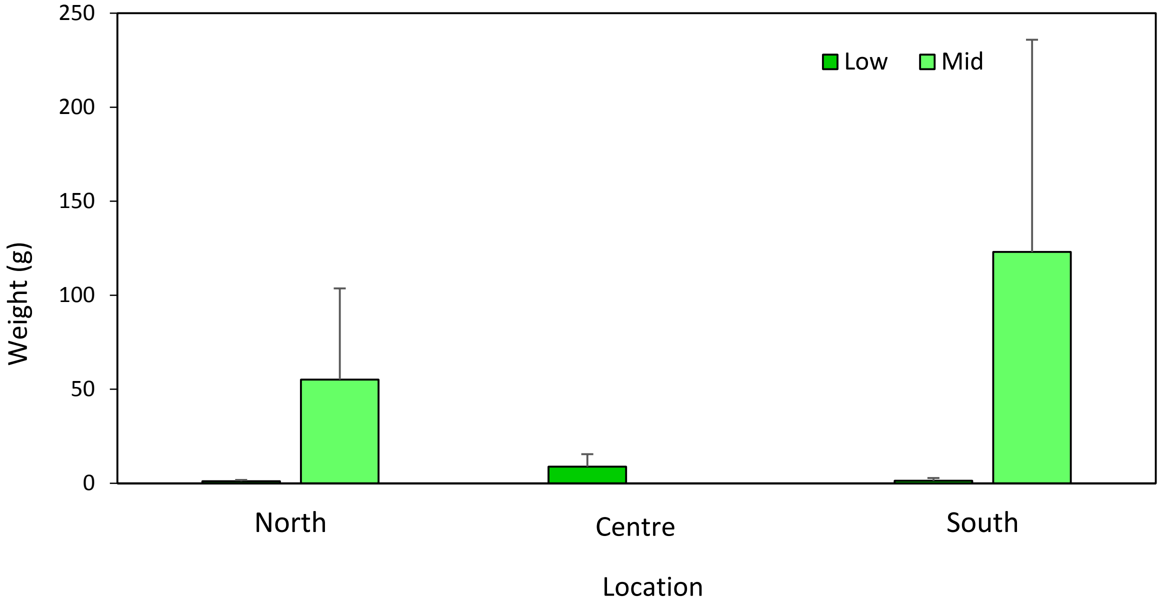

Figure 8. Average dry weight of sea lettuce m^{-2} (± SE) from the low and mid shore line from three locations within the seagrass bed.

Seagrass Parameters

Shoot length was greatest (close to 100 mm) in the southern part of the seagrass bed at the mid tide level (Figure 9). Shoot length was dependent on tidal level (F(1,30)=4.78, p=0.04) but the length was fairly consistent (60mm) for all of the low tide sites.

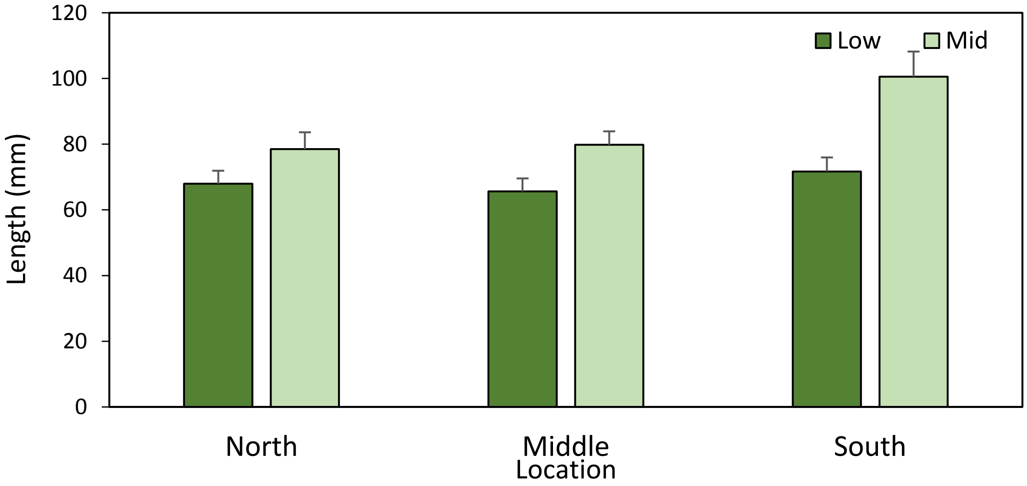

Figure 9. The average length (mm) of shoots (± SE) from the various sample locations along the low and mid shoreline.

Shoot density varied throughout the seagrass bed. Density was dependent on location and tidal level (F(2,30)=10.85, p<0.05) and was thicker in the centre and northern part of the seagrass bed at the low tidal zone (Figure 10).

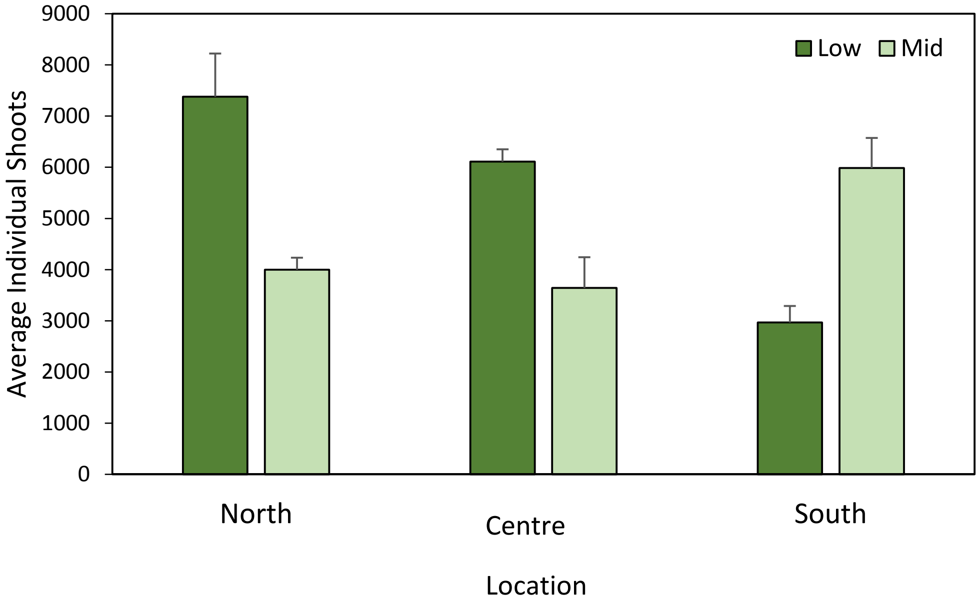

Figure 10. Average number of seagrass shoots m^{-2} (± SE) among the samples found at the three parts of the seagrass bed along the low and mid shoreline.

Macrofaunal abundance and size

Cockles were present in all seagrass samples but were not as evident in the northern part of the estuary. They were more abundant further south in of the seagrass bed; especially in the mid tide. Abundance of cockles was dependent on location (F(2,30)=3.3, $p<0.05$) (Figure 11).

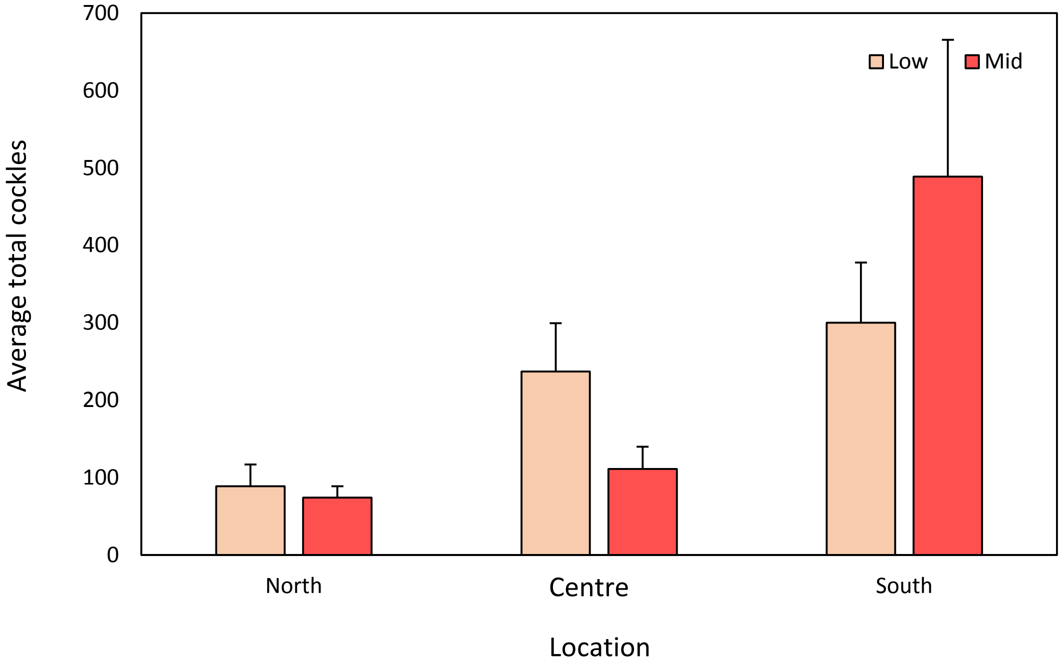

Figure 11. Average of cockles m^2 found (± SE) within the three regions of the seagrass bed on the low and mid shore line

The largest cockles (*Austrovenus stutchburyi)* were also found in the middle part of the bed on the low tide line and southern part of the mid tide line (Figure 12). Cockle length was dependent on both the location and tidal level (F(2,30)=8.43, $p<0.05$).

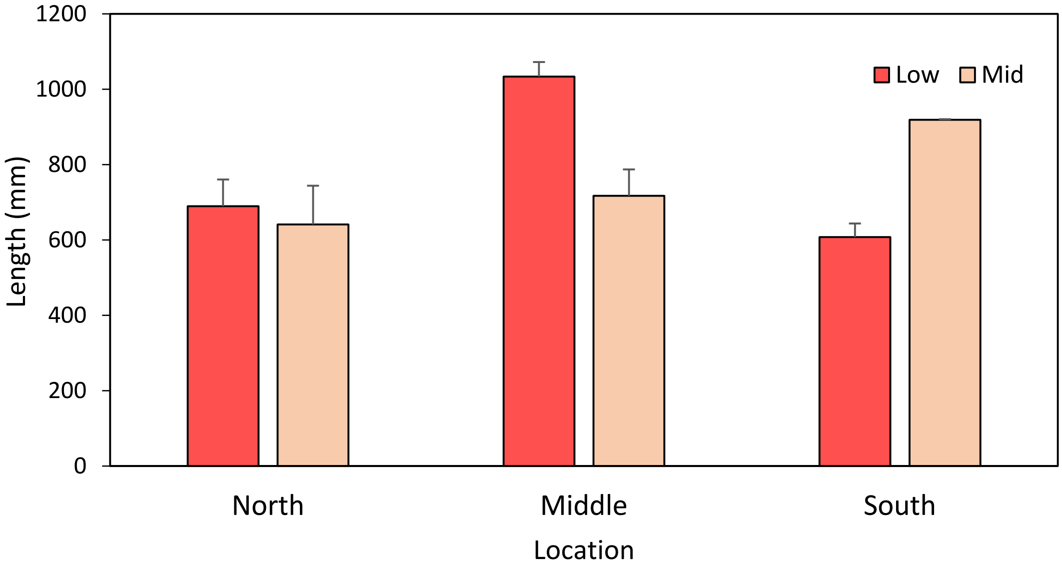

Figure 12. Average length of cockles (± SE) found within the three regions of the seagrass bed on the low and mid shore line.

Other invertebrates were *Micrelenchus tenebrosus, Diloma* sp., *A crenata* and the polychaete *Nicon* sp. (Figure 13). *M. tenebrosus* was mostly found in the mid tide seagrass and *Nicon*. was mostly found on the northern low tidal seagrass bed.

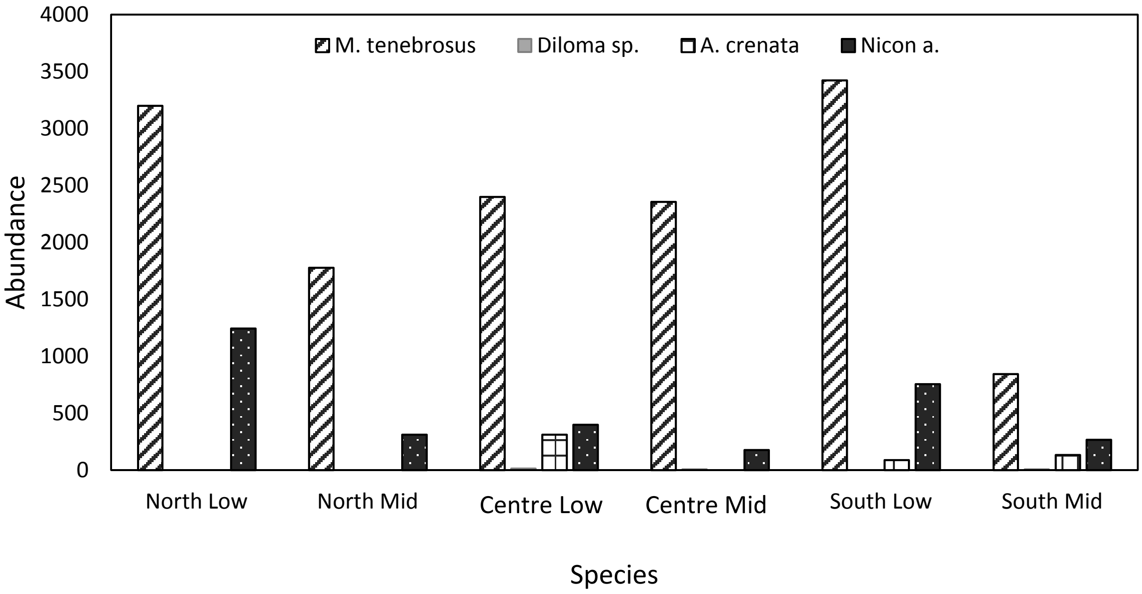

Figure 13. Total number of various invertebrates recorded at the six sample sites within in the north, middle, and southern part of the seagrass bed at low and mid tide

Discussion

Seagrass biomass was greatest in the centre region at the low tide mark and southern mid tidal zone of the seagrass bed. Roots were found in a similar pattern to the seagrass. Organic matter was also similar to seagrass results with most of the biomass found in the southern mid tide zone of the estuary. This was expected because areas that have more seagrass may have organic matter biomass deposited from older dead seagrass that lived there formerly. Sea lettuce biomass was greatest in the southern area on the mid tide shore. Because the sea lettuce is not attached it has the potential to drift anywhere and can shift from day to day. It was especially abundant in the southern part of the bed at the mid tide mark. This most likely indicates favourable environmental factors for deposition.

The average number of individual shoots is consistent with the average weight of seagrass (Figure 10). It is also similar to the organic matter and root biomass, suggesting there is healthy seagrass production within these areas. The cockle results parallel the seagrass biomass suggesting that the larger cockles were associated with higher seagrass biomass. Benthic invertebrates varied with location but were present in majority of the samples.

Our results (Table 4) are comparable to those of Congdon and Marsden (2004). In the present study blade density was reduced by 63% compared to 2004 values. Biomass of seagrass and roots also decreased by about 36% from the previous report. The weight range of seagrass and roots from various sites was similarly variable in both years. Seagrass are highly sensitive to light limitation caused by sediment burial, eutrophication or overgrowth by macroalgae (Borsje et al. 2011). It is also possible that the seagrass has not recovered completely from the 2011 earthquake disturbances.

Table 4. Comparison of blade density in this study with Congdon and Marsden (2004). Also shown are the average weight and range of seagrass and roots, and range of seagrass and root weight.

Variable	2004	2016
Blade Density m^{-2}	13,719	5,014
Seagrass & Roots Weight (g) m^{-2}	329.42	211.6
Seagrass &Roots Weight Range (g) m^{-2}	100-600	50-400

One of the main limitations of the study was the lack of replication of plots within each location and tide zone. Another obstacle was ensuring that all material was maintained when sieving muddy samples to properly separate organisms. Overall, this study should act as a guideline of the amount of seagrass that would be found around the given coordinates. The seagrass densities did vary throughout the bed as a personal observation. Future studies should look into having more 30 x 30 m plots within each zone to have a more accurate representation of the bed.

5. Transplant Experiment

Introduction

Anthropogenic activities have had a negative impact on seagrass meadows worldwide (Duarte 2010). Coastal ecosystems are particularly sensitive to anthropogenic effects because of the direct contact it has from rivers and runoff (Ehlers et al. 2008). These wastes are a result of dredging, reclamation, increase in sediment load, eutrophication, and pollution. It has had detrimental effects on seagrass and has sparked interest for coastal protection to minimize the impacts (Borsje et al. 2011). One of the biggest threats responsible for the decline of seagrass is due to excessive inputs of nutrients from eutrophication which results from coastal runoff, treated sewage disposal, and waterways used to clean machinery. While seagrass is fairly tolerable of nutrient fluctuations, it can be disadvantaged from ammonium toxicity and water-column nitrate inhibition through internal carbon limitation (Kilminster 2006).

Although the direct effects from pollution have the potential to be harmful to seagrass, indirect effects including macroalgae eutrophication are common in shallow water (Burkholder et al. 2007). Macroalgal blooms thrive in nutrient rich environments and can smother seagrass, preventing absorption of much needed sunlight (Hessing-Lewis 2015). Macroalgal presence can also hinder recruitment rate of seagrass as well as reduce growth (Hauxwell et al. 2001). In the Avon Heathcote Estuary, drift macroalgae is common at certain times of the year and may be a significant threat to seagrass in McCormacks Bay.

Seagrass transplants have been suggested as a useful mechanism for restoring lost seagrass habitats but they have not always been successful (Marsden 2015). Potentially transplants could increase genetic diversity which could assist survival associated with stressful conditions from anthropogenic activities (Reusch et al. 2005). There have been few seagrass transplant studies in New Zealand with the first trial of seagrass occurring in Manuka Harbour about 25 years ago (Turner 1995). The present research includes a trial transplant of seagrass within the Avon-Heathcote Estuary/Ihutai. Transplants were moved into bare areas within the northern, western, and southern part of the seagrass beds. Results from this study will be useful for planned transplants into other parts of the estuary where seagrass has occurred in the past.

Methods

A series of transplants were carried out January 26, 2016. Two donor sites were chosen at the most northern and southern part of the seagrass bed, 50 m from the edge. Using peg sticks and a measuring tape, the two 30 x 30 m plots were created by running a line parallel to the shore and one perpendicular in towards the shore. Both were put in areas that had over 90% seagrass coverage. A 25 x 25 cm quadrat was randomly thrown around the plot 6 times with a picture taken each time it landed. The photos were analysed to record the percentage cover.

Ten 15 x 15 cm quadrats within the northern plot and five in the southern plot were dug out to a 10 cm depth using a shovel and quadrat. Each chosen plot had 100% cover of seagrass. 5 patches, from the northern donor site, of dug out seagrass were transplanted to a clear area further north and 5 further west of the seagrass bed. 5 from the southern donor site were moved further south of the bed in another bare section.

A 10 x 10 m plot was laid out at each of the bare sediment sites with a 5 x 5 m plot in the middle. On each corner and in the middle of the 5 x 5m plot a 15 x 15cm square section was dug out. Each seagrass patch was carefully placed into each hole and patted on the sides to avoid spaces between the mud and transplanted seagrass (Figure 15). GPS location was recorded for each plot. Our plan was to check the survival of the transplants after 4 weeks and then every three months. Photos will be taken at each site with a 25 x 25 cm quadrat and analysed using percentage cover. In January 2017, the photos will be compared to determine which transplants maintained the most seagrass and in which location the most (if any) growth occurred.

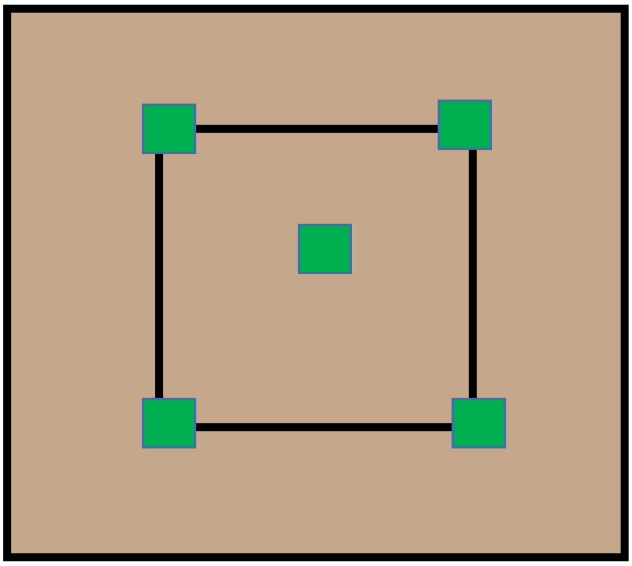

Figure 14. Experimental design of 10m x 10m plot showing the location of transplanted seagrass as green squares.

Table 5. Coordinates of three corners of the 30 x 30 m donor site.

30 x 30 m plot	Corner 1	Corner 2	Corner 3
Northern Plot	S43° 32.321' E172° 44.276'	S43° 32.308' E172° 44.289'	S43° 32.330' E172° 44.294'
Southern Plot	S43° 33.111' E172° 44.728'	S43° 33.125' E172° 44.738'	S43° 33.120' E172° 44.759'

Table 6. Coordinates of 10m x 10 m cleared area outside of the seagrass bed.

10 x 10 m Plot	1	2	3	4
North	S43° 32.311' E172° 44.228'	S43° 32.314' E172° 44.234'	S43° 32.319' E172° 44.230'	S43° 32.315' E172° 44.223'
West	S43° 32.468' E172° 44.258'	S43° 32.472' E172° 44.262'	S43° 32.474' E172° 44.256'	S43° 32.469' E172° 44.251'
South	S43° 33.194' E172° 44.771'	S43° 33.200' E172° 44.772'	S43° 33.201' E172° 44.766'	S43° 33.196' E172° 44.764'

Table 7. Coordinates of transplanted seagrass sites within the 5m x 5m square.

5 x 5 m Plot	**A**	**B**	**C**	**D**	**E**
North	S43° 32.312' E172° 44.227'	S43° 32.314' E172° 44.231'	S43° 32.316' E172° 44.230'	S43° 32.315' E172° 44.225'	S43° 32.315' E172° 44.229'
West	S43° 32.470' E172° 44.258'	S43° 32.471' E172° 44.259'	S43° 32.472' E172° 44.257'	S43° 32.470' E172° 44.255'	S43° 32.471' E172° 44.257'
South	S43° 33.195' E172° 44.769'	S43° 33.198' E172° 44.770'	S43° 33.200' E172° 44.766'	S43° 33.197' E172° 44.766'	S43° 33.198' E172° 44.768'

Photo 4. Sled used to relocate seagrass transplants.

Photo 5. Picture of the northern transplants prior to planting in bare area (patches of sea lettuce are also shown in the photo).

Photo 6. Seagrass transplanted into the estuary floor.

Results

Transplants were visited after a few weeks to determine their success. Thus far, two observations have been made one closely after being transplanted, and another 3 few months afterwards.

The transplant plots were visited on 9 February 2016, which was 14 days after they had been planted. At this time there had been low tides and rain which meant that the sediment was too soft to walk safely to access the northern site. Plants within the plot in the southern and northern sites had all survived but those in the southern site appeared bleached.

Photo 7. Northern transplant sites taken on 19th February 2016 and marked with metal stakes.

On 14th February a magnitude 5 earthquake hit Chrstchurch, once again disrupting the estuarine sediments. The effects were seen as disruption lines across the estuary and these were more pronounced in the northern parts of the estuary.

Photo 8. One of the transplanted plots taken 24 days after planting**.**

Revisiting the northern sites on the 19th February (Photos 7 and 8), the transplants were easily found but individual plants were looking brown and appeared to be trapping *Ulva* spp. At the southern site (Photo 9, 10 and 11) on 19th February there were occasional sand volcanoes in the seagrass bed , but the majority of the seagrass appeared healthy .

Photo 9. The southern transplant site showing the 5 plots, taken on 19th February 2016

Photo 10. Southern part of the seagrass bed showing disturbances resulting from 14th of February earthquake

Photo 11. Southern transplant plots taken on 19th February, 24 days after planting.

The sediment adjacent to the transplants appeared continuous with the mudflat surface but the individual plants from the southern transplant had lost colour. The bleaching which occurred here was greater than was observed in the northern plots.

Three months after planting all the transplant sites were revisited on May 26. at the southern transplant sites, all five seagrass patches were found. Each of the transplants in the southern area were bleached and dead. This suggests that the sun exposure on the southern area may be too intense. All but one transplant in the western site had washed away. The seagrass on the transplant was minimal and had an average blade height of 11 cm. The blades were mostly green and had little brown tips (Photo 12).

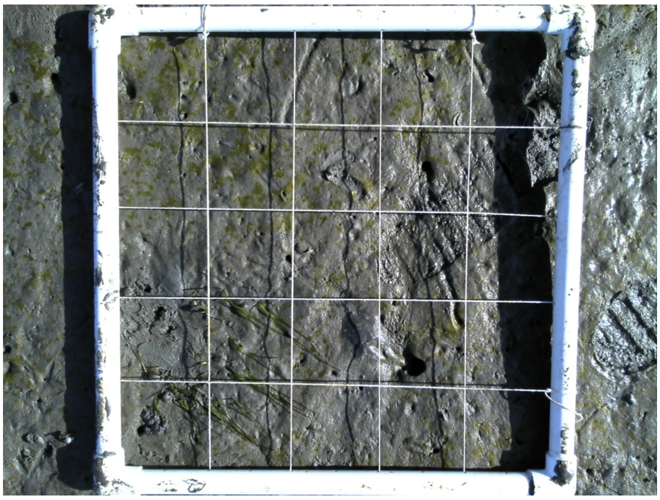

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Photo 12. Seagrass transplant in the western site.

The northern transplants had the most success compared to the western and southern sites. Three of the plots had seagrass, while the other two were smothered in *Ulva spp.* Average blade height ranged from 10.3-10.5 cm (Photo 13).

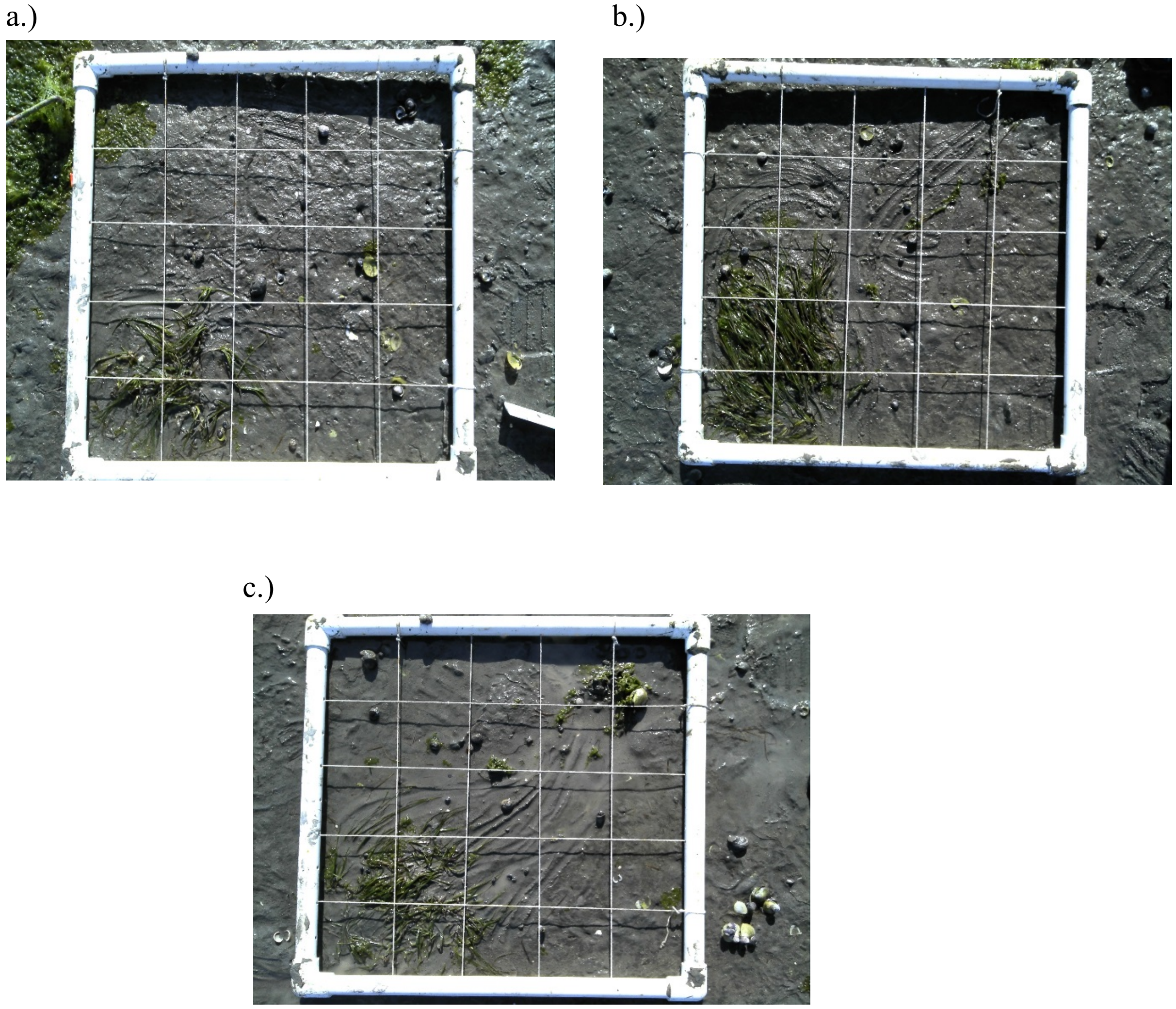

Photo 13 Three **s**eagrass transplants a), b) and c) in the northern site.

Discussion

This research is the first study to explore the potential of using transplanted seagrass plots for restoration of seagrass in the Avon-Heathcote Estuary/Ihutai. Our results indicate that the most successful transplant location is past the northern part of the existing seagrass bed within the estuary. The two transplants that did not survive in the northern site were smothered in *Ulva spp*. This suggests that although the northern locations may be suitable for successful transplanting, macroalgae may pose a threat to their survival. The western transplants were washed away with one plot remaining after 3 months. This indicates that there may be potential for seagrass restoration in the western area but conditions may not be optimal. Seagrass has previously been lost from areas close to the river channels during storms, flooding and erosion. The seagrass transplant that did survive looked relatively healthy suggesting that the transplant techniques could be successful.. After three months the southern transplants were completely bleached out. The southern end of the seagrass bed is extremely exposed and most likely had excess sun exposure, resulting in seagrass mortality. It would be useful to determine the different environmental factors between the north and the south part of the seagrass bed to ensure that future transplanting locations are more suitable.

Meadows of seagrass worldwide provide important functions for surrounding ecosystems, extending as far as the deep ocean. Natural and anthropogenic direct and indirect effects have led to an almost global decline in seagrass (Spalding et al. 2003). Since 1980, populations have dropped by about 29%. It is estimated that on average about 7% of seagrass meadows disappear annually which will increase if changes are not made (Waycott et al. 2009). This global crisis can be attributed to numerous anthropogenic and natural factors. This highlights the importance of finding effective methods of transplanting seagrass to aid in their dispersal and population size. Previous studies have suggested that the failure of transplants can be largely attributed to unknown environmental conditions prior to translocation of the seagrass (Matheson 2009). In Canterbury there are known disturbances which result from earthquake activity and these cannot be predicted. However, stressors from anthropogenic activities, such as eutrophication and pollutant output, are more easily predicted and can be managed appropriately to encourage transplant success. Transplanting of seagrass experiments may need to rely on trial and error to determine which location and environmental type is most suitable.

6. Conclusions and Recommendations

The present study reports on the current status of the seagrass in the Avon-Heathcote Estuary/Ihutai providing some information on how seagrass habitats may have changed as a result of seismic activity post 2011. The information presented here can be used for future monitoring and as a guide for those interested in restoration of seagrass habitats.

Since 2003 the seagrass bed on the southeastern side of the Estuary has expanded (Congdon and Marsden 2004, Maclaren and Marsden 2005). There are a number of reasons why seagrass beds enlarge but mostly these are due to improved water quality and/or drainage. The establishment of the ocean pipeline markedly improved water quality in the Estuary (Bolton-Ritchie, 2012) but seismic activity disrupted the recovery with direct inputs of untreated sewage. Both improved water quality and increased drainage due to the input of coarse sediment most likely explain the expansion of the seagrasss bed.

Seagrass expansion occurs due to spreading of vegetative parts or by seed production from adjacent habitats. Both mechanisms are possible and we have observed germinating seedlings on cockles in the intertidal. Over the past few years, seagrass has been recorded from McCormacks Bay, a location where seagrass had not previously been recorded since the 1950s. This natural recolonization has been recorded in the present study but detailed mapping was not possible. The presence and expansion of these patches could be an important indicator of the improved condition of McCormacks Bay following earthquake changes in elevation and improved drainage as a result of deepening the channels leading into the Estuary. McCormacks bay is therefore confirmed as a suitable site for future seagrass transplants.

One of the recommendations from this report is undertake yearly monitoring of the extent of seagrass bed in the Estuary and its presence in McCormacks Bay. More detailed monitoring could be undertaken in specific areas of the main seagrass to measure the natural variation. From this report it appears that although the seagrass area has expanded the seagrass biomass may be reduced in some locations compared with 2003. Recently we have seen large expanses of sea lettuce stranded on the seagrass beds and this could reduce seagrass growth. The associations between the macroalgae and seagrass is likely to be complex and in the future it is hoped that sea lettuce will be reduced in the Estuary as a result of improved water quality.

Photo 12. Taken on 19th February 2016 showing sea lettuce stranded on the seagrass beds

The regular assessment of seagrass biomass can be an important tool for use in managing the Estuary. We have experimented with aerial surveys undertaken using a small plane but recently drones with cameras attached have been used effectively to map vegetation and habitat types. Once we have information on the natural patterns of seagrass growth then we can use seagrass as an indicator of anthropogenic and natural change.

This study has found that the techniques used to transfer sods of mature seagrass are worth exploring further. The places where the sods had been removed from the donor areas quickly recovered and were not detectable after 3 months. Our transplants were done in January, later than we had initially intended. In the future we recommend that transplants be established in the spring, for example November once seagrass growth has resumed. This would allow more favourable monitoring conditions over the summer period.

From this study, it is suggested that if transplants were considered for McCormacks Bay from the Avon-Heathcote seagrass bed, it would best to select donor sites which are:

a) Within the magenta coloured area as shown in Figure. 1
b) From areas that have high biomass in seagrass and roots
c) Areas that have longer blades of seagrass

Finally, educating the public on the importance of seagrasss beds and issues of run off and pesticides should be considered to help promote a healthier estuary. Pollutants and wastes from the rivers have a huge impact on the estuary, and the health of the seagrass will be largely dependent on how contaminants are minimised. By improving water quality we can help protect special species which is crucial to many other organisms and contributes greatly to the unique ecology of the Avon-Heathcote/Ihutai Estuary.

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