Seagrass *Zostera novazelandica* in the Avon-Heathcote Estuary

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Summary

1. There have been changes in the abundance and location of seagrass *Zostera novazelandica* in the Avon-Heathcote Estuary between 1951 and 2002. From the start of the period, and up to 1996 there was little seagrass, and fluctuating values covering less than 0.04 km^2 . The seagrass increased from 1972 (0.15 km^2) to reach its highest value in 1975 (1 km^2). Between 1981 and 2002 the average value in surveys has ranged between 0.58 km^2 and a minimum of 0.17 km^2 in 2002.

2. Estuary surveys conducted between December 2003 and January 2004 recorded one major area of seagrass along the eastern edge (Spit side) of the Avon-Heathcote Estuary. This area, which is close to Heron Street in the north splits into two at about Penguin street and extends south to approximately Pukeko Street. The total area was estimated as 0.29km^2, which is about 4.2% of the total estuarine area.

3. Typical estuarine communities were found throughout the estuary. Seagrass was recorded in only 10% of the quadrats sampled. Sea lettuce (*Ulva lactuca*) and *Gracilaria chilensis* were recorded more often in intertidal transects than seagrass. The dominant estuarine fauna included cockles (*Austrovenus stutchbyri*), mudflat snails (*Amphibola crenata* and *Diloma subrostrata*), the whelk (*Cominella glandiformis*) and crabs (*Helice crassa* and *Hemigrapsus crenulatus*).

4. The percent cover, density (blades m^{-2}), and dry weight biomass (g. m^{-2}) was estimated for 5 sites along the main seagrass area in The Avon-Heathcote Estuary. The plants appeared healthy but there were no reproductive structures present. The average blade density ranged between 10,000 and 18,000 m^{-2}

(combined average = 13,719 m^{-2}) and average dry weight biomass was between 100 and 600 $g.m^{-2}$ (combined average = 329 m^{-2}). There was no significant difference in either density or biomass estimates between sites.

5. Seagrass populations were sampled at Duvauchelle (4 sites) and Kaikoura (4 Sites) to compare with those within the Avon-Heathcote Estuary. There was significant between-site variation at these localities and there were reproductive structures observed. Biomass estimates for Duvauchelle were between 100 and 200 g. m^{-2} and for Kaikoura between 900 and 1,700 g. m^{-2} . Average blade densitiy for Duvauchelle was 11,830 m^{-2} and for Kaikoura 20,622 m^{-2}).

6. It was concluded that seagrass population density and dry weight biomass in the Avon-Heathcote Estuary are within the range given for other seagrass beds wordwide (global seagrass biomass estimate = 205g m^{-2}). *Zostera* populations in the Avon-heathcote Estuary were more similar to those at Duvauchelle than Kaikoura.

7. Seagrass habitat within the Avon-Heathcote Estuary currently comprise approximately 4% of the total estuarine area. There is historic and current evidence showing that the patches are unstable and there are short and long term changes. There is an urgent need for accurate determination of the location of the current patches and the establishment of marked areas for long term monitoring.

8. It is recommended that the seagrass areas be resurveyed before any of the construction work on the ocean pipeline is started and that the seagrass be monitored regularly following the removal of waste water effluent from the Estuary.

1. Introduction

Seagrass, or eelgrass, is the common name given to any vascular plant that is able to grow whilst being fully submerged in seawater; they do not have a common origin, but their unique life history has led botanists to group them together. There are approximately 60 species of seagrasses (Inglis 2003), including tropical and temperate species. Water temperature has been found to be an important determinant of species distribution; salinity, irradiance, water depth, substratum and exposure are also important (Phillips & Menez 1988). Recent estimates place the total area covered by seagrasses at approximately 200,000 km^2, but not more than 500,000 km^2 (Spalding et al. 2003). Seagrass ecosystems are some of the most highly productive in the world, supporting a wide range of epiphytes, benthic invertebrates, bacteria, detritivores and even vertebrates, which is usually more diverse and supports greater numbers of individuals than the non-vegetated areas in the same region.

Seagrasses are generally limited to the mid to low tidal zone because of their light requirements and low tolerance of exposure. However, in areas with a high degree of water clarity, as is often the case in tropical areas, they can reach depths of more than 60 m. Some genera and species are restricted to temperate zones, such as the genus *Zostera* (Ramage 1997), and others to tropical or subtropical zones. Temperate seagrass populations fluctuate on a seasonal basis and many are unstable and therefore at risk of extinction in parts of its distribution (Ball 1997).

In New Zealand, there is only one species of seagrass: *Zostera novazelandica*. This species is restricted to the intertidal and is endemic to New Zealand, however, it has been suggested by some that it is conspecific with *Zostera capricorni*, a seagrass species from the east coast of Australia (Inglis 2003). Inglis (2003) reported that, in 1999, the area of *Zostera novazelandica* in the Estuary was estimated to be 0.137 km^2. This is considerably less that the amount observed by Christchurch’s settlers before 1900 (Deely 1992).

Seagrasses have a considerable effect on estuarine and coastal systems here and throughout the world. As the only marine plants with roots and rhizomes, they play a vital role in stabilising sediment (Spalding et al. 2003). They increase sedimentation rates, concentrate nutrients, add detritus, filter water, provide a habitat and nursery for fish and invertebrate species and store carbon (Inglis 2003), which can be seen as a major role in a world where global warming is one of the biggest issues. Seagrasses can also ameliorate some of the problems of nutrient loading by aiding the cycling of nutrients and removing them from the water column and have been found to concentrate heavy metals in their leaves, without any apparent affect on their growth (Kirkman 1997). Orth and Moore (1983) noted that wading birds had declined in Chesapeake Bay as a result of reduced areas of seagrass.

Seagrasses are undergoing what appears to be an almost global decline (Spalding et al 2003). For example, the decline of seagrasses in Cockburn Sound, Western Australia, has been well-documented, along with probable causes, such as harbour construction and the discharge of industrial wastes into the Sound. In 1919, seagrass was estimated to cover 150 km^2 of the western Wadden Sea but this had dropped to 5 km^2 by 1971 (Spalding et al. 2003).

There are many threats to the survival of seagrass patches worldwide, both natural and anthropogenic. Natural threats include cyclones and floods that can remove areas of seagrass, reduce water clarity and remove sediment or deposit it over the seagrass, resulting in erosion or smothering of the seagrass beds. These can cause considerable damage. In 1985, Cyclone Sandy “removed, undermined or smothered 70% of seagrass cover” in the Gulf of Carpentaria, in northern Australia, and by 1986 the entire seagrass bed, made up of various species, including *Halodule uninervis*, had disappeared. This area took approximately 10 years to recover (Kirkman 1997). Global warming could also impact on seagrass communities, as predicted consequences of increasing global air temperatures include increased storm activity and increasing water temperature. Combinations of natural and human disturbance can cause the loss of whole patches; for example, after dredging to make channels for container ships in Botany Bay, east Australia, the seagrass bed, made up of *Posidonia australis* and *Zostera capricorni*, was severely damaged after two storms (Kirkman 1997). In the 1930s, the "wasting disease" caused by the slime mould *Labyrinthula* resulted in losses of 90% of all affected *Zostera marina* populations along the eastern seaboard of North America within a year (Milne & Milne 1951).

Seagrasses may be detrimentally affected by both short and long term changes in environmental conditions. Any human activities that removed seagrass directly or are detrimental to water clarity have a negative impact on seagrass growth and survivorship. In many parts of the world seagrass beds have declined as a result of dredging, reclamation, pollution and increasing sediment loads. Seagrass beds have been purposefully removed for many reasons, including: harvesting the plant directly for its fibres; clearing paths for shipping routes; constructing wharfs; and mining of the sediments beneath seagrass beds. Boat propellers and moorings can also carve paths through the seagrass and undermine the integrity of the entire seagrass patch (Kirkman 1997). They are sensitive to environmental perturbations, especially nutrient enrichment, or eutrophication, which can enhance the growth of algal epiphytes and phytoplankton. Epiphytes on the leaves and phytoplankton in the water affect the seagrass' ability to capture light, either by smothering the plant or reducing the water clarity (Cambridge et al. 1986). In Danish estuaries, Sand-Jensen and Borum (1991) found that as mean total nitrogen increased, mean phytoplankton biomass also increased. Sewage, containing high levels of nutrients, especially nitrogen and phosphorus, is discharged into the Avon-Heathcote Estuary twice daily (Ball 1997) and this may enhance the growth of algae, such as *Ulva lactuca*, over the seagrass.

Activities such as construction work in the Estuary associated with the ocean pipeline could harm established seagrass beds, either by direct removal of seagrass or reduction in water clarity that is the result of disturbing the sediments. In the longer term removal of wastewater effluent from the estuary could improve water quality and promote the establishment or restoration of previous seagrass beds.

Very few areas where seagrass is present are legally protected and of those that are, in some cases it is merely coincidental. It is only within the last 30 years that the importance of seagrasses has been realised (Kirkman 1997). Public awareness is essential for encouraging policies for protecting seagrasses; this has been shown by the high level of protection that many coral reefs worldwide now have, after their plight was recognised publicly (Spalding et al. 2003).

The main aim of this research was to determine the distribution and health of *Zostera novazelandica* in the Avon-Heathcote Estuary. This report will describe the current distribution of the seagrass beds and the characteristics of patches. This includes the size, biomass and density of seagrass patches. Secondary aims include reviewing the history of seagrass in the Estuary and setting up a database of seagrass research.

2. The History of Zostera novazelandica *Distribution in the Estuary*

Background

Christchurch's Avon-Heathcote Estuary (43º33' S, 172º44' E) is approximately 8 km^2. The Avon River enters the estuary from the north and the Heathcote River enters at the southwest corner, while the mouth of the Estuary is situated in the southeast corner (Knox, 1992). These rivers originally flowed into the sea at separate locations (Ball 1997). The Avon River passes through residential and commercial Christchurch, however the Heathcote River flows from the Port Hills through rural, residential and industrial regions (Bressington, unpublished report, 2003).

The Estuary is mainly intertidal and the mudflats are almost completely exposed at low tide, except for the main channels of the Avon and the Heathcote Rivers and some regions of standing water (Knox 1992). The Estuary is shallow, being, on average, only 1.2 m deep. However, it was formerly much deeper than it is today, as shown by photographs of boats with 4 m keels moored at Ferrymead Bridge (Deely 1992). Increased levels of sediment entered the rivers, most likely caused by erosion in the Port Hills and stormwater runoff, and the rivers became considerably shallower as this sediment built up: some places that had previously been found to be 3-6 m deep measured only 8-10 cm by the early 1900s. After 1925, the sediment was moved using a mechanical river sweeper and most wound up in the Estuary. A layer of mud approximately 25 cm thick, containing seagrass, has been found in cores from the Estuary. which suggests that seagrass patches were smothered by the increased sediment (Deely 1992).

Human activities have had a considerable impact on the Estuary, especially on the margins, where vegetation was removed, land was raised and marshlands and swamps drained or filled to make way for houses and streets (Knox 1992). The discharge of industrial wastes and sewage, whether treated or untreated, has also had a major impact on the Estuary. In the 1860s water from the Avon River had to be boiled before it was drinkable (Deely 1992). From 1950 Christchurch's sewage underwent primary treatment at the Sewage Farm (situated where the Oxidation Ponds are now) before entering the Estuary, but effluent from factories was still being discharged directly into the Estuary. Industrial waste also entered both the Avon and Heathcote Rivers, but the Heathcote was especially polluted. Untreated waste from several factories continued to flow into it, even as late as 1968 (Ball 1997). The level of treated waste entering the Estuary has risen steadily since 1929; due in part to Christchurch's increasing population and also because formerly untreated waste was being redirected to the treatment plant (Knox 1992).

Many commercially and environmentally important organisms live in the Estuary, such as whitebait, fish and juvenile flatfish, and many of these are sensitive to disturbance and pollution or rely on a habitat, such as seagrass beds, which is sensitive to disturbance. The Estuary supports a wide range of wetland and wading bird species, such as spoonbills, dotterels, cormorants and terns. On average, between 15,000 and

22,000 birds use the Estuary and oxidation ponds. This includes 5-6% of the total world population of South Island Pied Oystercatcher and New Zealand Shoveler (Crossland 1992), which makes the Estuary internationally important. Algal species, such as the green algae *Ulva lactuca* and *Enteromorpha ramulosa*, are also causing more problems in the Estuary than formerly; this is thought to be due to the additional nutrient source in the treated effluent.

More recently the condition of the Estuary has improved following better management practices. A reduced amount of untreated effluent is discharged into the Estuary and wastes from the oxidation ponds are released at high tide, which helps to wash it out of the Estuary more effectively (Deely 1992).

Knox (1992) states that *Zostera novazelandica* was relatively abundant in the Estuary until approximately 1920, and that it was even present in McCormacks Bay before the Causeway was built in 1907 (Deely 1992). It had declined considerably by 1929 and by 1952 only a few patches remained (Knox 1992). This report includes ten maps showing the distribution of *Zostera* in the Estuary from 1951 to 2002. These maps simply show where *Zostera* was found; they provide no information about the density of each patch or the health of the patches.

Methods

The distributions drawn in Figures 1-9 are taken from distribution maps in Knox (1992), whereas the distribution in Figure 10 was drawn from an aerial photograph. The approximations of the total area covered by *Zostera* are a guide only and were calculated by comparing the number of pixels of magenta colour (representing the *Zostera*) with the total number of pixels in each square and thus the entire map. Each square contained 53,110 pixels and was taken to represent $1km^2$. There were approximately 20.5 squares in each map, hence there were approximately 1,088,755 pixels in the entire map. This method of calculation dictates that any mistakes in the size of *Zostera* patches drawn on the maps translate into inaccuracies in the estimates of the total seagrass area.

Results

1951 (Fig. 1) At this time, there was very little *Zostera* in the Estuary. There were only two patches, with an area of only approximately 0.01 km^2. These were at the point where the Avon River enters the Estuary, near Bridge Street.

1958-59 (Fig 2) The area of seagrass present in the Estuary had increased since 1951 but it was in the same area. The area of this patch was approximately 0.04 km^2.

1963 (Fig. 3) The area decreased to form two small patches again, with an area of these patches was approximately 0.01 km^2, similar to that of 1951.

1964-65 (Fig. 4) The patches at the mouth of the Avon River were not found. However, three new patches further down, alongside the Avon Channel, were recorded and the area of seagrass in the Estuary had increased. The area of these patches was approximately 0.04 km^2. A survey in 1969-70 found that these patches had disappeared.

1972 (Fig. 5) The area of *Zostera* had increased further by 1972, however the patches were further south towards the centre of the Estuary. The area of these patches was approximately 0.15 km^2. This distribution was drawn from Knox (1992), which was traced from aerial photographs.

1975 (Fig. 6) In 1975, the patches in the centre of the Estuary had increased further, forming two large patches. The total area of *Zostera* was approximately 1km^2.

Figure 1. 1951

Figure 2. 1958-59

Figure 3. 1963

Figure 4. 1964-65

Figure 5. 1972

Figure 6. 1975

Figure 7. February 1981

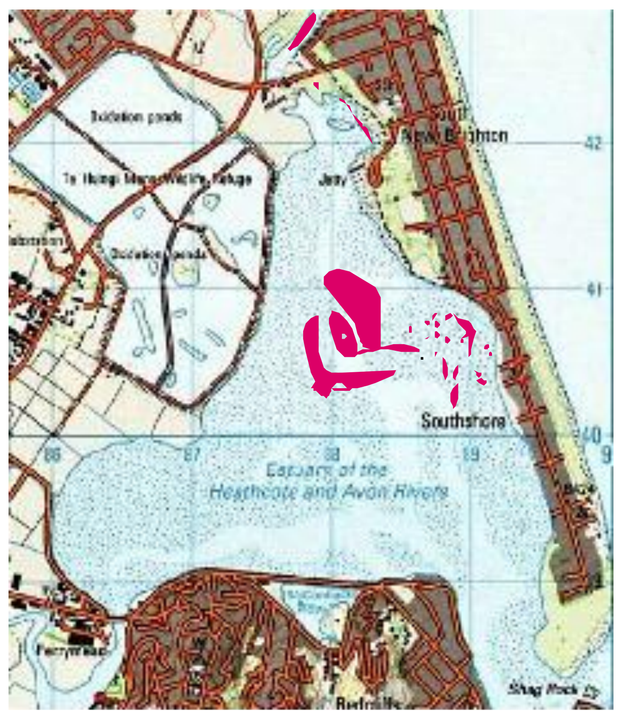

Figure 8. August 1981

Figure 9. 1992

Figure 10. 2002 (traced from aerial photographs)

Feb 1981 (Fig. 7) The area of *Zostera* was less than that recorded for 1975, but the two main patches remained and several smaller patches were recorded to the west and east of these patches in places where no *Zostera* had before been found. The area of these patches was approximately 0.58 km^2.

Aug 1981 (Fig. 8) The area had further declined by August of the same year and the two main patches showed signs that they were breaking up. Several smaller patches were recorded up around the mouth of the Avon River again. The total area of *Zostera* was approximately 0.35 km^2.

1992 (Fig. 9) This survey was carried out in June 1992. The central patches have disappeared; instead, there is one main patch along Southshore. The area of *Zostera* had not significantly increased since 1981. The area of these patches was approximately 0.55 km^2.

2002 (Fig. 10) The distribution shown in Figure 10 was drawn from aerial photographs taken in March. It was not clear whether the patches were *Zostera* or *Ulva*, nevertheless this indicates that there has been a considerable decline in area since 1992. The area of these patches was calculated to be approximately 0.17 km^2.

Discussion

The area occupied by *Zostera novazelandica* has fluctuated dramatically over the last 52 years. Also, the location of *Zostera* patches has changed during this time. Initially, *Zostera* could only be found in small patches at the point where the Avon River enters the Estuary. These patches then coalesced, before reducing in size and completely disappearing in 1964-65, when three patches down the centre of the Estuary were recorded. By 1972, these patches had also gone; instead the *Zostera* occurred in the centre of the Estuary. It had spread further by 1975 and there were now two main patches, which were found also to be present in 1981. Many smaller patches were being recorded further south and in August 1981 patches were found around the mouth of the Avon River, where they had not been found since 1964-65. The two distributions taken in the one year (February and August of 1981) indicate that there is seasonal variation in patch size. During summer (February), the patch was larger than during winter (August), although this may not have been the only factor in the decline. In 1992, there was only one large patch along Southshore. By 2002, this large patch has broken up, and another patch in the lower half of the Estuary had developed. The total area suggested by the aerial photographs, however, is significantly lower than that estimated for 1992.

No definite causes for these changes in distribution and the area covered have been determined. However, changing sedimentation patterns, nutrient and other inputs, grazing by Canada geese or simply natural cycles of growth and decay of *Zostera novazelandica* may have played a part.

3. Mapping the Current Distribution of Seagrass in the Estuary

Methods

Study Site:

The patches of *Zostera novazelandica* in the Avon-Heathcote Estuary were studied from November 2003 to January 2004. Nine transect lines were drawn across the Estuary from west to east at 400 metre intervals (Fig. 11), coinciding roughly with the transect lines shown in Knox and Kilner (1973). Along each transect, three 50 x 50 cm quadrats were assessed at 50 metre intervals. Sampling was not undertaken where the main channels intercepted a transect, since the ground was therefore underwater at all times, or where it became too boggy to progress further along the transect.

The presence and percent cover of *Zostera novazelandica* and macroalgae were recorded for each quadrat, as were the numbers of different fauna present (not included in this report) and the sediment type. Where the fauna was abundant, it was estimated into abundance groups from 20-30, 31-40, etc.; the midpoint of these intervals was entered into all spreadsheets.

An attempt was made to determine the total area of seagrass within the main seagrass region. This was done using a small hand held GPS which had relatively low precision. Readings were taken by walking around the seagrass patches in February 2004. The points were transferred on to a map and the area determined by counting pixels, combined with area estimates. This method is not considered to be very accurate.

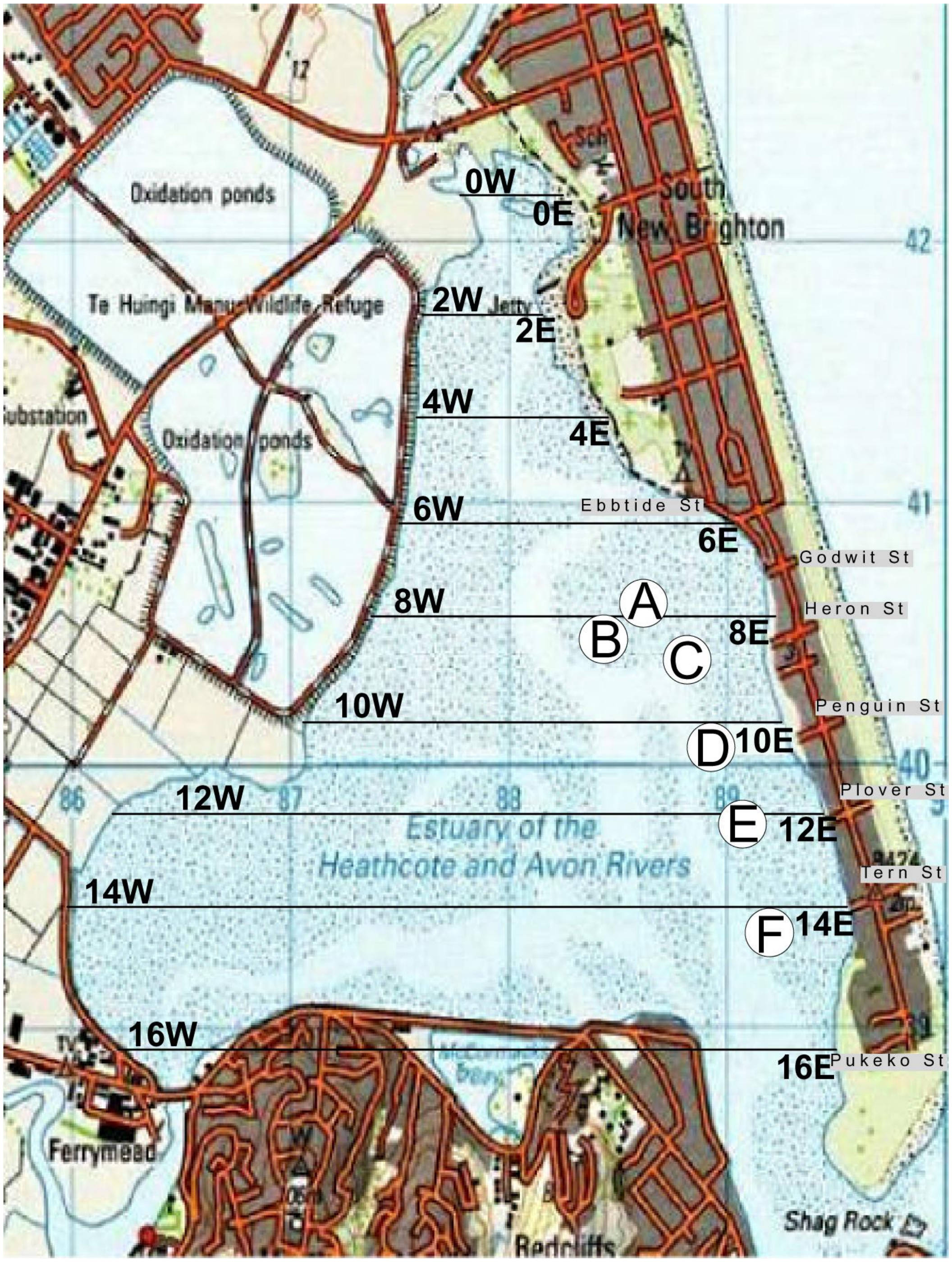

Fig. 11: Diagram showing the transects along which sampling was undertaken. Also shown: the six sites (A-F) from which samples were collected for the biomass and density analyses.

Photo showing the main seagrass area looking south in the Avon-Heathcote Estuary.

Photo showing dense patch of seagrass with cockles and estuarine topshells.

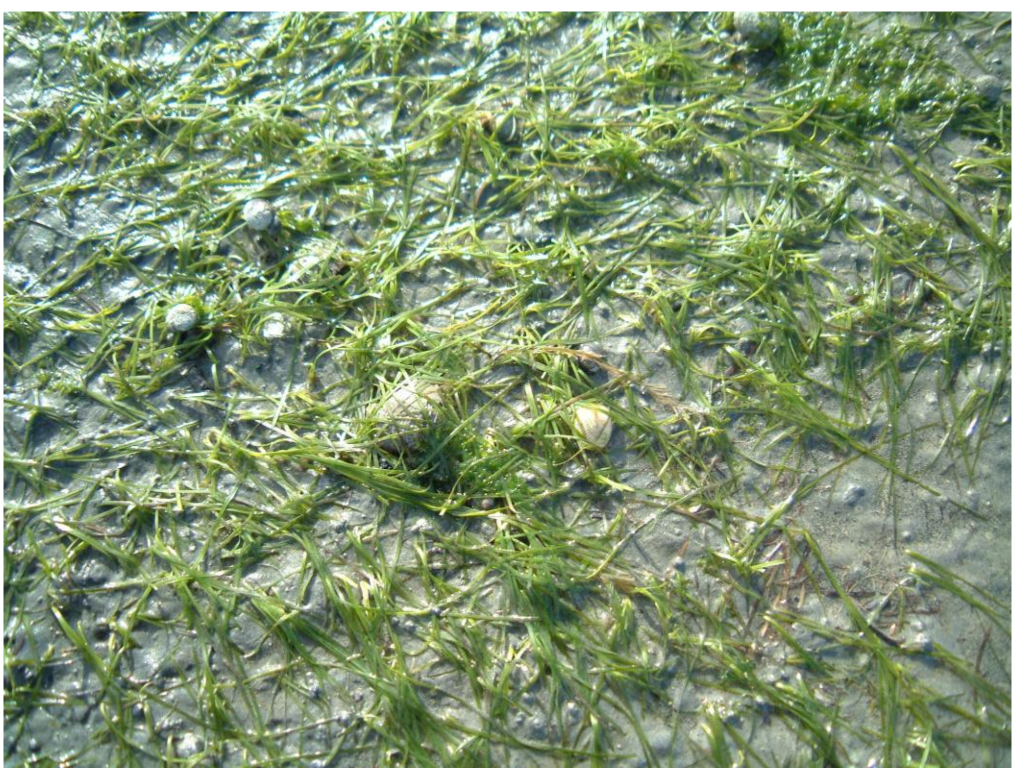

Table 1: Table showing the location of each transect, site description and the date sampled. NA: GPS readings were not available for these sites.

Site Number	Site Name	GPS Position	Site Description at Point 0 (high tide)	Date Sampled
0W	Bridge Street	43º31.771 S 172º43.512 E	*Juncus maritimus*, decaying macroalgae, shrubs, *Helice crassa* holes, sand	10 Dec 03
2W	Pond 1	43º31.969 S 172º43.358 E	*J. maritimus*, decaying algae, shrubs, ice plant, grasses, amphipods, *Cyclograpsus lavauxi*, *Amphibola crenata*, mud	10 Dec 03
4W	Pond Outlet 1	NA	*C. lavauxi*, *H. crassa* holes, shrubs, sandy mud	9 Dec 03
6W	Pond Outlet 2	NA	Epibenthic algae, small flies, shrubs, black mud	10 Dec 03
8W	Pond 2	NA	Shrubs (toi toi), sand	8 Dec 03
10W	Sandy Point	43º33.505 S 172º42.359 E	grass, *H. crassa* holes, sand	28 Nov 03
12W	Linwood Paddocks	43º33.058 S 172º42.268 E	grass, black mud	28 Nov 03
14W	Humphrey's Drive	43º33.210 S 172º42.173 E	ice plant, grass, flax, black mud, epibenthic algae, *Hemigrapsus crenulatus*	28 Nov 03
16W	Ferrymead Bridge & McCormacks Bay	43º33.513 S 172º42.365 E	*A. crenata*, *C. lavauxi*, *Anthopleura aureoradiata*, unattached macroalgae, ice plant	8 Dec 03 & 8 Jan 04
0E	New Brighton School	43º31.651 S 172º43.664 E	*H. crassa* holes, reeds	
2E	Slipway	43º31.962 S 172º43.843 E	*H. crassa* holes, sand	5 Dec 03
4E	Wetland	43º32.178 S 172º43.960 E	*H. crassa* holes, *J. maritimus*, sand	5 Dec 03
6E	Ebbtide-Caspian Street intersection	43º32.428 S 172º44.413 E	ice plants, *H. crassa* holes, sand	26 Nov 03
8E	Heron Street	43º32.652 S 172º44.556 E	*J. maritimus*, unattached *Ulva lactuca*, *C. lavauxi*	28 Nov 03
10E	Penguin Street	43º33.856 S 172º44.631 E	*J. maritimus*, *H. crassa* holes, sand (black), decaying algae, ice plant	11 Dec 03
12E	Plover Street	43º33.047 S 172º44.734 E	*Diloma subrostrata*, unattached *Zostera* blades, *H. crassa* holes, amphipods, sand (black)	
14E	Tern Street	43º33.227 S 172º44.807 E	ice plant, ants	4 Dec 03
16E	Pukeko Street	NA	ice plant, *Lupinus arboreus*, decaying macroalgae, sand	4 Dec 03

Results

Seagrass was found on the east of the Estuary along the South Brighton Spit, extending as far north as Heron Street and as far south as Pukeko Street. At the edge of the area, the seagrass was more sparse and the blades were shorter and thinner than in the centre. Many of these patches were sparse and consisted of single ramets. On the western side of the area the upper part of the seagrass roots could be seen. The total area of the seagrass area was approximately 0.29 km^2 which is approximately 4.2% of the estuarine area.

One main area of seagrass was found on the eastern side of the Avon-Heathcote Estuary. This area splits into two at its southern end, where the channels intersect it. At the northern end, the patches were separated from the main channel by 5-10m of mudflat. In general, the seagrass was found to be growing in mud or sandy mud. The percent cover scores were generally more than 20%, which can be considered dense cover.

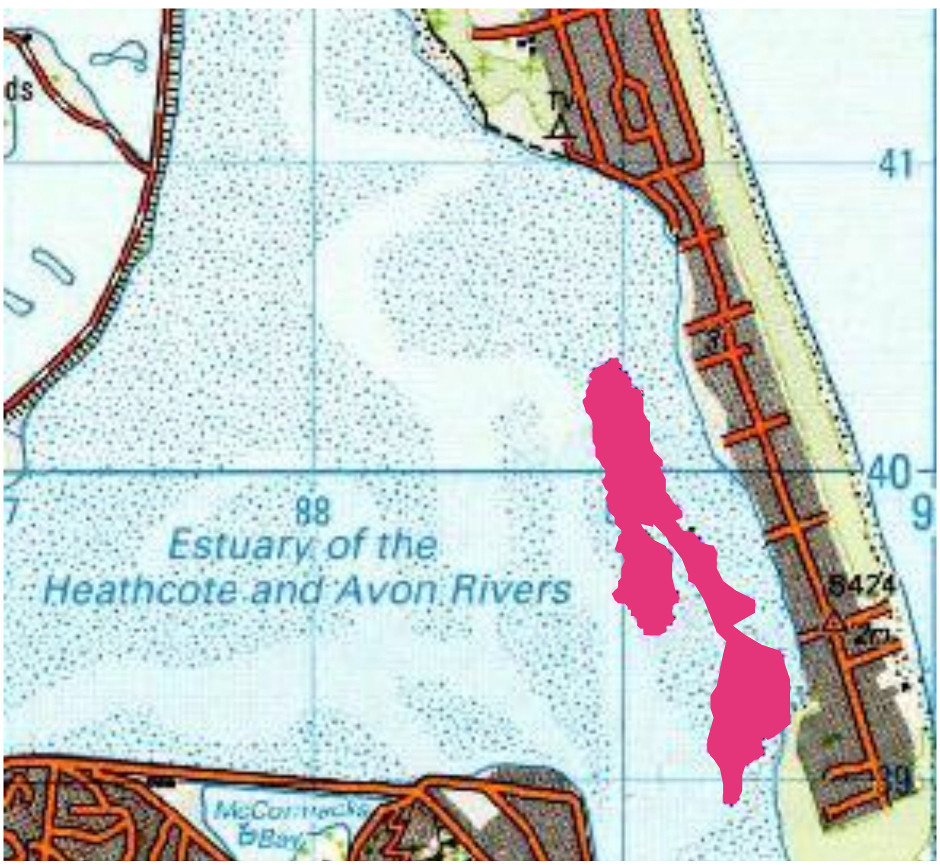

Fig. 12: Map showing the current distribution of seagrass at the Estuary.

Table 2: Average percent cover of seagrass in the Estuary along transects 8E to 14E, along with the sediment types at points where seagrass was found. The interval between each point was 50 metres. S = sand; SM = sandy mud; M = mud; NS = not sampled; P = seagrass known to be present but percent cover unknown; A = areas not sampled but seagrass known to be absent.

Transect	1	2	3	4	5	6	7	8	9	10	11	12
8E	<5	0	0	0	30-<50	P	NS	NS	NS	NS	NS	NS
10E	5-<10	0	0	10-<20	<5	20-<30	0	0	A	A	A	A
12E	0	0	20-<30	0	0	20-<30	50-<75	50-<75	0	0	10-<20	0
14E	0	75-100	30-<50	20-<30	0	0	0	0	A	A	A	A
Sediment Type	SM/M	M	M	M	M	M/SM	M	SM/S			M	

Table 3: Table showing the main species (excluding polychaetes) and their % abundance found in 16 of the 18 Estuary quadrats (n=233).

Taxonomic Group	Species Name	Common Name	% Abundance + (transects)
Algae/ Vascular plants	*Zostera novazelandica*	Seagrass	6
	Ulva lactuca	Sea lettuce	10
	Unidentified	Epibenthic algae	10
	Gracilaria chilensis		13
	Enteromorpha sp.		5
Anthozoa	*Anthopleura aureoradiata*	Sea anemones	9
Mollusca	*Austrovenus stutchburyi*	Cockle	69
	Amphibola crenata	Mud snail	46
	Cominella glandiformis	Mudflat whelk	31
	Diloma subrostrata	Mudflat top shell	50
	Siphonaria zelandica	False limpet	15
Crustacea	*Helice crassa*	Tunnelling mud crab	33
	Hemigrapsus crenulatus	Hairy-handed crab	32

As well as the seagrass, there were other primary producers present in the Estuary. They included sea lettuce (*Ulva lactuca*), *Gracilaria chilensis* and epibenthic algae all of which were recorded more often in intertidal transects than seagrass. The dominant estuarine fauna included cockles (*Austrovenus stutchbyri*), mudflat snails (*Amphibola crenata* and *Diloma subrostrata*), the whelk (*Cominella glandiformis*) and crabs (*Helice crassa* and *Hemigrapsus crenulatus*).

Photo showing sparse seagrass cover, topshells and epibenthic algae in the Avon-Heathcote Estuary.

Discussion

Seagrass was found in only a small proportion of the areas sampled within the Avon- Heathcote Estuary and the estimated total area was 4.2%. Most of the intertidal areas were dominated by mud dwelling invertebrates including cockles, mudsnails, crabs and polychaete worms.

There were dense patches of *Zostera novazelandica* along the length of the main seagrass area on the eastern side of the Estuary. However, at the northern end there were obvious patches together with relatively large areas of bare sand. Around the edges of the main patches there were sparser patches and even single ramets growing separately in the sand/mud. Large areas of sparse *Zostera* were found on the northeastern boundary. On the western border there appeared to be erosion of the seagrass bed such that the demarcation between the shoot and the roots was visible on solitary ramets. This is most likely due to wave action removing sediment and these ramets possibly represent part of the summer extension that will be washed away during the winter. Ball (1997) found that patch mortality increased for patches that were less than 0.4 m^2, and it is therefore likely that these areas may reduce over winter. Although it is expected that the patches recover the following summer the exact cyclic pattern has not been fully documented.

The northern extent of the seagrass area found in the present survey appears to have receded approximately 400 m since the 2002/2003 survey performed by Bressigton (unpublished report 2003). Biomass samples in her survey were taken from areas as far north as Ebbtide Street and Godwit Street, but no evidence of seagrass was found north of Heron Street in the present survey. This is of concern because it suggests that the seagrass total area may be reducing. However, the southern extent of Bressington's samples was Tern Street, which may indicate that the seagrass patch has shifted further south closer to Pukeko Street over the intervening year and may not have decreased in size. If the seagrass area continues to move south, then the substrate and environmental conditions may be less suitable for seagrass growth.

4. The Health of Zostera novazelandica *in the Estuary*

Although distribution maps are useful in determining the occurrence of particular species, biomass and density are measures that can be used to compare productivity over time. They provide an assessment of the health, permanence and condition of *Zostera novazelandica*. Many factors affect the growth of seagrass and biomass is a measure that can be used to compare the health of seagrass both within and between sites in the Estuary. When sampling seagrass populations it is important to consider both spatial and temporal scales. It is also necessary to allow for seasonal or climatic variability. This is usually achieved by sampling control sites, preferably close to the initial study site and/or unimpacted sites. Because there are relatively few areas containing seagrass close to the Avon-Heathcote Estuary, the control sites chosen were Duvauchelle on Banks Peninsula and Kaikoura, where there had been a previous study on the seagrass beds (Ramage & Schiel 1999).

Methods

In January three 15 x 15 cm quadrats were taken at six sites within the seagrass bed along Southshore (A-F on Fig 11). These sites were intended to match roughly with those from which samples were taken in the summer of 2002/2003 (Bressington, unpublished report 2003), so that comparisons could be possible. However, sites A and B did not match, since seagrass no longer extends beyond Heron Street. Within the quadrat, we removed all the seagrass present, including roots and rhizomes down to 5 cm.

The samples were then washed through a 5 mm mesh, weighed and the number of leaf blades counted, before being wrapped in tinfoil and dried in an oven at approximately 60°C for three to four days (or longer) until completely dry. Each sample was then reweighed to determine the dry weight.

Samples were also collected from Duvauchelle and the Kaikoura Peninsula for use as comparisons to the seagrass in the Avon-Heathcote Estuary. Twelve biomass samples were taken from four sites at Duvauchelle and at Kaikoura in January. These were gathered and subjected to the same treatment as the samples from the Estuary.

Duvauchelle Bay is on Banks Peninsula. It is predominantly flat and sandy and the area is divided roughly in half by a narrow channel (this fell between sites 2 and 3). The seagrass was not growing in this channel, replaced by clumps of macroalgae (*Gracilaria chilensis* and *Enteromorpha ramulosa*).

Fig 13: Map of Duvauchelle showing the four sites from which samples were collected.

In Kaikoura, the four sites were located at four locations around the Kaikoura Peninsula: Wairepo Flats, Lab Rocks and two sites at Mudstone Bay. These sampling sites were all within rocky reefs and were therefore different to the mud flats of the Avon-Heathcote Estuary and Duvauchelle. The sites at Mudstone Bay and Wairepo

Flats were similar to those sampled by Ramage (1997) from December 1995 to February 1997.

Fig 14: Map of the Kaikoura Peninsula showing the four sites (Mudstone Bay 1 & 2, Lab Rocks and Wairepo Flats) from which samples were collected.

Results

Avon-Heathcote Estuary

The percent cover of *Zostera novazelandica* within patches at 5 of the sample sites was between 75 and 100%. The exception was Site B, between Godwit and Heron St where the % cover was between 50% and less than 70%. The percent cover values did not correlate with either the average dry weight values or the average blade density suggesting that this is probably not a reliable index to measure density changes between areas. Although the seagrass appeared healthy there were no reproductive structures observed during the sampling within the Avon-Heathcote.

Density comparisons between sites in the Avon-Heathcote Estuary

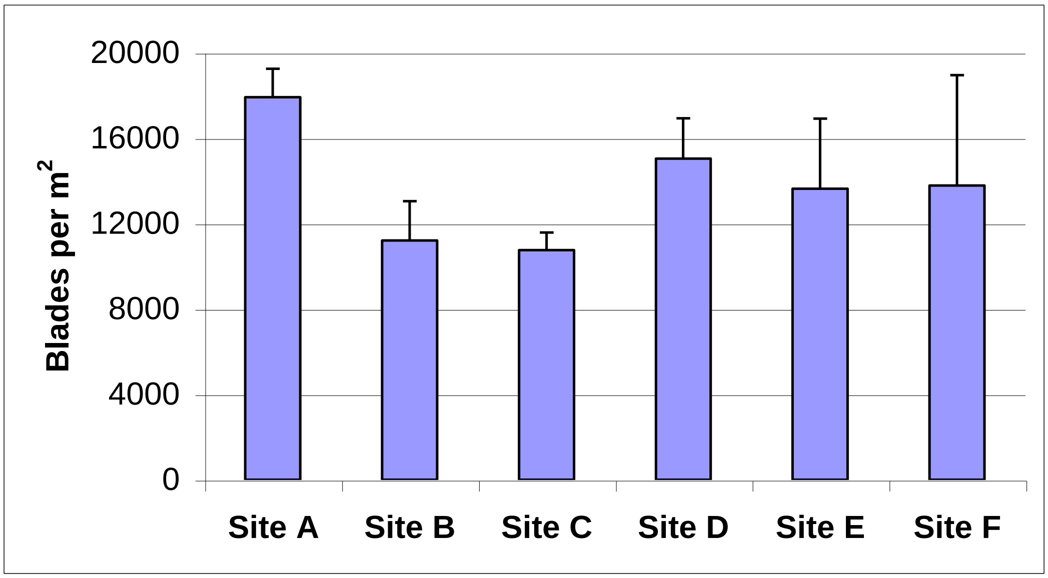

Figure 15: Bar graph showing the average density of leaf blades and standard deviation at six sites in the Avon-Heathcote Estuary.

The average blade density of seagrass for sites within the Avon-Heathcote Estuary was between 10,000 and 18,000 m^{-2}, and the standard deviations were generally small (Figure 15). The average blade density over all sites was 13,719 blades m^{-2}. A lower percent cover score was recorded at Site B and this is reflected by the lower density values for this site (Table 4). This table summarises the density information collected at sites A-F in the Avon-Heathcote Estuary and was drawn up in order to directly compare the data collected in this study with the unpublished data Bressington collected over the summer of 2002/2003 (see Table 6). In the present study neither the average biomass (average dry weight) nor the average density were significantly different between sites (p-value= 0.12 and 0.08 respectively Table).

Table 4: Table showing the average dry weight, percent cover and blade density of seagrass at six sites (A-F) in the Avon-Heathcote Estuary.

Site	Average Dry Weight (g.m^{-2})	Average Percent Blade Cover (within patch)	Average Blade Density per 0.225m^2
A	272.25	75-100%	403
B	122.22	50-<75%	252
C	115.50	75-100%	242
D	431.63	75-100%	338
E	634.50	75-100%	307
F	400.43	75-100%	310
Average	**329.42**	**75-100%**	**309**

Table 5: Table showing the results of a one-way Analysis of Variance (ANOVA) for seagrass biomass and density in the Avon-Heathcote Estuary.

Comparison	F	df	P-value	Significance
Biomass, Sites A-F	2.23	5:12	0.12	not significant
Density, Sites A-F	2.64	5:12	0.08	not significant

Photo showing researchers sampling seagrass biomass in the Avon Heathcote Estuary in the northern part of the seagrass area. Note the low lying pools and patches of seagrass and bare sand/mud.

Photo showing dense seagrass patch at Lab Rocks on the Kaikoura Peninsula.

Duvauchelle

At Duvauchelle, the seagrass was growing on a shallow, protected mudflat. The blades were shorter and thinner than those in the Estuary and at Kaikoura. Seagrass reproductive structures were found here. There was also a significant amount of algae present. *Enteromorpha ramulosa* was found in every quadrat and *Gracilaria chilensis* was present in 5 quadrats.

Density comparisons between sites within Duvauchelle

Average *Zostera* blade density varied between just less than 10,000 m^{-2} to 15,000 m^{-2} at the 4 sites at Duvauchelle with the average density of leaf blades across all sites was 11,830 blades m^{-2}. The standard deviations calculated for each site were low and there was a significant difference in blade density between sites (p-value= 0.03).

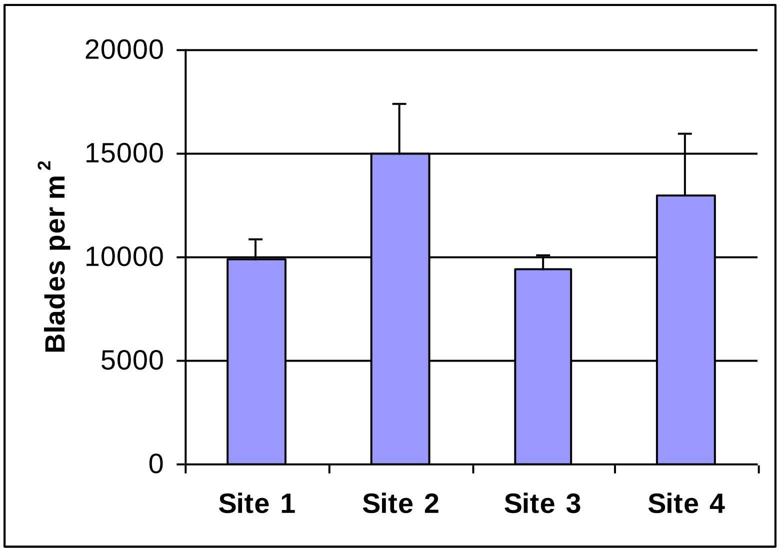

Figure 16: Bar graph showing the average density of leaf blades and standard deviation at four sites in Duvauchelle Bay (F= 5.22, df= 3:8, p-value= 0.03).

Kaikoura

At Wairepo Flats there is a seal colony and seagrass there grew densely between the mudstone rocks, in small channels and shallow tide pools. Also present: attached coralline algae, Neptune's necklace (*Hormosire banksii*) and *Ulva lactuca* as well as unattached pieces of other species of algae. The sediment at Wairepo Flats seemed to be shallower than at any other Kaikoura site. The seagrass appeared to be growing densely in all tidal zones (from high to low) and the exposed blades at high and mid tide were brown. There were no reproductive structures found here, though several were found at both sites in Mudstone Bay and at Lab Rocks.

Mudstone Bay similarly lacked large areas of suitable substrate, as the main substrate was mudstone platforms and coarse sand. At site 1 the seagrass was growing in channels in the mid to low tidal zones, although at site 2 the rocks were lower and more sediment had accumulated. The environment appeared more generally suitable and the patches were slightly less restricted; in some areas it grew more sparsely.

At Lab Rocks the seagrass was found growing in an area between rocks at high tide and those further out, at mid-low tide. Although there appeared to be a large area of suitable substrate present at this site, the patch was relatively small. The seagrass was dense in some areas (more than 50% cover) but it grew sparsely in some areas, especially on the edges of the patches.

Density comparisons between sites on the Kaikoura Peninsula

Average blade density for *Zostera* in 4 sites on the Kaikoura Peninsula varied between 15,000 and 27,000 m^{-2} . with the average density of leaf blades over all sites was 20,622 blades. There was a significant difference in blade density between sites at Kaikoura (p-value= 0.01). Blades from Lab Rocks and Wairepo were observed to be longer and wider than those from Mudstone Bay. Reproductive structures were found in seagrass at Lab Rocks and both sites at Mudstone Bay, but not at Wairepo Flats.

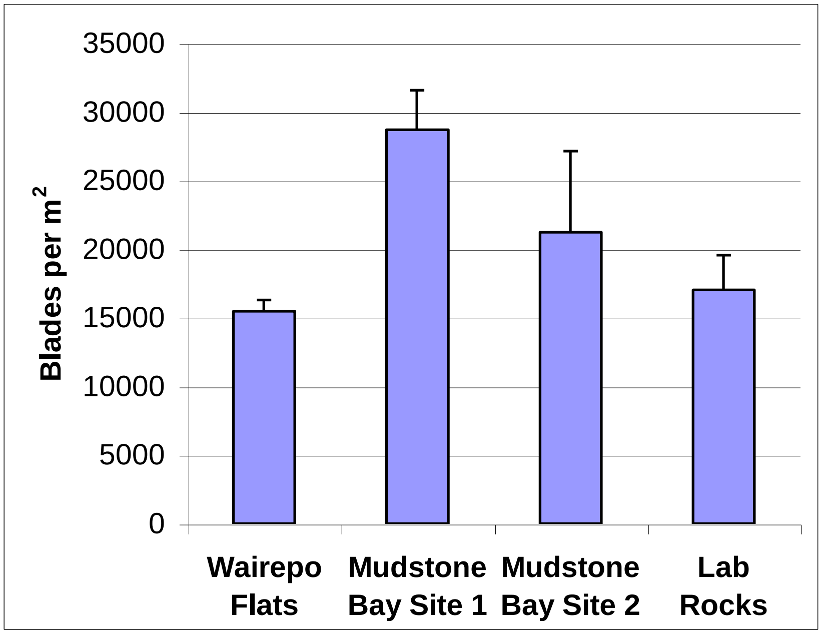

Figure 17: Bar graph showing the average density of leaf blades and standard deviation at four sites in the Kaikoura region (F= 8.39, df= 3:8, p-value= 0.01).

Biomass comparisons between sites in the Avon-Heathcote Estuary

There was considerable variation in the biomass estimates in sites within the Estuary with average values between 100 and 600 g m^{-2} (Figure 18). Variation between sites was not significant (Table 5, p-value= 0.12) and the average biomass was 329.4 g.m^{-2}. Sites B and C (opposite Godwit and Heron Streets respectively), had the lowest biomass values, while biomass was highest at site E. The last three sites, which were situated closer to the mouth of the Estuary, had considerably higher biomass than the first three sites.

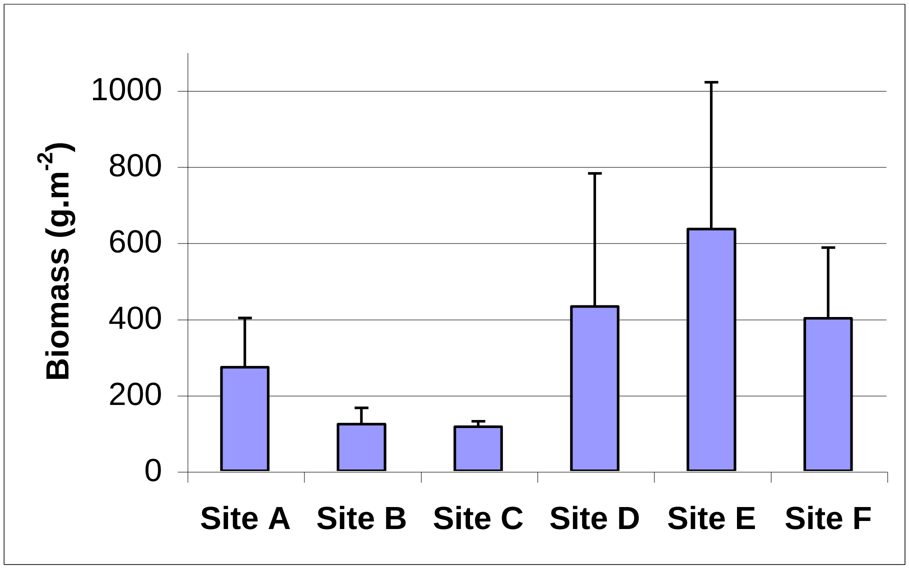

Figure 18: Bar graph showing the average biomass of seagrass (in g.m^{-2}) and standard deviation at six sites in the Avon-Heathcote Estuary.

Biomass comparisons within sites at Duvauchelle

The average biomass for seagrass at Duvauchelle was between 100 and 200 g.m^{-2}. Although there was high variability within sites there was significant variation between sites (p-value= 0.23), Site 2 had the highest biomass value and the average across all sites was 155.3 g.m^{-2}. The lower values are similar to values calculated for Avon-Heathcote Estuary, although there is less variation between sites at Duvauchelle (the range is approximately 100 g.m^{-2}) and the overall average is higher for the seagrass in the Estuary.

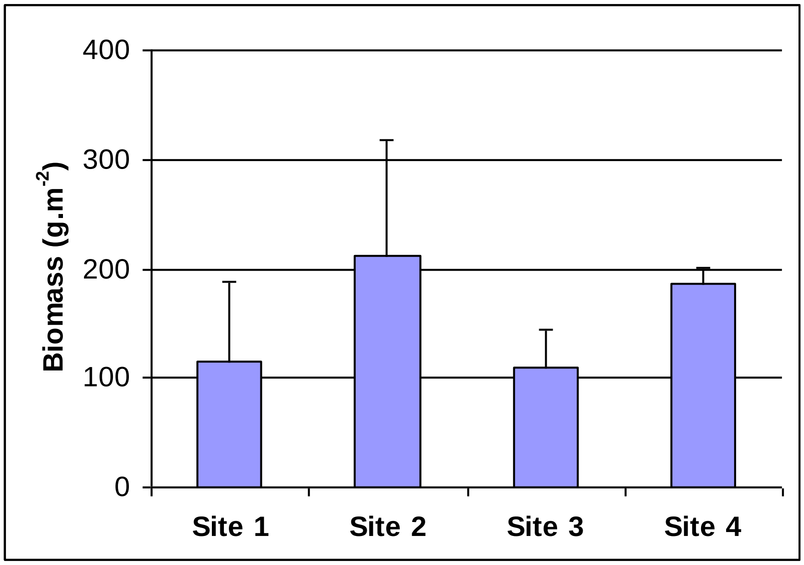

Figure 19: Bar graph showing the average biomass of seagrass (g.m^{-2}) and standard deviation at four sites in Duvauchelle (F= 1.75, df= 3:8, p-value= 0.23).

Biomass comparisons within sites at Kaikoura

Zostera biomass values for sites at Kaikoura were high with average values between 900 and 1,700 g.m^{-2}. There were significant differences between the sites (p-value= 0.01) and there was low within site variability. The biomass atMudstone Bay was significantly higher than that of Wairepo Flats.

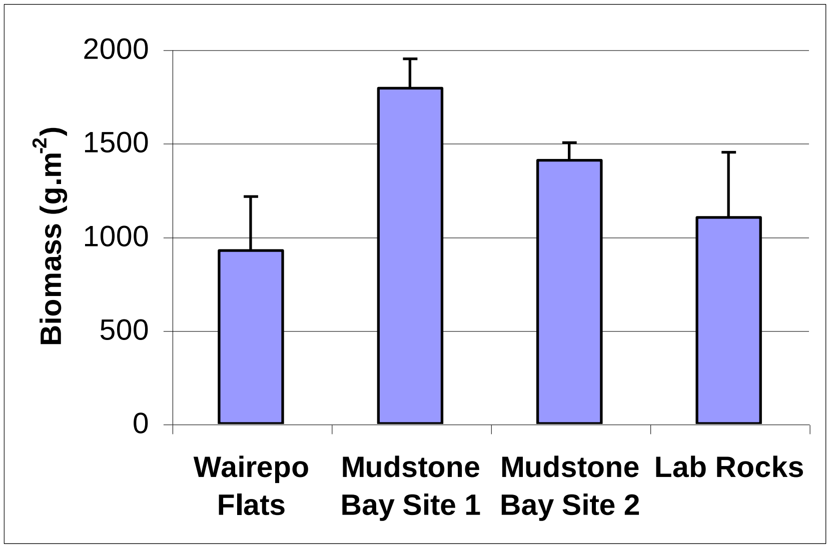

Figure 20: Bar graph showing the average biomass of seagrass (in g.m^{-2}) and standard deviation at four sites in the Kaikoura Region (F= 7.34, df= 3:8, p-value= 0.01).

Between area comparisons

The average biomass of seagrass across all sites in the Avon-Heathcote Estuary was calculated at 329.4 g.m^{-2}; at Duvauchelle the biomass was 155.3 g.m^{-2} and that for Kaikoura was considerably higher, at 1,306.9 g.m^{-2}. The average densities for the Estuary, Duvauchelle and Kaikoura were 13,719 blades/m^2, 11,830 blades/m^2 and 20,622 blades/m^2 respectively. Hence the seagrass populations at the Avon-Heathcote Estuary and that at Duvauchelle were found to be the most similar.

Discussion

This study has found considerable variability in both the density and biomass of seagrass at different sites along the main area of seagrass along the eastern region of the Avon-Heathcote Estuary. However, no significant differences were found between sites. This was most likely due to the high level of variation within sites and the small number of replicates taken. There are other factors that could contribute to the variability . There were observed differences in the amount of roots and rhizomes between sites and if blades and rhizomes/roots had been weighed and dried separately, there may have been less variation.

The biomass, density and percent cover values obtained in the present study can be compared with 2003 samples (Table 6). The percent cover scores observed in this 2003/2004 study were generally higher than those observed by Bressington,

Table 6: Table showing the average dry weight, percent cover and blade density of seagrass at six sites in the Avon-Heathcote Estuary (taken from Bressington, unpublished report 2003).

Site	Average Dry Weight (g.m^{-2})	Percent Blade Cover (within patch)	Estimated Blade Density per 0.0225m^2
A	68	50->75%	50-150
B	196	75-100%	135
C	320	75-100%	162
D	245	50->75%	100-200
E	347	75-100%	~
F	595	50->75%	~
Average	**295**	**50-100%**	**500-600**

The average dry weight of Zostera (g.m^{-2}) recorded by Bressigton (unpublished report 2003) was lower than that found in this study. However, if Site A is not included, then the average for sites B-F is 355 g.m^{-2} is similar to that calculated in the present study. Also, because the blade densities were more accurately estimated in this study than in Bressington's study, this may account for the higher average value. In both studies the three sites, which were situated closer to the mouth of the Estuary, had considerably higher biomass than the first three sites. This pattern was also found by Ball (1997).

The average density of leaf blades for *Zostera* in Duvauchelle was 11,830 blades m^{-2}, which is slightly lower than that recorded for seagrass in the Avon-Heathcote Estuary. In contrast, blade densities of *Zostera* in sites on the Kaikoura Peninsula were exceptionally high, up to 27,000 m^{-2} . Ramage (1995) found densities of approximately 6,000 blades per m^2 at Mudstone Bay and 5,000 blades per m^2 at Wairepo Flats during January. She also noted that leaf blades at Mudstone Bay were approximately three times longer than those at Wairepo Flats.

Biomass values for *Zostera* from sites on the Kaikoura Peninsula were also significantly higher than those calculated for Duvauchelle and the Avon-Heathcote Estuary. There were significant between site differences in seagrass biomass and density at sites in Duvauchelle and sites in Kaikoura. As in the present study, Ramage (1995) found that the total biomass of Mudstone Bay was significantly higher than that of Wairepo Flats. The recorded differences may imply that environmental conditions differ more within these localities than they do within the Avon-Heathcote Estuary. *Zostera* habitat at Duvauchelle appeared to be more similar to that of the Avon-Heathcote Estuary than Kaikoura and this was reflected in the results.

Seagrass reproductive structures may provide an assessment of seagrass health and reproductive potential. Reproductive structures were not found in Zostera populations within the Avon-Heathcote Estuary whereas they were found at the other two localities. These observations are consistent with previous studies (Ramage 1995, Ball 1997) and suggest that at present the conditions for growth in the Avon- Heathcote Estuary are not optimal.

Global seagrass biomass has been estimated at 205 g dry weight per m^2 (Spalding et al. 2003). This estimate is lower than the average biomass for sites in the Estuary and at Kaikoura, but higher than that for Duvauchelle. This may be due to the higher biomass of macroalgae present at Duvauchelle compared to the Estuary and Kaikoura, or because the leaf blades were smaller and thinner, but this may be related to algal biomass. However, seagrass appears to be healthy and growing well in all three areas.

Although seagrass biomass ($g.m^{-2}$) is within international levels for the Avon-Heathcote Estuary, the main concern is the total biomass for the estuary. The area of seagrass was estimated as 4.2% of the total estuary. Also, there is some suggestion that the seagrass area may have moved southwards since the summer of 2002/2003 but this cannot be confirmed.

5. Conclusions and Recommendations for the Future

Disturbance, from both anthropogenic and natural sources, has affected the distribution of seagrass over time in the Avon-Heathcote Estuary. In the past, sedimentation caused by changing land use in Christchurch and changes made to the channels and tidal movements have caused considerable decline of seagrass. This is especially clear in McCormacks Bay. Before the Causeway was built, large areas were covered in dense seagrass beds, but now there is no seagrass and it is choked up with *Ulva lactuca* and *Enteromorpha ramulosa*.

There is a need for more detailed mapping of the main seagrass area within the Avon-Heathcote Estuary. The priority is to determine with more accuracy the location and extent of the seagrass area using more accurate GPS methods together with aerial mapping. Some ground truthing would be necessary to asses the health of the seagrass patches and potential inundation by sea lettuce. In the past, seagrass distributions have changed within relatively short time frames. Temperate seagrass populations have been found to be naturally unstable both in the Estuary (Ball 1997) and internationally (Harlin 1980). It is therefore important to be able to distinguish between natural fluctuations and significant declines. Hence, measuring growth rates should also be an important part of future studies.

The Christchurch City Council are planning to put in a 1.8 m diameter pipeline in a 3.2 m trench across the Estuary to transport effluent to an ocean outfall into Pegasus Bay. Although the construction details of this have not been finalised there are likely to be environmental impacts. It will be necessary to try to reduce the impacts of this work and protect vulnerable intertidal habitats including the seagrass beds and saltmarshes. It is suggested that the seagrass beds should be resampled prior to any construction work and that fixed areas, marked with stakes, be established to evaluate the potential impacts of the pipeline construction. Overseas research indicates that disturbing the sediment could reduce the water clarity or smother the seagrass. Also, if large quantities of sediment are washed towards the mouth of the Estuary, then the release of contaminants into the water could have at least short-term effects on the current seagrass population.

Although not part of the present study, the researchers also recorded the presence of nuisance algae and dominant macrofauna (excluding polychaetes) along the intertidal transects. We would recommend an extension of this research over the next few years so that there is a database of intertidal invertebrates and a saltmarsh inventory established before the proposed Estuary work starts.

6. Computer Database of Seagrass Research

A computer database of scientific papers and books regarding seagrass biology was created using EndNote. It concentrates especially on *Zostera novazelandica* and on the effects of pollution, such as nutrient enrichment, and disturbance of seagrass beds in general.

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