Baseline Environmental Monitoring for Project Next Generation: In-harbour assessment

Prepared by

Ryder Consulting

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environment + planning + project management

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Executive Summary

Port Otago Ltd has been granted consents to carry out dredging and disposal work that will deepen the approaches to Port Chalmers. Conditions of the consent stipulate that baseline environmental monitoring must be carried out before work commences. To this end seagrass beds, saltmarsh, cockle beds, rocky shore and soft bottoms were surveyed by Ryder Consulting Ltd. Surveys included the collection of randomly located cores along transects across soft substrates and the analysis of collected infauna. Also included was examination of photoquadrats taken along transects across both soft shores and rocky shores and an estimation of areas of selected seagrass and saltmarsh beds. An estimate of the biomass of cockles was made for cockle beds and representative substrate cores were analysed for particle size, heavy metal contamination and depth of redox discontinuity layer.

Seagrass beds are recognised as being ecologically significant in providing nursery grounds for a wide variety of intertidal invertebrates and fish and as feeding areas for birds and fish. Sampling of control and potential impact areas showed that the beds appeared to be in good health, with high density of shoots and good biomass despite occasional heavy grazing by waterfowl.

Saltmarsh areas at Aramoana are recognized as being regionally important with high ecological and cultural values. Once again sampling showed that the Aramoana saltmarsh appears to be in good health, with the suite of organisms encountered reflecting those found in previous surveys.

Cockle beds have been extensively studied due to their importance as a source of mahika kai and the potential of the beds as a commercial resource. The communities associated with the cockle beds appear to be in good health and are comparable to those observed during similar recent studies. Biomass, too, is as expected and ties in well with biomass calculated for much more extensive surveys associated with cockle harvesting. Despite some slight differences in sampling techniques, the survey provides a robust baseline study against which any changes may be measured.

Sheltered rocky shores within Otago are quite rare, but have been extensively studied. The communities encountered during this survey are flourishing and typical of those one would expect to find on sheltered rocky shores in southern New Zealand. The assemblages comprise largely foliose red and brown algae, sponges, ascidians, crabs and gastropod molluscs. Organisms living on rocky substrate are at risk of smothering by fine sediments that may, from time to time, reach quite high levels in the water column within the harbour. However, it is recognized that dredging activity is unlikely to be the only source of such sediments, nor the

most significant source. The use of spatially separated sites and control sites will allow some measure of differentiation of sources.

Deep channel communities will be directly impacted by dredging activities in the approach channel to Port Chalmers. The aim of this survey was to determine what suite of organisms currently inhabits the deeper channels and how quickly re-colonisation may take place.

Substrate analysis was not a required condition of the resource consent but was thought to be useful to assist in tracking the fate of sediments disturbed during the dredging process.

Overall, the infaunal and rocky shore communities encountered during this baseline survey are typical near shore communities in sheltered inlets and harbours around most of New Zealand. It is reasonable to expect that the assemblages will remain essentially unchanged unless some other extrinsic factor has a discernible impact on the communities. A number of uni- and multivariate statistical tests are used to characterize the communities and will be used to detect any changes in community structure once further surveys have been carried out.

1. Introduction

The approaches to Port Chalmers are considered to be inadequate to accommodate the passage of large containers vessels that may visit the port in future years (Plunket 2011). To address this concern Port Otago Ltd (POL) applied for and has been granted consents enabling dredging of the channel between Port Chalmers and the entrance to Otago Harbour at Taiaroa Head. Dredging will ultimately result in the disposal of up to 7.2 million cubic metres of dredged material at a site known as A0, some 6.3 km north-east of Taiaroa Head. It is proposed that the dredging will be carried out at two intensities; incremental capital works dredging (ICW), which is relatively small scale, and major capital works dredging (MCW), which is at a larger scale.

As part of the resource consent application process POL engaged various consultants to carry out a raft of investigations including comprehensive assessments of the ecology of the lower Otago Harbour (e.g. James *et al*. 2007, Paavo and Probert 2005, Paavo *et al.* 2008, Paavo 2009).

A condition of the resource consent granted to carry out the proposed dredging work specifies that POL must carry out appropriate biological monitoring to determine baseline conditions before the commencement of dredging. Additional monitoring must also be carried out during and after the completion of capital works to gauge any effects that might be attributable to the works. Should adverse effects be found modifications may be made to the dredging regime if necessary.

To this end, POL has engaged Ryder Consulting Ltd (RCL) to carry out the baseline assessment. The following report presents the findings of the investigations carried out by RCL and compares them with the findings presented in the initial reports commissioned by POL.

The baseline survey within the harbour focuses on five distinct habitats that may be affected by the proposed dredging, either by altered turbidity, the settlement of disturbed sediment or alteration of the substrate, or a combination of the three. The habitats examined have been chosen for their ecological importance and/or likelihood of potential impact as a result of dredging.

The habitats are:

- Seagrass (*Zostera muelleri* subsp. *capricorni*) beds, due to their significance as important shelter, feeding, spawning and nursery habitat for a number of epifaunal species and fish (Reed and Hovel 2006, Mills 2006). It is assumed that the Seagrass beds off Harwood are indicative of the health of such beds in the area of the harbour likely to be affected by the capital works. Part of the Seagrass beds off Harwood fall within CPA17 in the Otago Regional Plan: Coast.

- Saltmarsh at Aramoana, which is recognised by the Otago Regional Council as a Coastal Protection Area (CPA1 Otago Regional Plan: Coast); as an Area of Significant Conservation Value in the Dunedin City District Plan; is Gazetted and managed by the Department of Conservation as nationally significant; and is highly valued by Kai Tahu for mahika kai or other waahi taoka.
- Rocky Shore, which is a relatively limited habitat within Otago Harbour (Stewart 2005).
- Cockle (clam) beds, due to their significance as a source of mahika kai.
- Deep Channels. Given that this habitat will be affected directly it is of interest to determine the rate and extent of recolonisation once dredging is completed and compare this with existing flora and fauna found in the channels.

In addition, for completeness, substrate from three of the habitat types was collected for assessment of heavy metal concentration and grain size analysis.

2. Methods

All methods for this survey are widely used in the assessment of intertidal and subtidal marine habitats and provide a robust baseline against which future changes may be compared (Kingsford and Batttershill 1998; Robertson *et al*. 2002). It is believed that the sampling intensity used throughout this survey will be adequate to determine whether of not there are any changes in community structure when compared with future surveys.

2.1 Seagrass Beds

Four randomly placed transects across the seagrass beds at Harwood were surveyed (Figure 2.1.1). Two additional transects were surveyed at Papanui Inlet as control sites (Figure 2.1.2).

Each transect was 100 m long with a $1m^2$ quadrat photographed at 20 m intervals. At each quadrat a randomly located 75 mm diameter core was taken to a depth that ensured collection of *Zostera* plant stems and root systems (i.e. 200 mm). Cores were labelled and returned to the laboratory where they were rinsed using a 1 mm sieve to separate plant material from substrate.

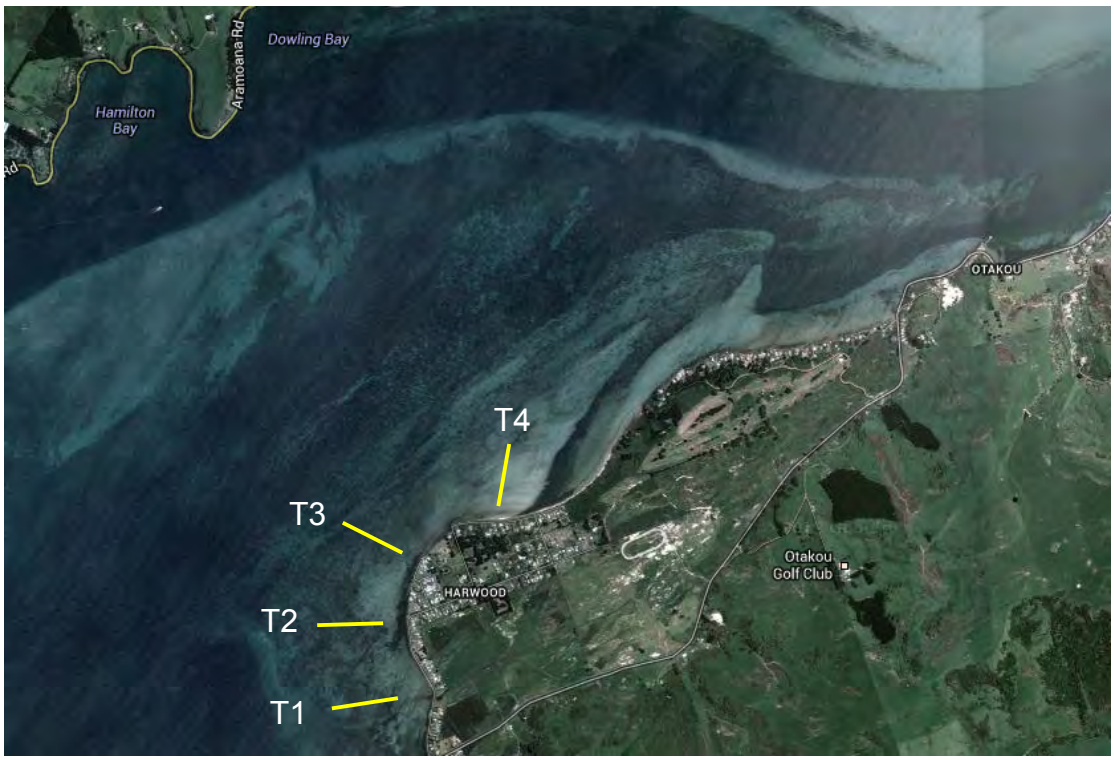


Figure 2.1.1. *Location of transects across seagrass beds off Harwood, Otago Harbour.*

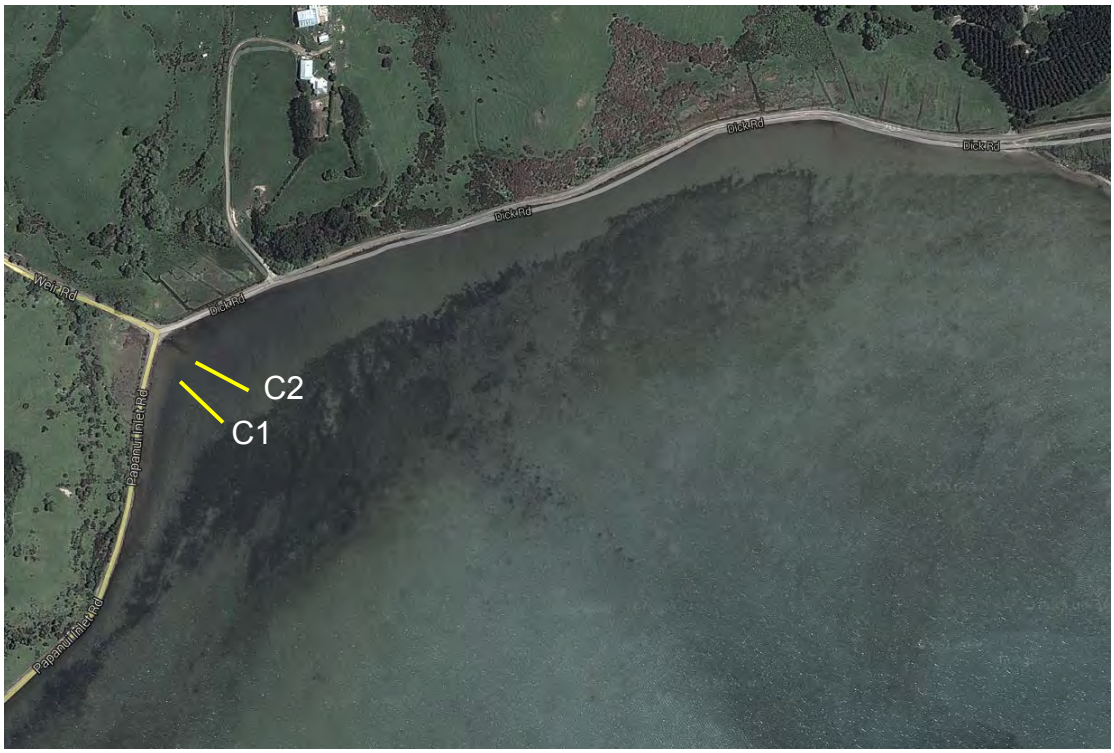


Figure 2.1.2. *Seagrass bed transect locations at Papanui Inlet.*

It was assumed that only the parts of *Zostera* plants that appeared above the substrate contained chlorophyll and as such, individual *Zostera* blades were measured from the point at which they became distinctly green (Figure 2.3). Shoots were counted as a 'set' of blades

obviously grouped together, regardless of whether or not they arose on the same stolon (Figure 2.4) and shoots per square metre calculated.

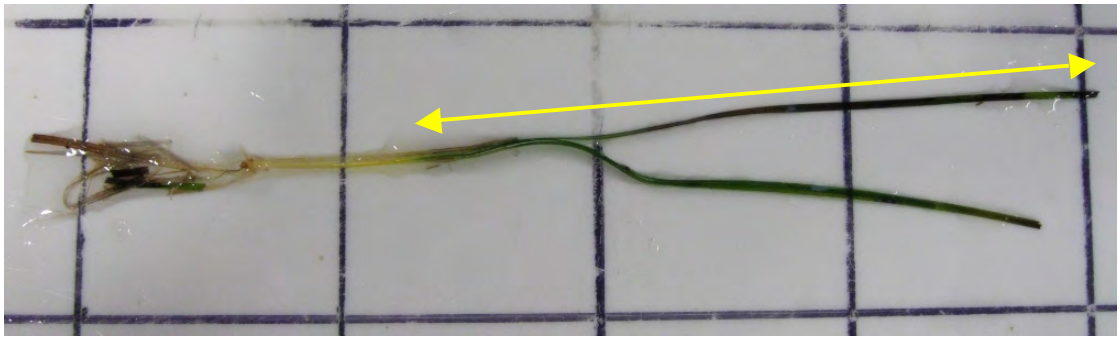


Figure 2.1.3. Zostera *blade length measured as length of yellow arrow.*

Finally all Zostera plant material, including blades, stolons and root system were squeezed to remove excess water and weighed to give biomass per core, from which biomass per square metre was calculated.

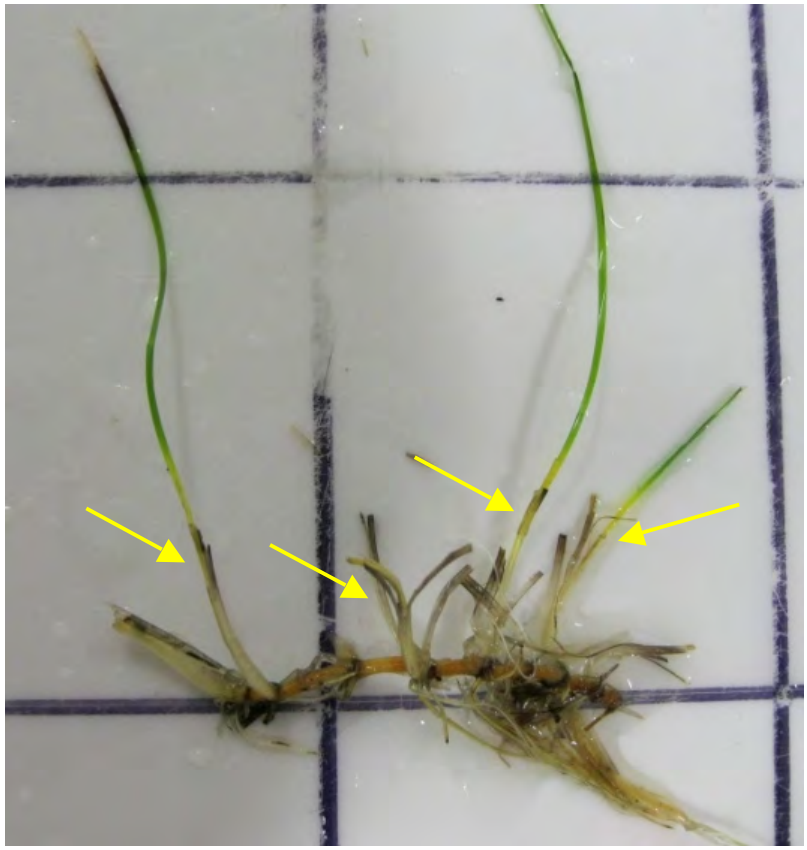


Figure 2.1.4. *Four* Zostera *'shoots' (arrows) arising from a single stolon.*

High-resolution aerial photographs were taken of the seagrass beds at both locations and areal extent of a representative portion of the beds calculated using ImageJ® for later comparison.

Port Otago Ltd (POL) has specified that quarterly surveys (winter, spring, summer and autumn) of seagrass beds off Harwood be undertaken. It is anticipated that the same sites and methods will be used in these repeat surveys. For future surveys, aerial photographs should be taken at the same time of season each year as surface biomass of *Zostera* beds may change significantly with season (Norhadi 2001). The methodology for seagrass and salt marsh monitoring incorporates elements of the methods recommended in the national estuary monitoring protocol (Robertson *et al.* 2002).

2.2 Saltmarsh

The Aramoana saltmarsh is completely inundated only at extreme high water spring tides (EHWS). Consequently, it is unlikely that sediment generated during the dredging process will have a significant impact on areas of the saltmarsh that are only infrequently submerged. With this in mind the focus of this survey was on the intertidal area adjacent to the saltmarsh and extending a little way into it. Four randomly placed transects were surveyed across the saltmarsh at Aramoana (Figure 2.2.1). Transects were of variable length, dependent on the extent of the intertidal zone.

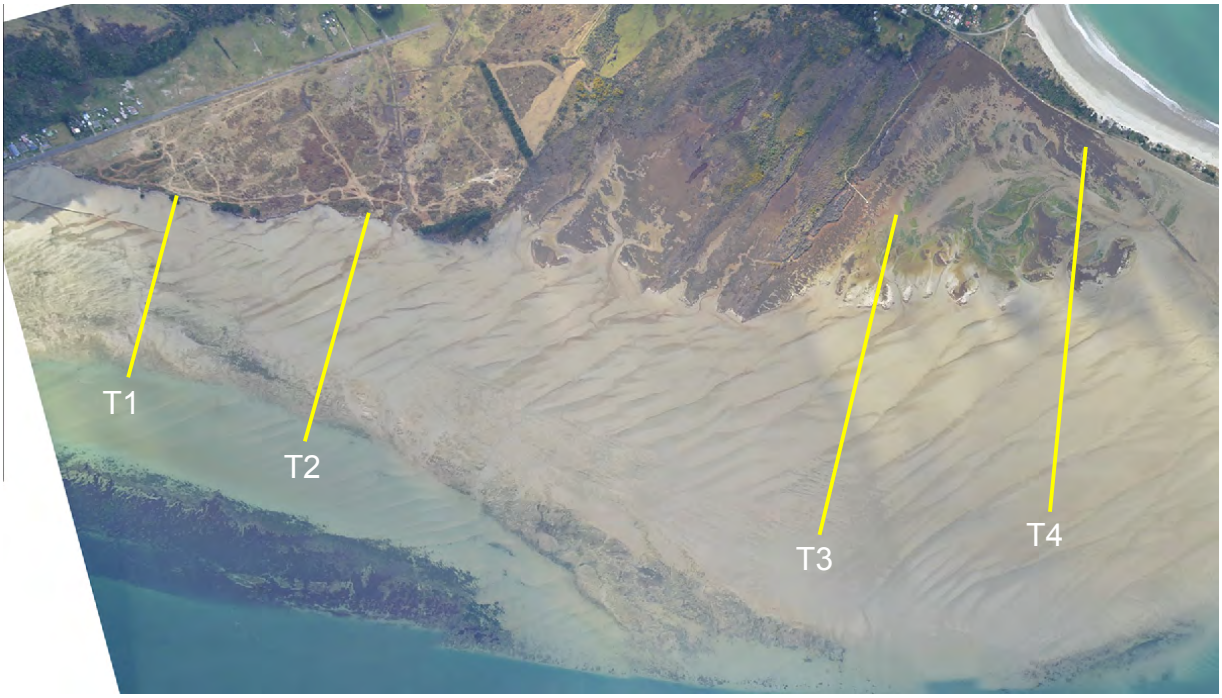


Figure 2.2.1. *Location of transects across intertidal zone and saltmarsh at Aramoana, Otago Harbour.*

Five randomly located 1m^2 quadrats were photographed along each transect and epifauna noted. Within each quadrat two randomly located 150 mm diameter cores were taken to a depth of 200 mm. Cores were sieved on site through a 0.5 mm mesh and macro-invertebrates retained were returned to the laboratory for preservation, identification and enumeration by suitably qualified and experienced personnel. An additional 75 mm

diameter core was taken to 200 mm depth at each quadrat and was photographed for assessment of the depth of the redox discontinuity layer (RDL) (i.e. how far down oxygen poor sediments are). The RDL gives an indication of how thick life supporting layers of sediment are.

Simple measures of species diversity (number of different 'types' of animals per sample) and animal abundance (number of animals per sample) were calculated from the collected data. A diversity index was also calculated using the Shannon-Weiner method (Zar 1996). Such indices provide a ready method for comparing diversity at sites from year to year or, in this case, before and after a possible impact.

High-resolution aerial photographs were taken of the saltmarsh and areal extent of a representative herb bed calculated using ImageJ® for later comparison.

2.3 Cockle Beds

Cockles (*Austrovenus stutchburyi*) are, in fact, New Zealand littleneck clams or tuaki. However, the term cockle is in common usage and will be used throughout this report. Surveys of cockle beds were undertaken at 4 sites within Otago Harbour and at a control site in Papanui inlet (Figures 2.3.1a-d).

Figure 2.3.1a. *Location of quadrats at cockle sites opposite Pulling Point, Otago Harbour.*

Figure 2.3.1b. *Location of quadrats at cockle site 3 near Otafelo Point, Otago Harbour.*

Figure 2.3.1c. *Location of quadrats at cockle site 4, Te Rauone Beach, Otago Harbour.*

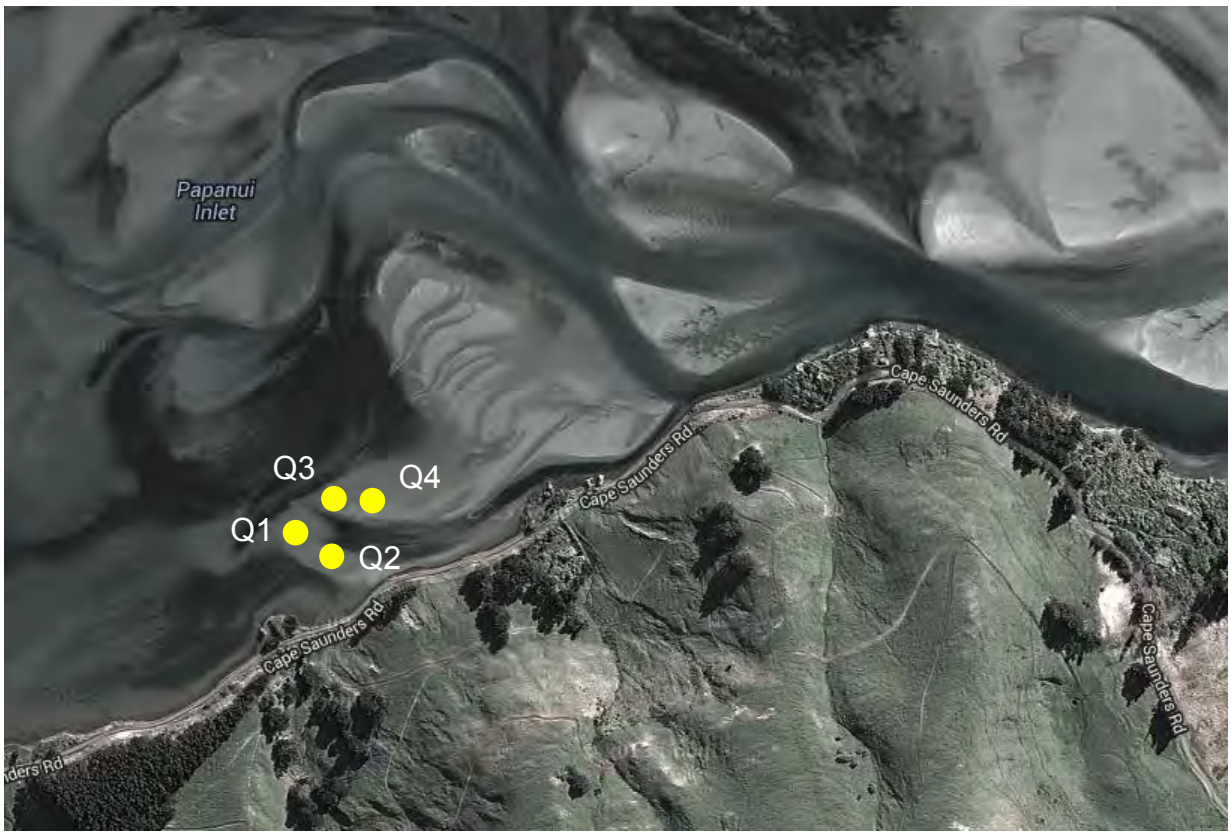


Figure 2.3.1d. *Location of quadrats at control cockle site, Papanui Inlet.*

Cockle density, size structure and biomass were assessed for each site. As the cockle beds opposite Pulling Point are subject to experimental commercial harvesting, care was taken to ensure that sampling sites were in Southern Clams Ltd's control areas (i.e. have not been harvested) (Stewart 2006, 2013).

To assess the cockles, and the flora and fauna associated with the cockle population within the beds, two 10m x 10m quadrats were sampled at each site and four in the control area at Papanui Inlet. Cockles are known to be patchily distributed on local beds (Stewart 2013) so a stratified sampling regime was employed with respect to cockles (Kingsford and Battershill 1998). Thus, three 150 mm diameter cores within each large quadrat were excavated and cockles that were collected were returned to the laboratory for weighing and measuring. If cockles were judged to be abundant within a particular large quadrat, a further two 0.1 m^2 quadrats were excavated. If error looked likely to be large (i.e. sample sizes were highly variable) additional cores were collected in an attempt to reduce error.

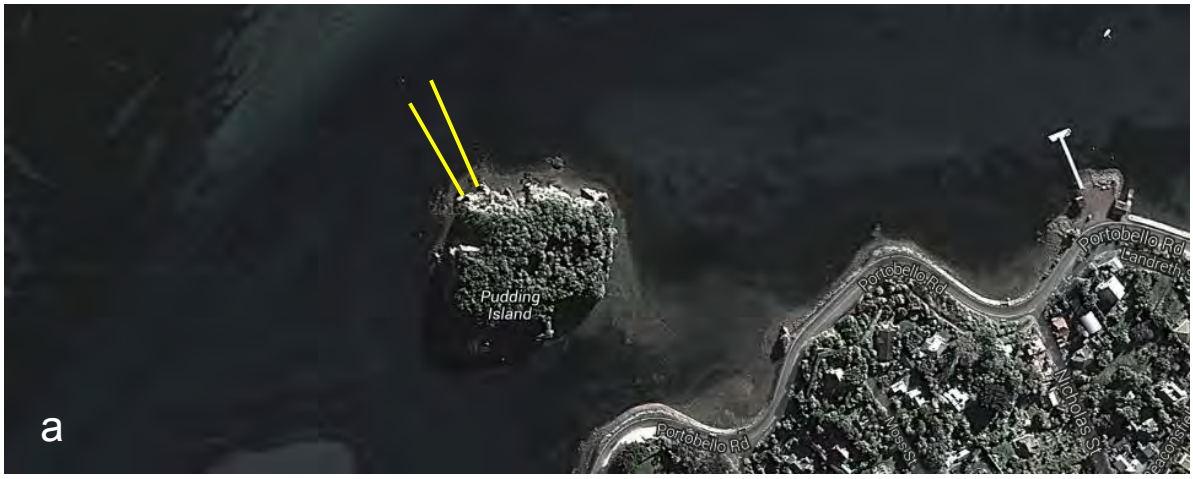
For other biota, two random 1 m^2 quadrats within each large quadrat were photographed and percentage cover of macroalgae estimated. One randomly placed 200 mm deep core sample was collected from within each large quadrat using an 85mm diameter coring device. Cores were photographed to allow determination of the depth of the redox discontinuity layer (RDL), if present. An additional five 150 mm diameter cores were collected to a depth of 200 mm

from within each large quadrat and sieved on site using a 500 µm sieve. All animals retained were returned to the laboratory preserved, identified to at least family level by suitably experienced personnel and counted.

Simple measures of species diversity (number of different 'types' of animals per sample) and animal abundance (number of animals per sample) were calculated from the collected data. A diversity index was also calculated using the Shannon-Weiner method (Zar 1996) to allow comparison with future surveys. Variability among sites was measured using the Index of Multivariate Dispersion (IMD) (Warwick 1993). Multidimensional scaling (MSD) was used to 'graph' the invertebrate communities as ordination plots. In such plots, how close the core values appear to each other reflects how similar they are in terms of species composition and abundance patterns. Analysis of similarities (ANOSIM) was used to test whether there were significant differences between the invertebrate communities at the various sites on cockle beds. It is suggested that future surveys be conducted at a similar time of year to minimise any seasonal differences in the abundance of organisms.

2.4 Rocky Shore

Two shore-normal transects in areas close to those surveyed by Paavo (2009) were surveyed at each of three sites, one at Pulling Point and one at Quarantine Island, from (mean high water, spring (MHWS) down to at least 5 m water depth across obvious sub-tidal habitat. An additional pair were surveyed off Pudding Island due to this area being a recorded refuge of the small brachiopod, *Pumilus antiquatus* (Robinson 2010) (Figures 2.4.1a-c).



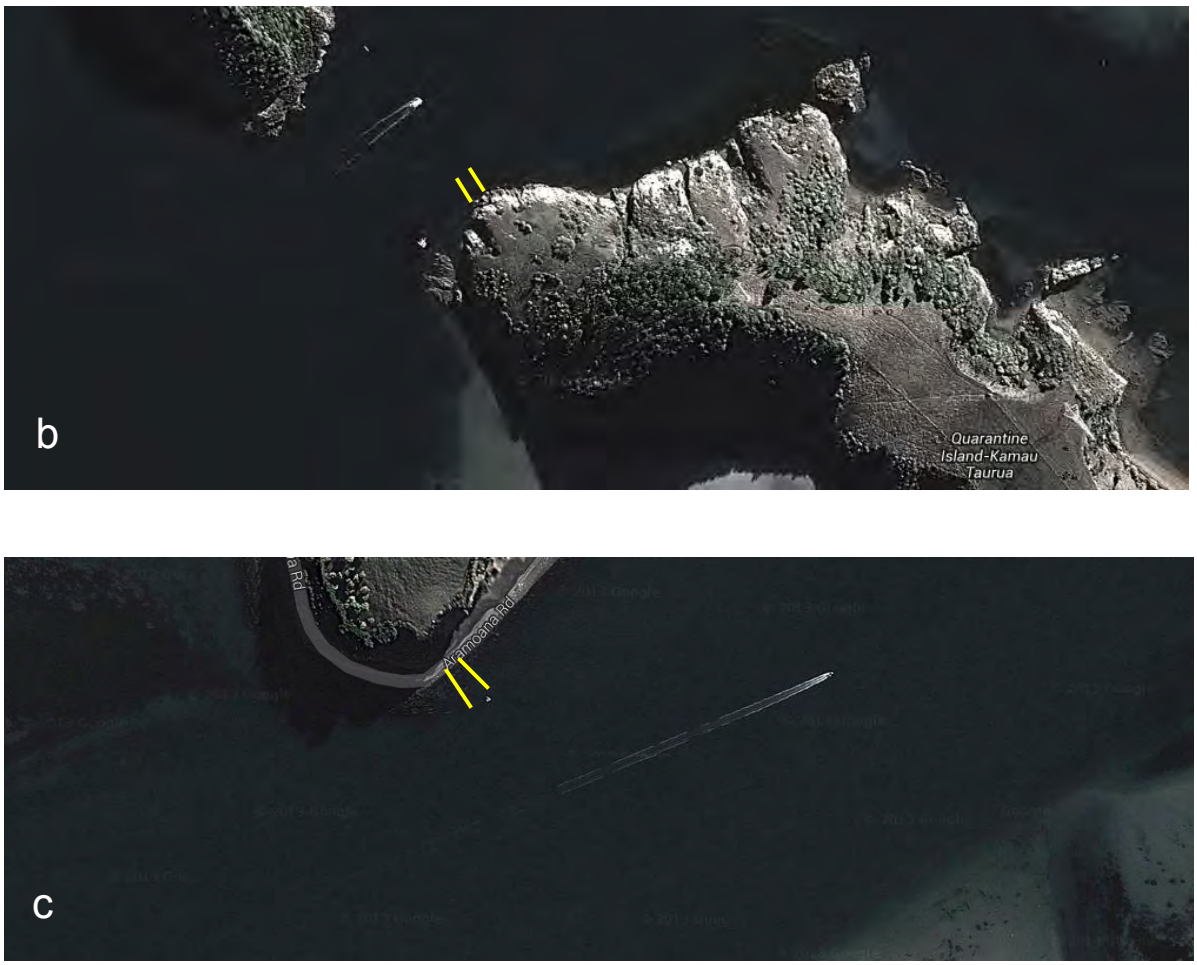


Figure 2.4.1. *Location of rocky shore transects at (a) Pudding Island; (b) Quarantine Island and (c) Pulling Point, Otago Harbour.*

Intertidal sampling comprised randomly placed 1m^2 quadrats at high tide, mid tide and low tide levels at each transect. Quadrats were photographed and obvious fauna and flora identified and counted. Loose rock/cobbles were turned over and concealed species were also identified and counted.

Subtidal sampling utilised five 0.25 m^2 photo quadrats randomly placed at each 1m depth interval where possible, or at roughly even intervals across obvious subtidal habitat along shallower transects. Photographs were then viewed by experienced personnel and obvious flora and fauna identified and counted, or percentage cover estimated, as appropriate. As pointed out by Paavo (2009), algae typically form multi-species aggregations and it is not feasible to identify most individual algal taxa in some quadrats. Consequently, only large, well-documented taxa were identified individually. Similarly, colonial or cryptic animal species (particularly sponges, colonial tunicates, and bryozoans) cannot be reliably identified in the field and a best guess based on form and colour was made. Infauna were not counted unless they were clearly identifiable as individuals.

Transects were then re-swum and video recorded to assess the distribution and abundance of

different invertebrate species and semi-quantitative observations were made of macro-algal distribution. Transect locations were recorded using hand help GPS to facilitate repeat surveys when necessary.

2.5 Deep Channels

A single video transect was swum within the swinging basin at Port Chalmers and a second transect was surveyed across the main channel within the harbour near Pulling Point (Figure 2.5.1).

Figure 2.5.1. *Location of deep channel transects at the swinging basin (left) and Pulling Point (right), Otago Harbour.*

Transects were at least 100 m long and at right angles to the channel at depths ranging from <2 m to the channel bottom. The video recording was then viewed later to assess the distribution and abundance of different invertebrate species and semi-quantitative observations were made of macro-algal distribution.

Three replicate cores were taken at six points 20 m apart along each of the two transects. Cores were 85 mm in diameter and were collected to 200 mm depth by divers using custom built corers (Figure 2.5.2).

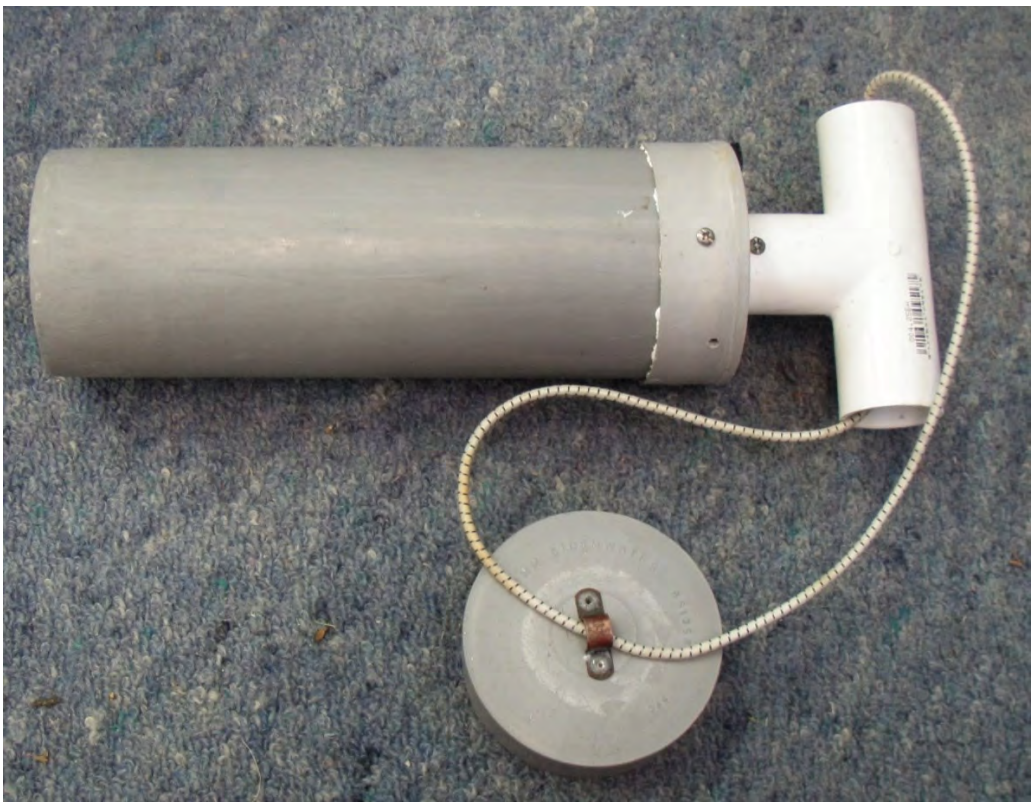


Figure 2.5.2. *Core sampler used for deep channel core sampling*.

Cores were sieved on site and retained animals preserved and returned to the laboratory for identification and enumeration. Substrate material obtained from two of the cores collected for infaunal sampling was kept and returned to the laboratory for particle size analysis and analysis of heavy metals (see Section 2.6).

2.6 Substrate Analysis

Six cores were collected to a depth of 200mm from soft bottom substrate, comprising two from Seagrass beds, two from saltmarsh and two from deep channels. Where possible, cores were photographed to allow recording of the depth of the redox discontinuity layer (RDL). A subsample was obtained from the top 20mm of each core and sent for analysis of heavy metals by Hill laboratories, Hamilton. Cores were then thoroughly mixed to ensure homogeneity and a 50cc subsample was dried for 24 hours at 60 ˚C, then sieved using graded Endicott sieves on a sieve shaker. The proportion of sample passing through 2 mm, 500 µm, 250 µm, 125 µm and 63 µm sieves was then recorded. In addition all cores collected at saltmarsh and cockle bed sites were photographed and depth of RDL determined.

3. Results

3.1 Seagrass beds

Seagrass beds were visited at low tide on 23rd and 26th July 2013. GPS co-ordinates (NZMG) for all transects and quadrat locations are presented in Table 3.1.1 to facilitate

revisits to the sites in future surveys.

Table 3.1.1 *GPS locations of seagrass assessment sites. Co-ordinates are expressed as NZMG.*

Harwood	Transect 1					
	QA	QB	QC	QD	QE	QF
	E2328600	E2328580	E2328559	E2328540	E2328521	E2328502
	N5484829	N5484836	N5484841	N5484845	N5484848	N5484855
	Transect 2					
	QA	QB	QC	QD	QE	QF
	E2328577	E2328558	E2328540	E2328521	E2328502	E2328480
	N5485157	N5485162	N5485167	N5485170	N5485175	N5485179
	Transect 3					
	QA	QB	QC	QD	QE	QF
	E2328630	E2328613	E2328596	E2328580	E2328562	E2328545
	N5485474	N5485483	N5485494	N5485506	N5485517	N5485528
	Transect 4					
	QA	QB	QC	QD	QE	QF
	E2329367	E2329374	E2329382	E2329389	E2329397	E2329406
	N5485828	N5485843	N5485864	N5485881	N5485899	N5485920
Papanui Inlet	Control 1					
	QA	QB	QC	QD	QE	QF
	E2330260	E2330267	E2330278	E2330291	E2330304	E2330315
	N5482688	N5482671	N5482658	N5482640	N5482627	N5482606
	Control 2					
	QA	QB	QC	QD	QE	QF
	E2330278	E2330296	E2330312	E2330330	E2330347	E2330365
	N5482708	N5482700	N5482690	N5482680	N5482673	N5482663

Cover by seagrass was generally high along transects, with very few quadrats falling on sparsely vegetated areas (Appendix 1). There were, however, frequent patches of bare sand scattered throughout the seagrass beds beyond the transects (Figure 3.1.1). *Zostera* blade length was variable among transects and also along the length of each transect (Figure 3.1.2). The greatest mean blade length was observed at Quadrats F and B of Transect 4 at Harwood with next longest being at Quadrat B of Transect 2 (C2) in Papanui Inlet. Most consistent lengths were found along Transect 1 (C1) in Papanui Inlet, with shortest blades being found along Transect 3 at Harwood (Figure 3.1.2).

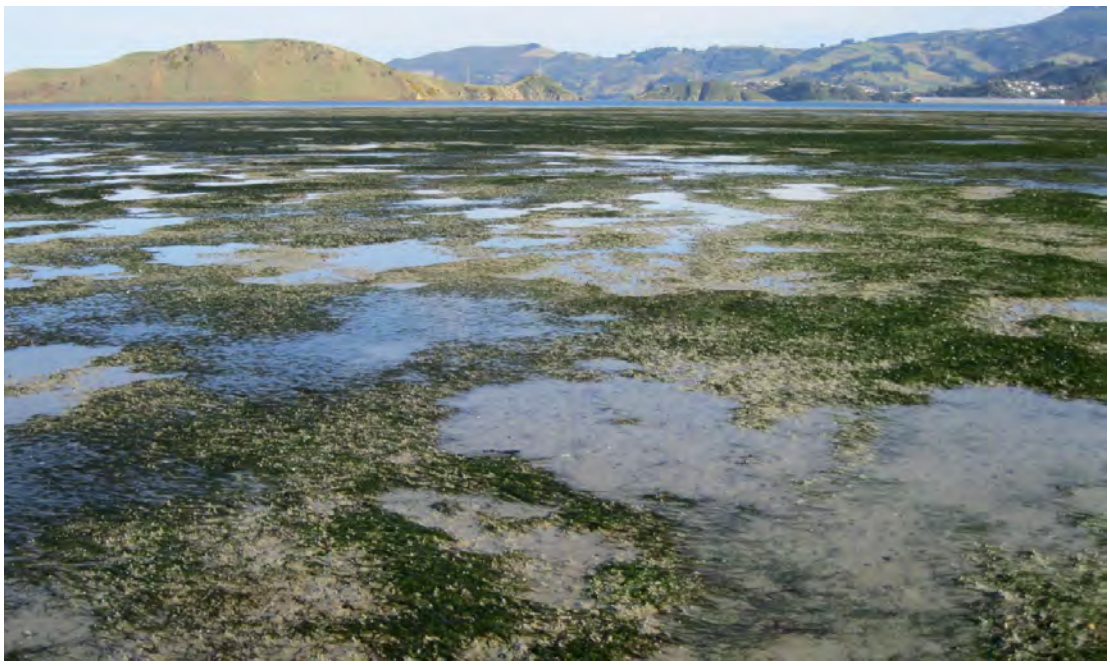


Figure 3.1.1. Zostera *bed at Harwood showing patchy nature of cover.*

The density of *Zostera* shoots was reasonably consistent among transects at both Harwood and Papanui Inlet (Figure 3.1.3). Density appears greatest along Transect 2 at Harwood but one way analysis of variance (ANOVA) reveals no significant difference among transects ($F_{5,30}$ = 1.928; p = 0.119). Note that p values of less than 0.05 indicate significant differences.

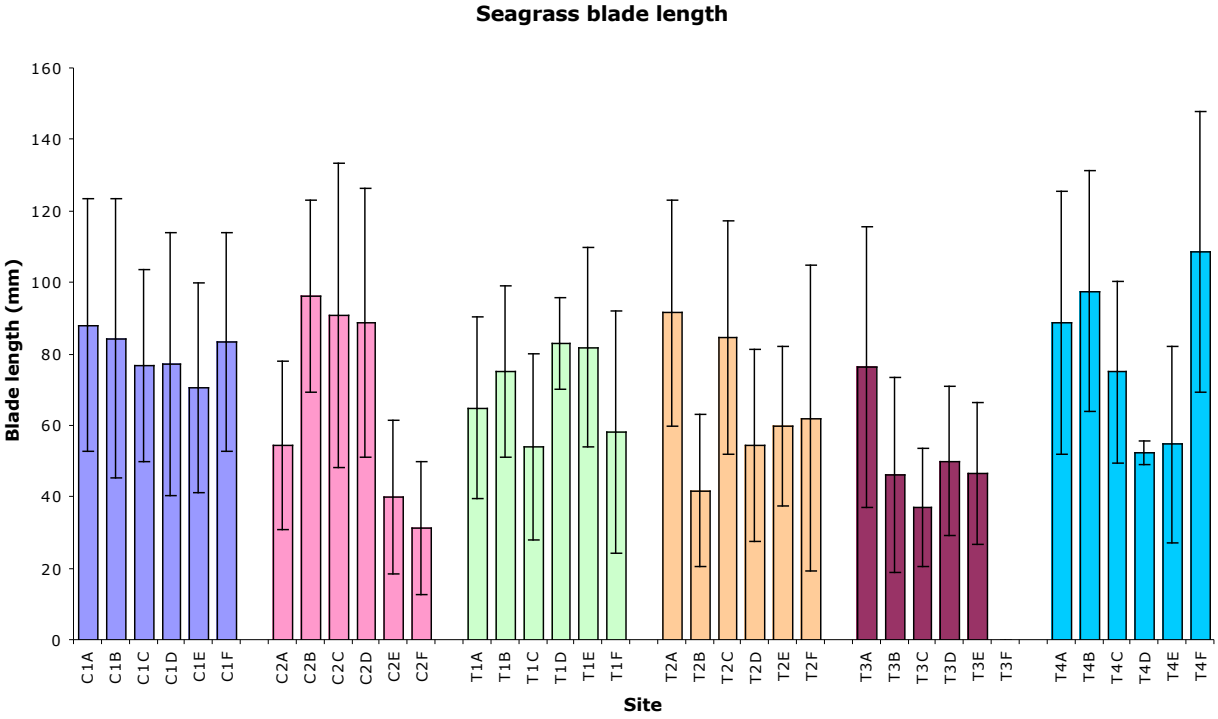


Figure 3.1.2. Zostera *mean blade lengths in quadrats at Papanui Inlet (C) and Harwood (T). Error bars are +/- one standard deviation.*

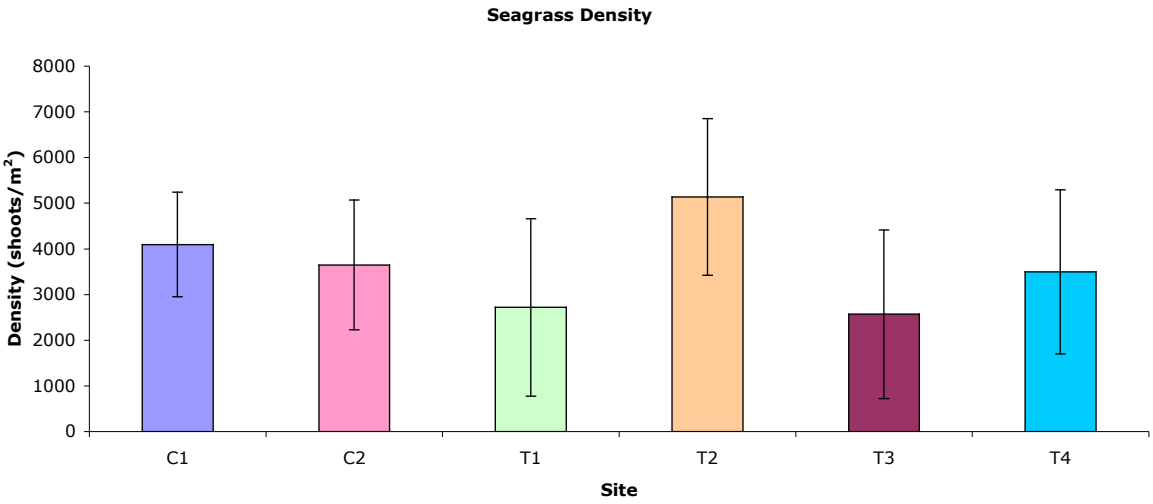


Figure 3.1.3. *Mean* Zostera *shoot density along transects at Papanui Inlet (C) and Harwood (T). Error bars are +/- one standard deviation.*

Biomass was greatest along Transect 2 at Harwood (Figure 3.1.4). This is consistent with the highest density also being along this transect. Unlike density, however, there is a significant difference in biomass among transects with T2 at Harwood being highest and T3 at Harwood the lowest ($F_{5,30} = 3.702$; $p = 0.001$).

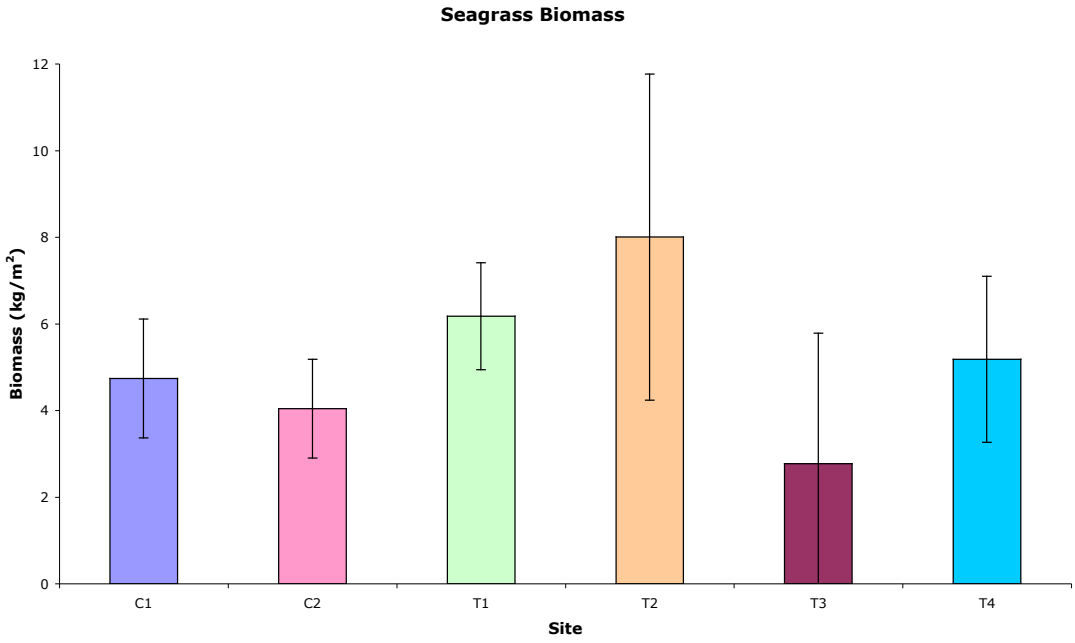


Figure 3.1.4. *Mean* Zostera *biomass along transects at Papanui Inlet (C) and Harwood (T). Error bars are +/- one standard deviation.*

High-resolution aerial photographs of Papanui Inlet were taken on 28th July. The large seagrass bed across which control transects were surveyed had an area of 14,507 m^2 (Figure 3.1.5).

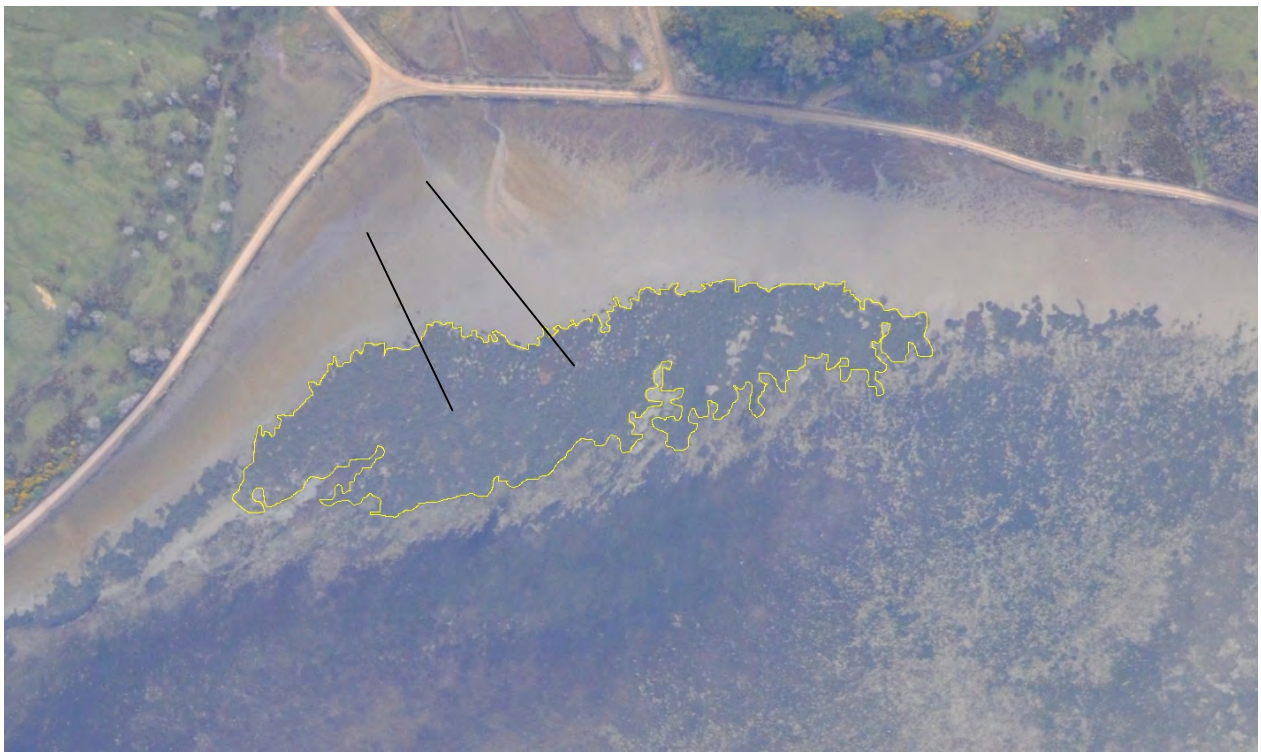


Figure 3.1.5. *Measured seagrass bed, Papanui Inlet (outlined in yellow). Seagrass transects shown as black lines.*

At Harwood the seagrass beds were more patchy. However a large clearly defined bed was located close to shore. This had an area of 4447 m^2 (Figure 3.1.6).

Figure 3.1.6. *Measured seagrass bed, Harwood (outlined in yellow). Seagrass transect shown as black line.*

Both sites will be re-photographed during future surveys and areas recalculated to determine differences. The above photographs and those presented in Appendix 5 may also be made semi-transparent and laid over future photographs for direct comparison.

Results for substrate analysis for Seagrass sites are presented in Section 3.6.

3.2 Saltmarsh

The Aramoana saltmarsh was visited at low tide on 7th August 2013. GPS co-ordinates (NZMG) for all transects and quadrat locations are presented in Table 3.2.1 to facilitate revisits to the sites in future surveys. Substrate was generally clean sand, markedly rippled in lower tide zones (Appendix 2).

Table 3.2.1 *GPS locations of saltmarsh assessment sites. Co-ordinates are expressed as NZMG.*

Transect 1				
Q1	Q2	Q3	Q4	Q5
E2329795	E2329779	E2329759	E2329742	E2329730
N5488923	N5488862	N5488755	N5488683	N5488620
Transect 2				
Q1	Q2	Q3	Q4	Q5
E2330181	E2330121	E2330096	E2330064	E2330040
N5488924	N5488786	N5488698	N5488614	N5488544
Transect 3				
Q1	Q2	Q3	Q4	Q5
E2331430	E2331404	E2331363	E2331317	E2331292
N5489058	N5488941	N5488762	N5488572	N5488471
Transect 4				
Q1	Q2	Q3	Q4	Q5
E2331892	E2331862	E2331837	E2331805	E2331789
N5489228	N5489075	N5488914	N5488753	N5488539

There was a general paucity of macroflora within the quadrats along the surveyed transects (Appendix 2). Sparse *Zostera meulleri* (seagrass) cover was present at Transect 1, Quadrats A, D and E; Transect 2, Quadrats D and E; and Transect 4, Quadrat B. Macroalgae was very rare and extremely patchily distributed, with just one quadrat (T3QA) having some very small clumps of *Enteromorpha* spp. and *Gracilaria chilensis*. A quite thick diatomaceous film was evident within Quadrat B at Transect 3 and Quadrat A at Transect 4 (Appendix 2).

Epifauna were almost completely absent from all quadrats, the exceptions being a few snails (*Melagraphia aethiops*) in Quadrats D and E on Transects 1 and 2. The mud snail (*Amphibola crenata*) was evident in parts of the saltmarsh at the high tide zone between herbaceous islands, but not within quadrats, and occasional cockles were visible on the surface of the substrate in the low tide zone at Transects 1 and 2.

Infaunal communities were reasonably diverse and showed high abundance of some animals. A small bivalve (*Perrierina harrisoni*) and amphipods were abundant along all transects with moderately high numbers of polychaete worms also present (Table 3.2.2). This is usual for sheltered soft shores around New Zealand (Morton and Miller 1973) and is consistent with the observations of Paavo *et al*. (2008). Numbers for *Perrierina harrisoni* were as high as 4738 m^{-2} (Transect 2 Quadrat D), although it should be pointed out that these bivalves are tiny, reaching just 1-3 mm in length and contribute very little to biomass. Amphipods reached densities of almost 4800 m^{-2} (Transect 3 Quadrat A). It should be noted that animals were generally identified only to family level as this is considered enough to allow reasonable characterisation of an invertebrate community (Bates *et al*. 2007).

Table 3.2.2. *Infaunal animals collected from cores at saltmarsh assessment sites. Diversity (number of taxa) and abundance m^{-2} are also shown.*

				Transect 1										Transect 2									
Phylum	**Class**	**Family**	**Genus/species**	1a1	1a2	1b1	1b2	1c1	1c2	1d1	1d2	1e1	1e2	2a1	2a2	2b1	2b2	2c1	2c2	2d1	2d2	2e1	2e2
Annelida	Polychaeta	Arenicolidae																					
		Capitellidae				1				3	7	2										6	11
		Cirratulidae																					
		Glyceridae										3										1	2
		Nephtyidae									1												1
		Neriididae						2					2										
		Opheliidae																					
		Oweniidae									1	3	1							1			1
		Spionidae									3	1	1									2	4
		Syllidae							2	2			2							2	1		1
		Terebellidae										2										1	3
Hemichordata	Enteropneusta				1																		
Crustacea	Amphipoda	Gammaridae																					
		Haustoriidae			2	5	1	1		1	1			1		2	3	2	1		1		
		Jassidae		10	7	24	26	3	5	2	4			46	59	5	8	6	4		4		1
		Lysianassidae						1				1		1						1	2	2	
		Phoxocephalidae				2	1	2	1	4	3		2	1	1	3	2	3	2	3	8	1	
	Isopoda		*Isocladus armatus*											2									
	Tanaidacea							2	1	3	8			3						1		3	2
	Cumacea										1	1											
	Ostracoda										1												
Mollusca	Gastropoda	Amphibolidae	*Amphibola crenata*																				
		Cominellidae	*Cominella glandiformis*							1													
		Trochidae	*Micrelenchus tenebrosus*										1										
	Bivalvia	Veneridae	*Austrovenus stutchburyi*								1	2	2							4	2		1
		Cyaniidae	*Perrierina harrisoni*	9	12	18	17	22	19	10	9	7	3	10	11	6	4	5	4	86	30	1	2
		Mesodesmatidae	*Paphies australis*	1					1						1								
		Tellinidae	*Macomona liliana*																			1	
Insecta	Diptera		Fly larvae																				
Nemertea			Nemertean worm																				
			Number of taxa	3	4	5	4	7	6	8	12	9	8	7	4	4	4	4	4	7	7	9	11
			Abundance per core	20	22	50	45	33	29	26	40	22	14	64	72	16	17	16	11	98	48	18	29
			Abundance per m^{-2}	1102	1212	2755	2480	1818	1598	1433	2204	1212	771	3526	3967	882	937	882	606	5400	2645	992	1598

Table 3.2.2. *Continued….*

				Transect 3										Transect 4									
Phylum	**Class**	**Family**	**Genus/species**	3a1	3a2	3b1	3b2	3c1	3c2	3d1	3d2	3e1	3e2	4a1	4a2	4b1	4b2	4c1	4c2	4d1	4d2	4e1	4e2
Annelida	Polychaeta	Arenicolidae															1						
		Capitellidae		3	11		2					2		3	3		3						
		Cirratulidae															1			1			
		Glyceridae																1					
		Nephtyidae		3		18	2						1	10				1				1	1
		Neriididae		4	3	4								3	12			3				1	
		Opheliidae					2																
		Oweniidae		2	12											1	3					2	1
		Spionidae		4								1		2								2	
		Syllidae		1	14	8	7							5	2	2		2	4				
		Terebellidae																				2	1
Hemichordata	Enteropneusta			2		5	1							1	7	1	2						
Crustacea	Amphipoda	Gammaridae		23	18									8	8				16				
		Haustoriidae						2		2	9	4								2	5		2
		Jassidae		87	43	4		11	5	2	6	9	8	24	66	4	8	26	23		3	4	11
		Lysianassidae		1				1	1			1	1			1	6				5		
		Phoxocephalidae		2				2	1	8	2	6	4	2		4	7			7			
	Isopoda		*Isocladus armatus*																				
	Tanaidacea								1			13	18			2	11				14		
	Cumacea																						
	Ostracoda																						
Mollusca	Gastropoda	Amphibolidae	*Amphibola crenata*		1																		
		Cominellidae	*Cominella glandiformis*																				
		Trochidae	*Micrelenchus tenebrosus*																				
	Bivalvia	Veneridae	*Austrovenus stutchburyi*																				
		Cyaniidae	*Perrierina harrisoni*			2	3	41	53	59	84	38	46		1		1			5	19	10	21
		Mesodesmatidae	*Paphies australis*																				
		Tellinidae	*Macomona liliana*																				
Insecta	Diptera		Fly larvae			4																	
Nemertea			Nemertean worm																1				
			Number of taxa	11	7	7	6	5	5	4	4	8	6	9	7	7	10	5	4	4	5	7	6
			Abundance per core	132	102	45	17	57	61	71	101	74	78	58	99	15	43	33	44	15	46	22	37
			Abundance per m^{-2}	7273	5620	2480	937	3141	3361	3912	5565	4077	4298	3196	5455	827	2369	1818	2424	827	2535	1212	2039

Multi-dimensional scaling was used to plot ordinations showing similarities in the infaunal communities among sites at each transect. In such procedures the invertebrate abundance data were first transformed (fourth root) to overcome the large number of zeros in the data. Bray-Curtis similarity among samples were then calculated. To interpret an ordination plot the closer any symbols are to each other, the more similar they are. Each symbol represents a quadrat sampled during the survey. Note that for ordinations the stress value of an ordination is an indication of the relationship between the similarity in species composition and the closeness in ordination space. A stress of less than 0.2 is considered quite good.

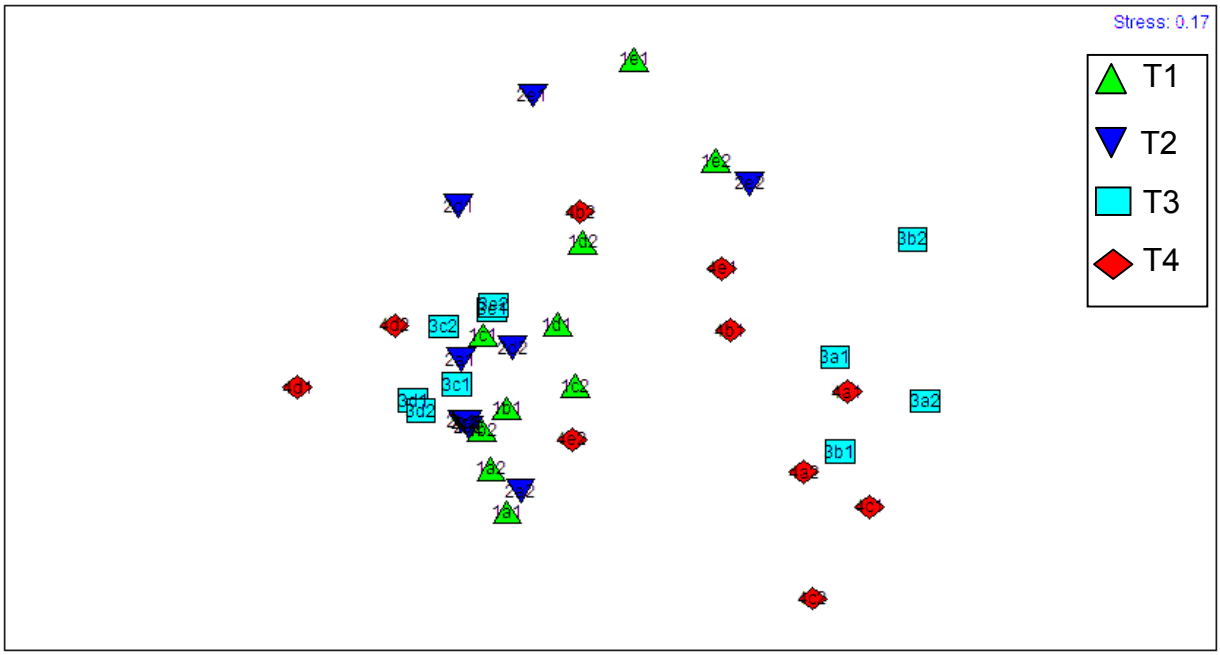
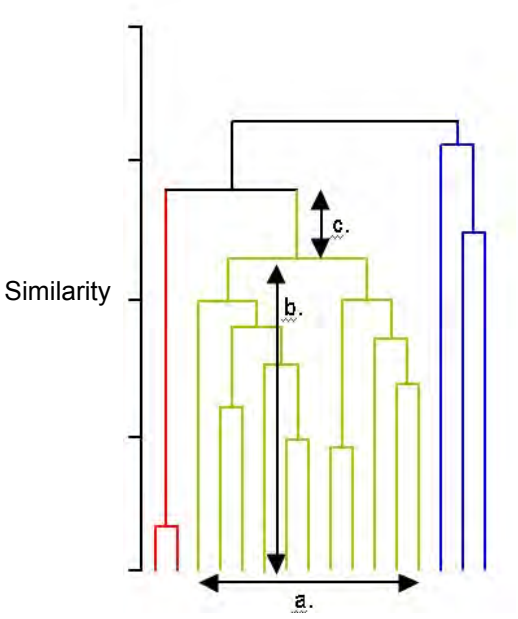


Figure 3.2.1. *Ordination plot for intertidal communities on saltmarsh transects.*

The moderately wide scatter of the symbols in the ordination plot (Figure 3.2.1) shows that there was considerable variability among communities along each of the four transects. However, the reasonably high degree of intermingling of symbols also suggests that there is considerable similarity in the infaunal community structure among transects. In other words, no one transect is significantly different from any other.

Cluster analysis also shows similarities among cores in the form of a dendrogram with cores having higher similarity being more closely linked. Weight, compactness and distinctness (Figure 3.2.2) are then considered.



a. Weight - the rough percentage of all individuals that fall within a particular cluster.
b. Compactness - how similar to one another the elements of a cluster are.
c. Distinctness - how different one cluster is from its closest neighbour.

Figure 3.2.2. *How to interpret a dendrogram.*

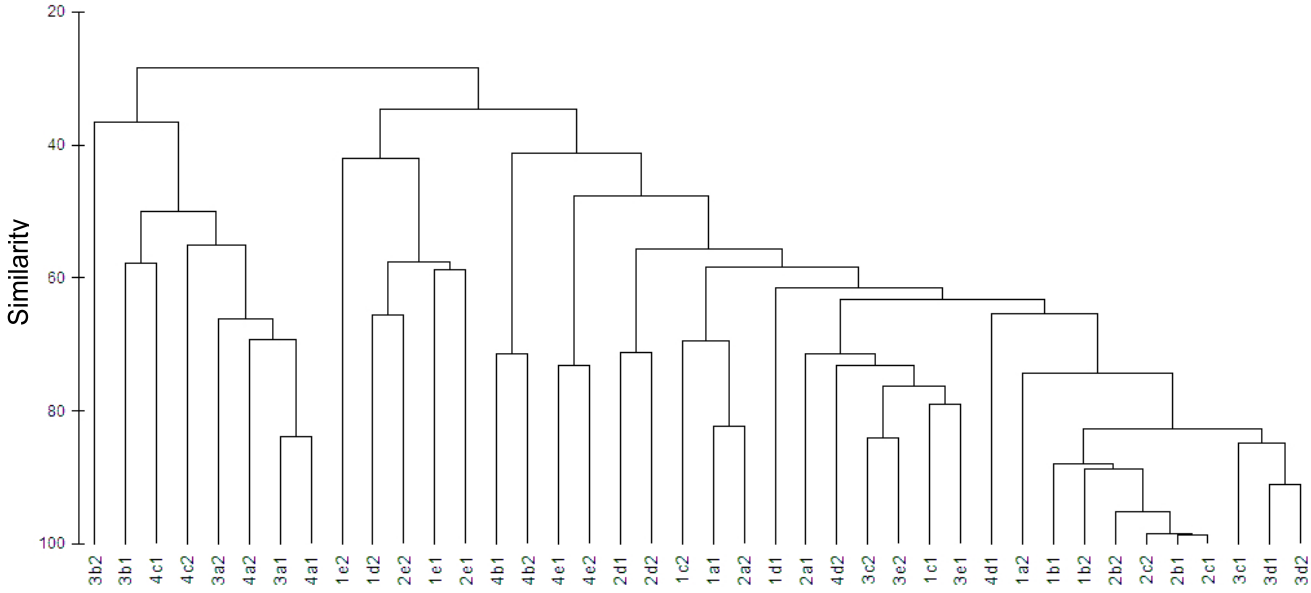


Figure 3.2.3. *Dendrogram showing the relationship among communities along transects at the Aramoana saltmarsh intertidal zone.*

The dendrogram (Figure 3.2.3) also shows a reasonable degree of compactness and low distinctness for most clusters.

Analysis of similarities (ANOSIM) among transects further supports the lack of difference with R = 0.01 (p = 0.382) for communities. Note that the nearer to zero the R value is, the

more similar the samples are. Conversely, values for R close to 1.0 indicate samples that are very different in community composition.

Similarity percentages for transects across the intertidal zone at the Aramoana saltmarsh show that differences among sites are not unduly large and are similar to differences within sites (Table 3.2.3). The transect showing most uniformity is Transect 2, and this is reflected in the very slightly tighter grouping of T2 symbols in the ordination above (Figure 3.2.1).

Table 3.2.3. *Similarity percentages calculated for different transects across the intertidal zone at Aramoana saltmarsh, Otago Harbour. A value of 100% would indicate that the communities at two locations are identical in terms of species present and the number of animals in each species.*

Saltmarsh	T1	T2	T3	T4
T1	48.62			
T2	52.83	53.86		
T3	47.27	47.75	44.58	
T4	39.46	39.36	40.31	35.55

Variability in the infaunal community at each site for each survey was measured using an index of multivariate dispersion (IMD) (Warwick and Clarke 1993). Higher values of the IMD indicate higher variability within a site. It can be seen that the highest variability was encountered at Transect 4 and the lowest at Transect 2 (Table 3.2.4).

Table 3.2.4. *Indices of multivariate dispersion calculated for different transects across the intertidal zone at Aramoana saltmarsh, Otago Harbour.*

Site	IMD
T1	0.904
T2	0.816
T3	1.049
T4	1.231

Perhaps more useful is a calculation of an infaunal diversity index at each site (Table 3.2.5). The diversity index considers the number of taxa present and the abundance of animals within each taxon and provides a score (H'). The higher the value of H' the more diverse the community is. Diversity indices ranged from 0.92 at Quadrat D1 on Transect 1 to 0.23 at Quadrat C2 on Transect 3.

The diversity indices allow the infaunal community at each site to be easily compared with other sites, or, more pertinently, from year to year or survey to survey, providing an indication of whether or not diversity is changing through time naturally or as a result of outside influences.

Table 3.2.5. *Diversity indices calculated for each site at different transects across the intertidal zone at Aramoana saltmarsh, Otago Harbour.*

H'	Transect			
Quadrat	T1	T2	T3	T4
a1	0.37	0.42	0.53	0.76
a2	0.46	0.25	0.69	0.50
b1	0.50	0.57	0.74	0.77
b2	0.37	0.54	0.69	0.87
c1	0.53	0.57	0.37	0.34
c2	0.48	0.55	0.23	0.44
d1	0.78	0.25	0.26	0.51
d2	0.92	0.53	0.27	0.60
e1	0.86	0.85	0.64	0.70
e2	0.87	0.87	0.50	0.49

High-resolution aerial photographs of the Aramoana saltmarsh were taken on 28th July. The area of a moderately large saltmarsh island across which Transect 4 runs was measured to be 6345 m^2 (Figure 3.2.4). It is assumed that this island will be representative of the greater saltmarsh and any changes in area to the island will reasonably be expected to reflect changes to the saltmarsh *in toto*. The photograph, as a whole (Appendix 5), can be made partially transparent and laid over similar photographs to provide a direct comparison with saltmarsh island at any point during future surveys.

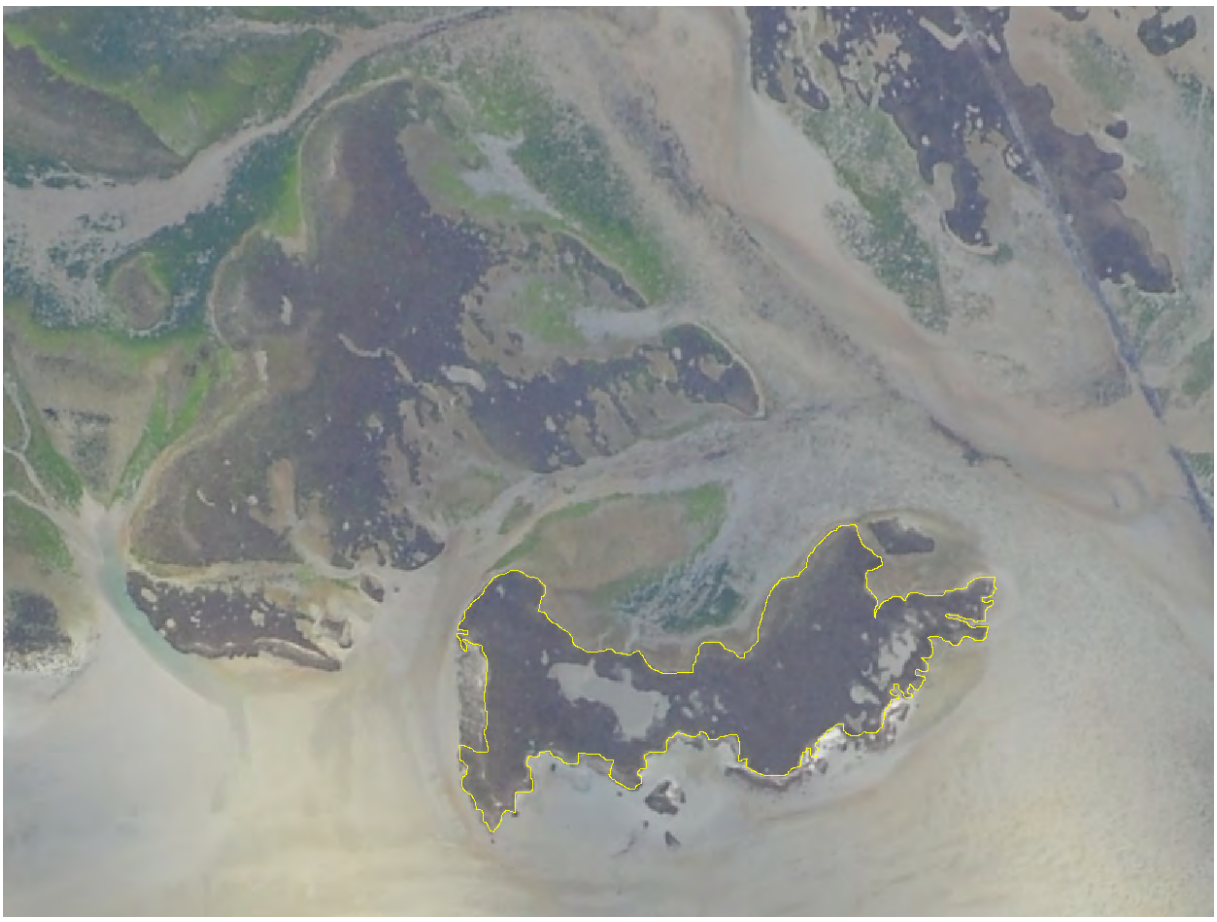


Figure 3.2.4. *Measured herbaceous island, Aramoana saltmarsh (outlined in yellow).*

Results for substrate analysis for saltmarsh sites are presented in Section 3.6.

3.3 Cockle Beds

Cockle sites were visited at low tide on 24th July and 6th August 2013. GPS co-ordinates (NZMG) for all transects and quadrat locations are presented in Table 3.3.1 to facilitate revisits to the sites in future surveys. GPS readings were taken at the south-western corner of each large (10 m x 10 m) quadrat. Substrate was generally clean sand, with occasional patches of dead cockle shell (Appendix 3).

Table 3.3.1 *GPS locations of cockle bed assessment sites. Co-ordinates are expressed as NZMG.*

Cockle Sites	Q1	Q2		
Aramoana	E2329400	E2329449		
	N5488665	N5488646		
Bed 1804	Q1	Q2	Q3	Q4
	E2327403	E2327383	E2327858	E2327897
	N5487023	N5487047	N5487151	N5487279
Te Rauone Beach	Q1	Q2		
	E2332701	E2332759		
	N5487720	N5487764		
Papanui Inlet	Q1	Q2	Q3	Q4
	E2331330	E2331383	E2331386	E2331446
	N5481633	N5481624	N5481672	N5481661

Zostera (Seagrass) cover was moderate at Sites 3 and 4 at the bed opposite Pulling Point and light at Sites 1 and 2 at Aramoana (Appendix 3). Macroalgae was very sparse with just Site 1 at the Pulling Point site having some very small clumps of *Ulva lactuca*. In Papanui Inlet Site 2 contained scattered *Ulva* and a small clump of *Gracilaria chilensis*. *Gracilaria* was also present at Site 3 here. Te Rauone Beach had a very sparse cover of Seagrass at Site 2 (Appendix 3).

Epifauna were almost completely absent from all quadrats, the exceptions being a few dislodged cockles at Site 1 opposite Pulling Point and occasional snails (*Melagraphia aethiops* and *Micrelenchus tenebrosus*) at Site 4 in Papanui Inlet.

Infaunal communities were reasonably diverse and showed high abundance of some animals. As at saltmarsh sites, bivalves (*Perrierina harrisoni, Austrovenus stutchburyi) were* most abundant, with high numbers of amphipods and polychaete worms also present (Table 3.3.2). Once again, this is consistent with the observations of Paavo *et al*. (2008), although numbers of oligochaetes were lower than observed in their study. Numbers for cockles were as high as 716 m^{-2} (Quadrat C at Papanui Inlet Site 4) and P*errierina harrisoni* reached over 1500 m^{-2} at Quadrat E at the Pulling Point bed, Site 4. Amphipods reached densities of almost 1000

m^{-2} (Quadrat C, Papanui Inlet Site 1). Polychaetes of various species reached densities of a little over 1800 m^{-2} with highest abundance being at Quadrat D at Site 4 on the bed opposite Pulling Point. Tanaid crustaceans were notably abundant in Quadrat E at Aramoana, Site 2.

Table 3.3.2. *Infaunal animals collected from cores at cockle bed assessment sites. Diversity (number of taxa) and abundance m^{-2} are also shown.*

				Quadrat																													
Phylum		**Family**	**Genus/species**	Ara1a	Ara1b	Ara1c	Ara1d	Ara1e	Ara2a	Ara2b	Ara2c	Ara2d	Ara2e	Bed1a	Bed1b	Bed1c	Bed1d	Bed1e	Bed2a	Bed2b	Bed2c	Bed2d	Bed2e	Bed3a	Bed3b	Bed3c	Bed3d	Bed3e	Bed4a	Bed4b	Bed4c	Bed4d	Bed4e
Annelida	Oligochaeta									2		1	3	2													3					2	
	Polychaeta	Capitellidae		3	3		1			13	9	3	11	4	1	3		2		1		1	1		1	7	9	5	7	6		21	2
		Glyceridae			1					1	1		3												1							2	
		Nephtyidae		1	2					2	2	1	3	1				1								1							
		Nereididae					1	1		1		4	6	1				1						3					1				3
		Opheliidae													1						1		6			1				1	1		
		Orbiniidae		1																													
		Oweniidae				1		4		5	2	4	1	1	2	1	2	1	3	10	8	3	3					2					1
		Spionidae			1								3	1		1								6	2	3	4		17	3		8	4
		Syllidae		3	9	1	1	5		2	1	3	4	7	3	6	3	7				4				2	1	2		1	1	2	1
		Terebellidae								1	1						2			2													
Hemichordata	Enteropneusta																				1										2	1	2
Crustacea	Malacostraca		*Elamena producta*																														1
			Helice crassa																									1		1			
		Callianassidae	*Callianassa filholi*																				1										
	Amphipoda	Haustoriidae				1		1		1		2							2	3	6	7	3							1			
		Jassidae		4	2	3	1	4		4			1	1					1							1			2	1		1	1
		Lysianassidae		3		1	1		2	3	1	1	3	1		1									1	3		2	3			2	
		Phoxocephalidae		3	1	1	1		3	7		3	8			1					2	1	1		2		1		2	2		2	2
	Isopoda	Cirolanidae																												4			1
	Tanaidacea			6	3		1	1	1	3		2	14																	1			1
	Cumacea					1			1	1	1	1	1																				
Mollusca	Gastropoda	Trochidae	*Micrelenchus tenebrosus*											4		2		1					1	1	1	4	5	4		1		2	1	
	Bivalvia	Veneridae	*Austrovenus stutchburyi*	8	6	5	9		2		7	4	1	2	8	8	5	7									3	2	4			1		
		Cyaniidae	*Perrierina harrisoni*	19	26	17	6	23	9	13	11	13	12			2	1		8	2	17	8	3	3	11	1	17	7	2	2	24		28
			Nucula spp.																									1					
		Tellinidae	*Macomona liliana*								1				1		1									1	1	2					
			Number of taxa	10	10	9	9	7	6	14	11	12	14	10	6	9	6	7	4	5	6	6	8	4	7	11	8	9	8	11	6	9	12
			Abundance per core	51	54	31	22	39	18	57	37	41	71	23	16	25	14	20	14	18	35	24	19	13	22	28	39	26	35	23	31	40	47
			Abundance per m^{-2}	2810	2975	1708	1212	2149	992	3141	2039	2259	3912	1267	882	1378	771	1102	771	992	1929	1322	1047	716	1212	1543	2149	1433	1929	1267	1708	2204	2590

Table 3.3.2. *Continued….*

				Quadrat																														
Phylum		**Family**	**Genus/species**	TR1a	TR1b	TR1c	TR1d	TR1e	TR2a	TR2b	TR2c	TR2d	TR2e	Pap1a	Pap1b	Pap1c	Pap1d	Pap1e	Pap2a	Pap2b	Pap2c	Pap2d	Pap2e	Pap3a	Pap3b	Pap3c	Pap3d	Pap3e	Pap4a	Pap4b	Pap4c	Pap4d	Pap4e
Annelida	Oligochaeta																		1										1		1		
	Polychaeta	Capitellidae			2					1	1				3		1	2	4	2	1	3	3	1	3	2	4	1	2	3	3	4	3
		Cirratulidae																					1											
		Glyceridae		1				1											1	1			1	1		1	2		2		1	2	1
		Nephtyidae					2													1		1					1			1	2			
		Nereididae			1											1			1											1			
		Opheliidae									1																						1
		Oweniidae		4	1	7	7	3	3	8	2		4	5	1	1	5		1	4	3	1	5	4	2	5	6	1	1	2		2	2
		Spionidae																	1			1		1	1				2	1	1	2	2
		Syllidae			1						2			1		1						3			3					2	3		
		Terebellidae																				2			1	1				2		3	1
Hemichordata	Enteropneusta													2			1	2						2					1	5			1
Crustacea	Malacostraca		*Macrophthalmus hirtipes*																		1		1			1							
		Callianassidae	*Callianassa filholi*																		1						1	1					
	Stomatopoda		*Squilla armata*													1								1									
	Amphipoda	Haustoriidae		3	1	3	3	7	2	4		4	3	3	4	17		8			1	4						3	7		5		2
		Jassidae				1	1							2	2			4		3	2	1		2	1			5	2			1	2
		Lysianassidae										1		2							3	2					1		1				
		Phoxocephalidae						3				2	2	1	1	1		1						1			1		1			1	1
		Talitridae												1																			
	Tanaidacea													1						2			1					1					
	Cumacea																	1															
	Ostracoda															1																	
Mollusca	Gastropoda	Acmaeidae	*Notoacmea* spp																										2				
		Cominellidae	*Cominella glandiformis*																									1			2		
		Trochidae	*Micrelenchus tenebrosus*																	3			1		1	1	1						
	Bivalvia	Veneridae	*Austrovenus stutchburyi*		1					2			1	2	1	1		1	4	5	4	9	2	2	2	4	5	2	7	9	13	10	9
		Cyaniidae	*Perrierina harrisoni*	3	13	2	1	7		8				3	3	1	1			1					1	3			2		1		
			Divalucina			1																											
			Nucula spp.			1									1			2	1		2	1				2							
		Mesodesmatidae	*Paphies australis*																									1					
		Tellinidae	*Macomona liliana*											1		1			3	2	1	2	2	2	2	1	1	1	2	2	2	1	3
			Number of taxa	4	7	6	5	5	2	5	4	3	4	12	8	10	4	8	8	10	10	12	9	10	10	10	10	10	13	10	10	9	12
			Abundance per core	11	20	15	14	21	5	23	6	7	10	24	16	26	8	21	16	24	19	30	17	17	17	21	23	17	32	28	33	26	28
			Abundance per m^{-2}	606	1102	827	771	1157	276	1267	331	386	551	1322	882	1433	441	1157	882	1322	1047	1653	937	937	937	1157	1267	937	1763	1543	1818	1433	1543

Multi-dimensional scaling was used to plot ordinations showing similarities in the infaunal communities among sites at each quadrat. Once again invertebrate abundance data were first transformed (fourth root) to overcome the large number of zeros in the data.

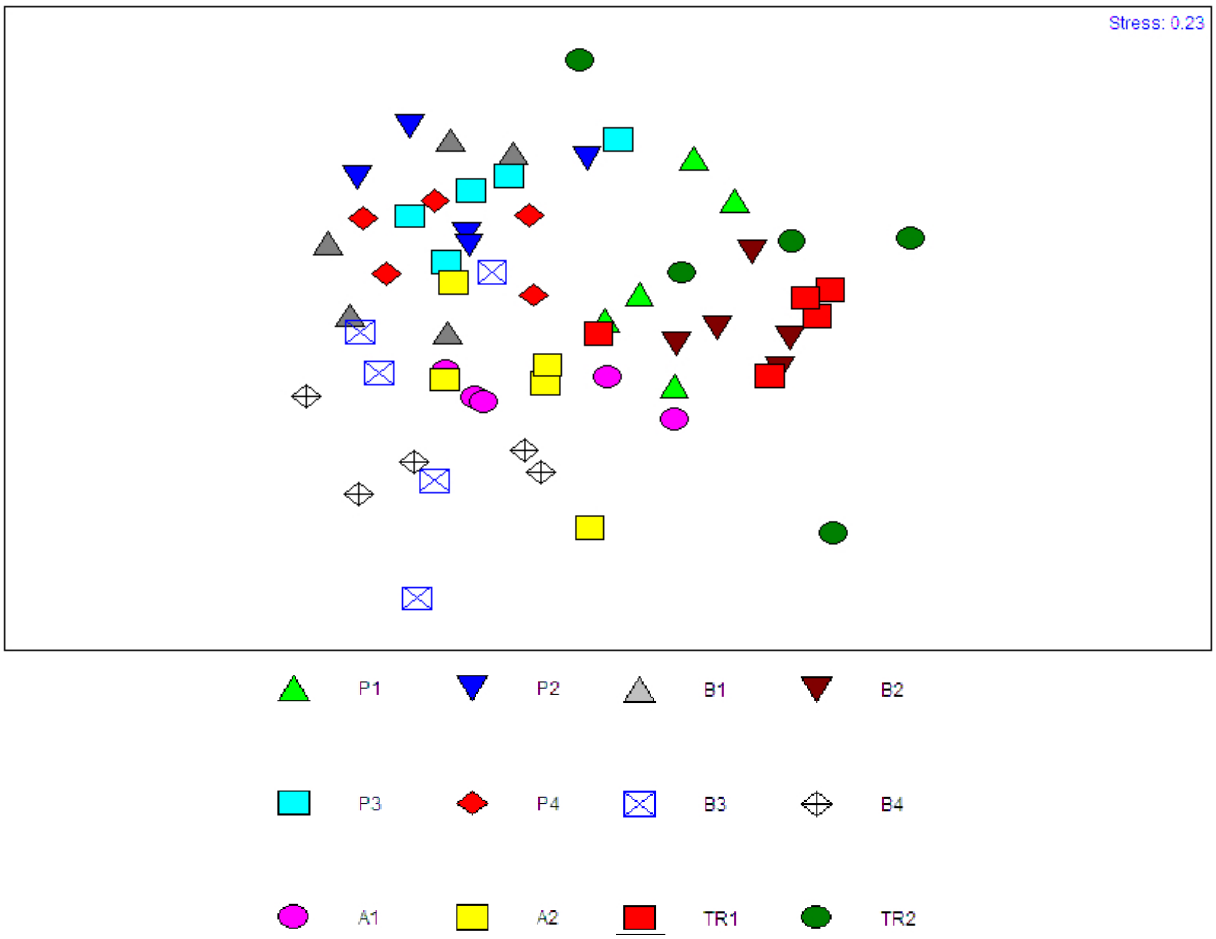


Figure 3.3.1. *Ordination plot for intertidal communities within cockle bed quadrats. P = Papanui Inlet; B = bed opposite Pulling Point; A = Aramoana; TR = Te Rauone Beach.*

The relatively high stress and moderately wide scatter of the symbols in the ordination plot (Figure 3.3.1) shows that there was considerable variability among communities at the various sites. However, some sites have their symbols moderately tightly grouped (e.g. Papanui Site 3, Te Rauone Site 1, Pulling Point Bed 4), suggesting that similarities among quadrats within sites can be quite strong.

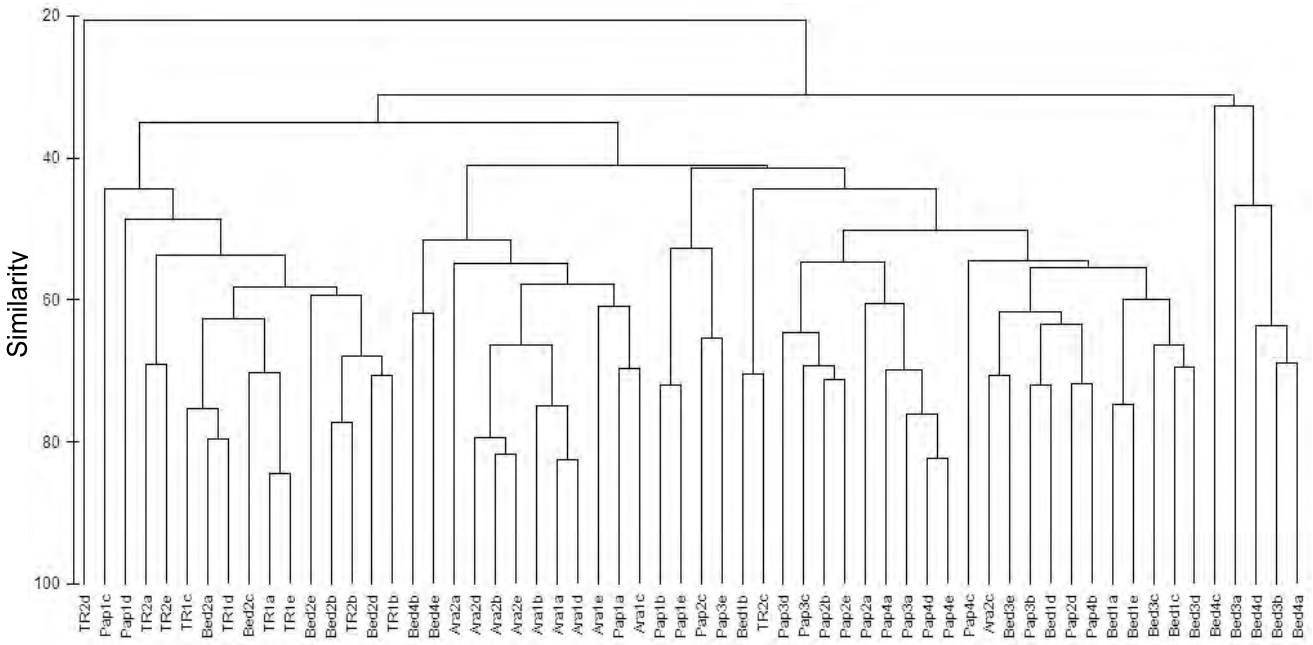


Figure 3.3.2. *Dendrogram showing the relationship among communities in different quadrats at cockle bed sites, Otago Harbour.*

The dendrogram (Figure 3.3.2) shows somewhat less compactness among clusters, once again suggesting differences in communities, but groups of quadrats within sites are reasonably closely linked.

Analysis of similarities (ANOSIM) among quadrats further suggest a moderate difference in community structure among Sites with R = 0.546 (p = 0.01). Note once again that the nearer to zero the R value is, the more similar the samples are. Conversely, values for R close to 1.0 indicate samples that are very different in community composition.

Similarity percentages for quadrats at cockle bed sites show that some sites have very low similarities (e.g. Site 2 at Te Rauone Beach and Site 3 on the bed opposite Pulling Point) while others (e.g. Site 1 at Te Rauone Beach and Site 2 on the bed opposite Pulling Point) have quite high similarities (Table 3.3.3). However, differences among many sites are not unduly large and are similar to differences within sites (Table 3.3.3). The Site showing most uniformity is Site 2 at Aramoana, although this is not obvious from the grouping of A2 symbols in the ordination above (Figure 3.3.1).

Table 3.3.3. *Similarity percentages calculated for different quadrats at calm bed assessment sites, Otago Harbour. A value of 100% would indicate that the communities at two locations are identical in terms of species present and the number of animals in each species.*

Clam Beds	Bed1	Bed2	Bed3	Bed4	TR1	TR2	Ara1	Ara2	Pap1	Pap2	Pap3	Pap4
Bed1	58.46											
Bed2	32.09	63.77										
Bed3	43.8	31.22	48.51									
Bed4	35.3	33.72	46.4	45.68								
TR1	28.71	60.99	27.59	26.92	58.36							
TR2	30.28	49.16	19.11	19.3	46.09	41.65						
Ara1	49.85	45.19	42.81	46.52	40.95	28.1	63.94					
Ara2	48.64	44.61	43.86	41.96	38	28.89	59.66	64.34				
Pap1	36.42	48.57	32.55	36.11	46.24	39.07	45.34	42.67	46.56			
Pap2	48.3	29.23	38.24	28.78	32.1	28.29	38.2	42	39.21	54.24		
Pap3	48.49	35.34	40.21	32.94	33.42	29.58	39.17	41.16	42.48	57.5	52.41	
Pap4	49.79	34.29	40.83	38.3	33	29.16	41.39	45.04	43.24	54.48	55.86	62.06

It can be seen from values for the indices of multivariate dispersion that the highest variability was encountered at Site 4 on the bed opposite Pulling Point, and the lowest at Site 2 on the same bed (Table 3.3.4).

Table 3.3.4. Indices of multivariate dispersion calculated for different quadrats at cockle bed assessment sites, Otago Harbour. Pap = Papanui Inlet; Bed = bed opposite Pulling Point; Ara = Aramoana; TR = Te Rauone Beach.

Site	IMD
Bed1	0.855
Bed2	0.569
Bed3	1.238
Bed4	1.364
TR1	0.919
TR2	1.357
Ara1	0.66
Ara2	0.681
Pap1	1.347
Pap2	1.074
Pap3	1.18
Pap4	0.757

Diversity indices calculated for each quadrat show a high degree of variability with a range of 0.29 – 1.03 (Table 3.3.5).

Table 3.3.5. *Diversity indices calculated for each quadrat at cockle bed assessment sites, Otago Harbour.*

Clam Beds	Bed1	Bed2	Bed3	Bed4	TR1	TR2	Ara1	Ara2	Pap1	Pap2	Pap3	Pap4
Quadrat A	0.92	0.48	0.53	0.68	0.56	0.29	0.84	0.63	1.002	0.863	0.95	1.03
Quadrat B	0.63	0.55	0.66	0.94	0.55	0.6	0.73	1.01	0.837	0.939	0.96	0.88
Quadrat C	0.82	0.59	0.93	0.38	0.65	0.58	0.66	0.83	0.61	0.94	0.91	0.86
Quadrat D	0.71	0.67	0.76	0.72	0.58	0.42	0.74	0.97	0.466	0.95	0.88	0.81
Quadrat E	0.68	0.81	0.87	0.69	0.62	0.56	0.57	1.03	0.778	0.87	0.91	0.95

For biomass determination the initial target was three cores per site with extra cores being added should cockles be found to occur at high density or if sample sizes showed a high degree of variability. In the event five cores were sampled at each site. Despite the extra samples, the biomass for some sites show quite large errors, but it is felt that the results are indicative of the biomass at the sampled sites and will serve adequately to compare future surveys with.

Biomass calculated for each site ranges from no measurable cockles to greater than 11 kgm^{-2} (Table 3.3.6). This falls within the range observed for previous more comprehensive studies of the cockle beds opposite Pulling Point where cockle biomass has ranged from 0 - 26.4 kgm^{-2}, with a mean biomass of 8.3 kgm^{-2} (Stewart 2013).

Table 3.3.6. *Biomass plus or minus one standard deviation calculated for each quadrat at cockle bed assessment sites, Otago Harbour. Pap = Papanui Inlet; Bed = bed opposite Pulling Point; Ara = Aramoana; TR = Te Rauone Beach.*

Site	Biomass (kg $m^{-2)}$
A1	8.72±2.06
A2	5.49±4.37
Bed1	11.83±5.51
Bed2	0.00±0.00
Bed3	3.39±4.30
Bed4	0.33±0.75
TR1	0.45±1.00
TR2	1.55±2.32
PAP1	0.73±0.97
PAP2	4.10±1.99
PAP3	2.39±1.16
PAP4	5.20±1.11

All cockles greater than 2 mm shell length were measured as well as weighed. Any cockles less than 2 mm were merely counted. Size frequencies for the various sites surveyed are presented in Figure 3.3.3a-d.

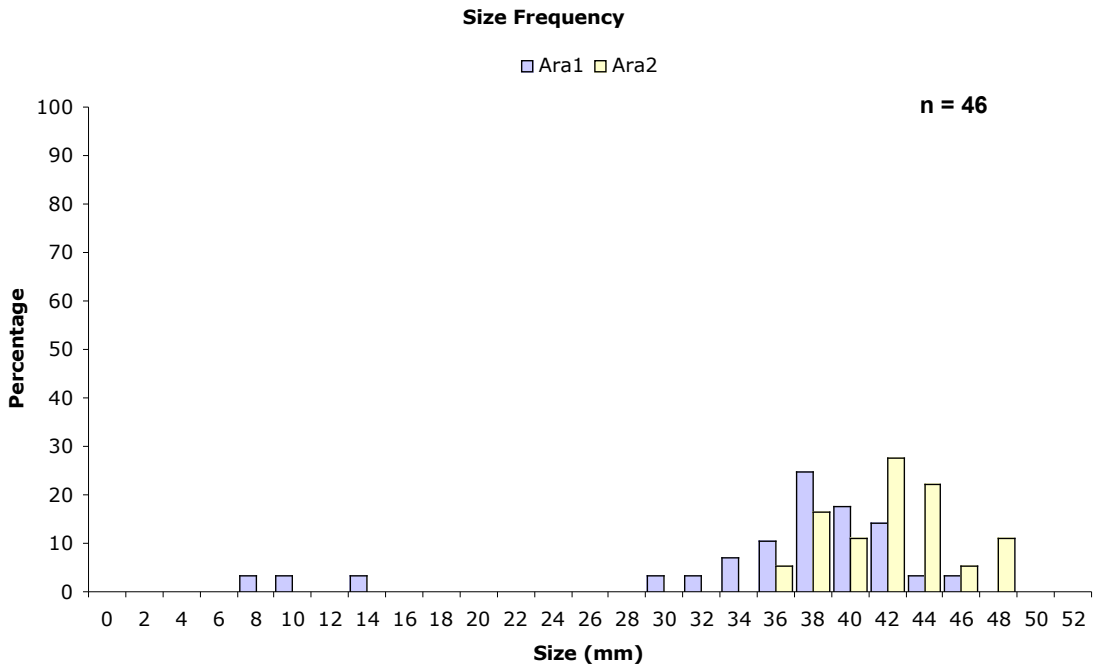


Figure 3.3.3a. *Size frequency distribution (%) for cockles at Sites 1 and 2, Aramoana, Otago Harbour.*

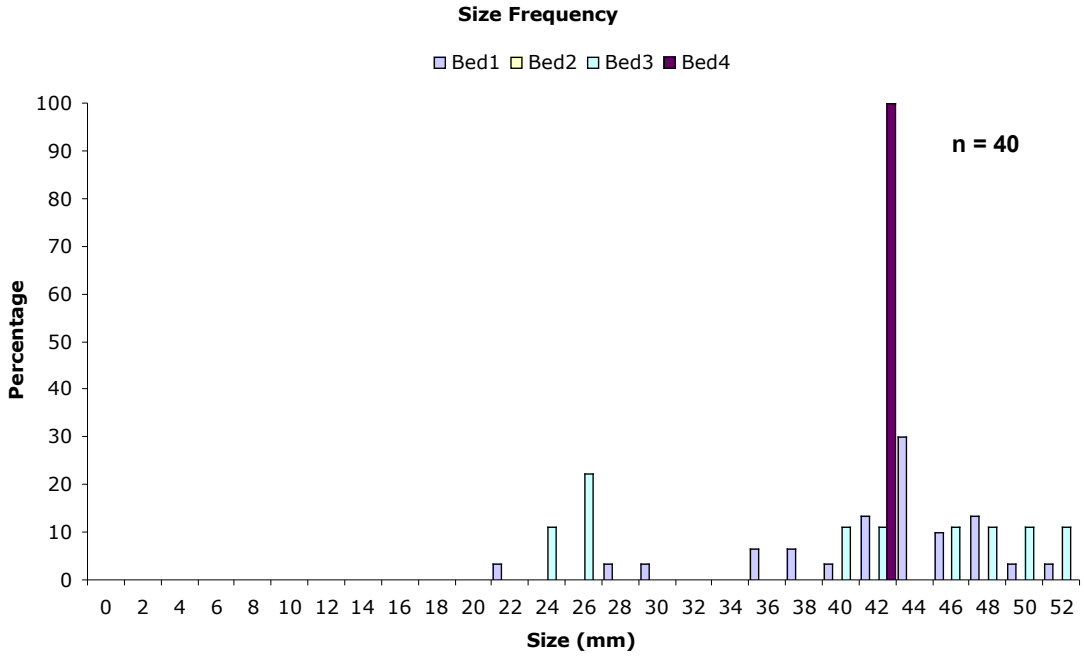


Figure 3.3.3b. *Size frequency distribution (%) for cockles at Sites 1, 2, 3 and 4 on the cockle beds opposite Pulling Point, Otago harbour.*

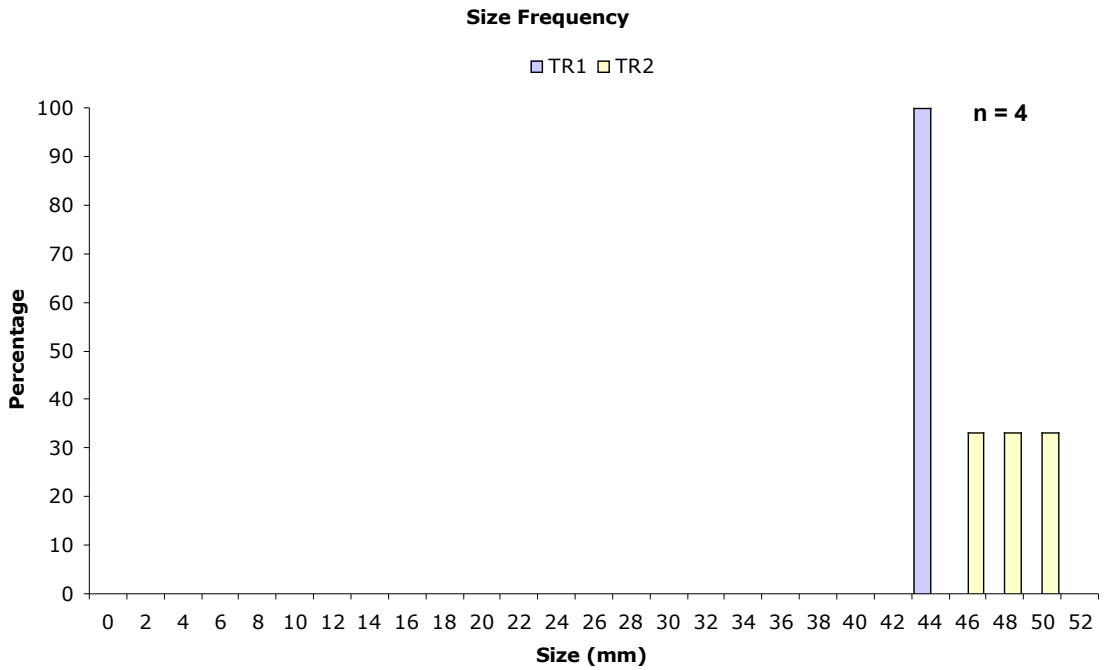


Figure 3.3.3c. *Size frequency distribution (%) for cockles at Sites 1 and 2 at Te Rauone Beach, Otago harbour.*

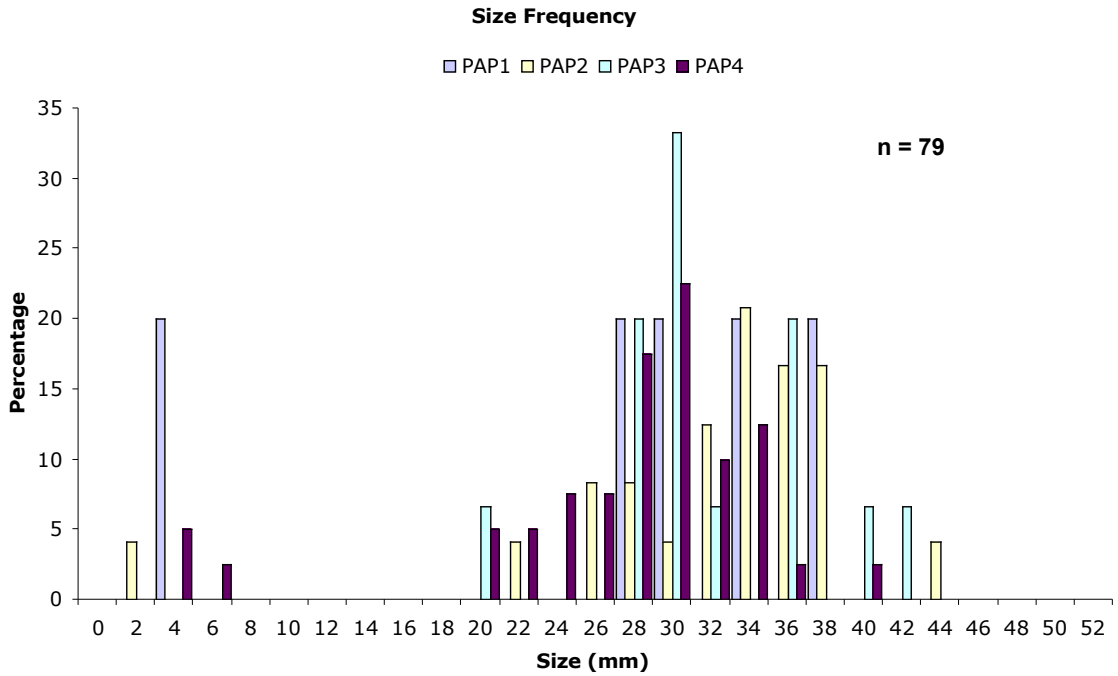


Figure 3.3.3d. *Size frequency distribution (%) for cockles at control Sites 1, 2, 3 and 4 at Papanui Inlet.*

Papanui Inlet was the only site at which there were a reasonable number of new recruits, with a somewhat lesser abundance present at Aramoana. This may be a reflection of the time of year the survey was conducted as similar surveys carried out in Otago Harbour and Waitati Inlet in mid summer often show high numbers of recruits (e.g. Stewart 2011, 2013).

Should these recruits survive it may be possible to track their progress as a discrete cohort that advances through the size classes over time.

3.4 Rocky Shores

Rocky shore sites were visited at low tide on 28th and 29th July and 6th August 2013. GPS co-ordinates were recorded for the high tide point for each Transect 1 surveyed (Table 3.4.1). At each site Transect 2 was located 3m up-harbour from Transect 1.

Table 3.4.1. *GPS locations of rocky shore assessment sites. Co-ordinates are expressed as NZMG.*

Rocky Shore	T1	T2
Pulling point	E2327669	3m up-harbour
	N5487610	
Quarantine island	T1	T2
	E2325618	3m up-harbour
	N5484136	
Pudding Island	T1	T2
	E2326480	3m up-harbour
	N5482982	

The 5 m water depth target was easily achieved at Pulling Point and Quarantine Island, but at Pudding Island the maximum water depth available at the time of the survey (MLW) was 3 m. Results for the intertidal zone at each site are presented separately from subtidal results.

There was relatively low diversity of algae in the intertidal zones, with six taxa observed at Pudding Island, seven at Quarantine Island and five taxa at Pulling Point. Cover was generally sparse except at the low tide zone on Pudding Island, where *Hormosira banksii* was abundant, and at high and mid tide zones at Quarantine Island where *Stictosiphonia arbuscula* dominated (Table 3.4.2)(Appendix 4). The species present, and cover, appear to be typical of sheltered intertidal rocky shores within Otago Harbour (Batham 1956; Probert and Jillett 1998; Stewart 2005).

Animals too, showed reasonable diversity with a total of 16 taxa observed at Pudding Island and 15 at both Quarantine Island and Pulling Point. Abundance, however, was not especially high (Table 3.4.3) (Appendix 4). Exceptions were for tubeworms at high and mid tide quadrats at Pudding Island, barnacles at Quarantine Island, and topshells (*Diloma* spp.) at high and mid tide quadrats at Pulling Point (Table 3.4.3). The results are once again generally consistent with other studies of rocky shores within Otago Harbour (Batham 1956; Probert and Jillett 1998; Stewart 2005, Paavo 2009).

Table 3.4.2. *Percentage algal cover within 1m² quadrats in the intertidal zone at Pudding Island, Quarantine Island and Pulling Point, Otago Harbour. H = High tide, M = mid tide, L = low tide.*

	Pud T1H	PudT2H	PudT1M	PudT2M	PudT1L	PudT2L	Q T1H	QT2H	QT1M	QT2M	QT1L	QT2L	Pull T1H	PullT2H	PullT1M	PullT2M	PullT1L	PullT2L
Green																		
Ulva lactuca			1		6				2	3	4	8						1
Red																		
Ballia hirsuta			1				4		7		10	1						
Stictosiphonia arbuscula	7	9					25	12	6	28				8				
Porphyra spp.										1								
Pachymenia lusoria											10	4						
Corallina spp.						3												
Lenormandia													1	2		2	4	
Liththamnion	2	8		2	2	75			4	3		18			1		1	
Brown																		
Hormosira banksii			5		25	80												
Carpophyllum flexuosum																	2	
Macrocystis Pyrifera															5			
Splachnidium rugosum											1							

Table 3.4.3. *Animals encountered within 1m² quadrats in the intertidal zone at Pudding Island, Quarantine Island and Pulling Point, Otago Harbour. H = High tide, M = mid tide, L = low tide.*

Animals (number per m²)	Pud T1H	PudT2H	PudT1M	PudT2M	PudT1L	PudT2L	Q T1H	QT2H	QT1M	QT2M	QT1L	QT2L	Pull T1H	PullT2H	PullT1M	PullT2M	PullT1L	PullT2L
Gastropod Snails																		
Diloma nigerrima		1		2		3							37	13	28	17	7	9
Diloma aethiops	2	5	6	7	3	7	3	2	5	3	1	4	6	4	9	6	13	3
Zeacumantus subcarinatus				2													1	4
Austrolittorina cincta	1	6					6	9		14								
Chitons																		
Chiton glaucus													4	3	8	4	7	4
Sypharochiton pelliserpentis	2						2	3	3	1		4	2	1	3	2		
Limpets																		
Cellana ornata						2	2		1		1	1					1	
Cellana radians					1		2	2	2		1						1	
Cellana strigilis							1		2			2						
Notoacmea spp.					3	5		1	5		1	2		1		1		
Siphonaria spp.		2			2	11	41	9	2			1	1					
Bivalves																		
Saccostrea glomerulata				1	13													8
Mytilus galloprovincialis									1									
Barnacles																		
Epopella plicata										4	31							
Chamaesipho columna										29	78							
Chamaesipho brunnea										2	17							
Elminius modestus										15						7		32
Crabs																		
Petrolisthes elongatus					9	1							8	4		8	7	4
Hemigrapsus sexdentata																	1	
Amphipods																		
Gammarid amphipod						6			2						1			
Polychaetes																		
Pomatoceros caerulus	36	13	67	54					2		13						1	7
Nereidae						1												
Sponges																		
Halichondria sp.					3													
Haliclona spp					1	3												
Number of taxa	4	5	2	5	8	9	7	6	10	7	8	6	6	6	5	7	9	8
Abundance per m²	41	27	73	66	35	39	57	26	25	68	143	14	58	26	49	45	39	71

Multi-dimensional scaling was used to plot ordinations showing similarities in the infaunal communities among sites at each quadrat. As before, invertebrate abundance data were first transformed (fourth root) to overcome the large number of zeros in the data. As is to be expected, most paired quadrats from each site show a high degree of similarity (Figure 3.4.1). Overall, each site forms a loose grouping somewhat separate from other groups, with Pulling point on the left, Pudding Island in the middle and Quarantine Island on the right (Figure 3.4.1).

To determine if tide height had any bearing on community structure a second ordination was carried out using tidal zone as the determiner (Figure 3.4.2). None of the tide heights show a distinct grouping.

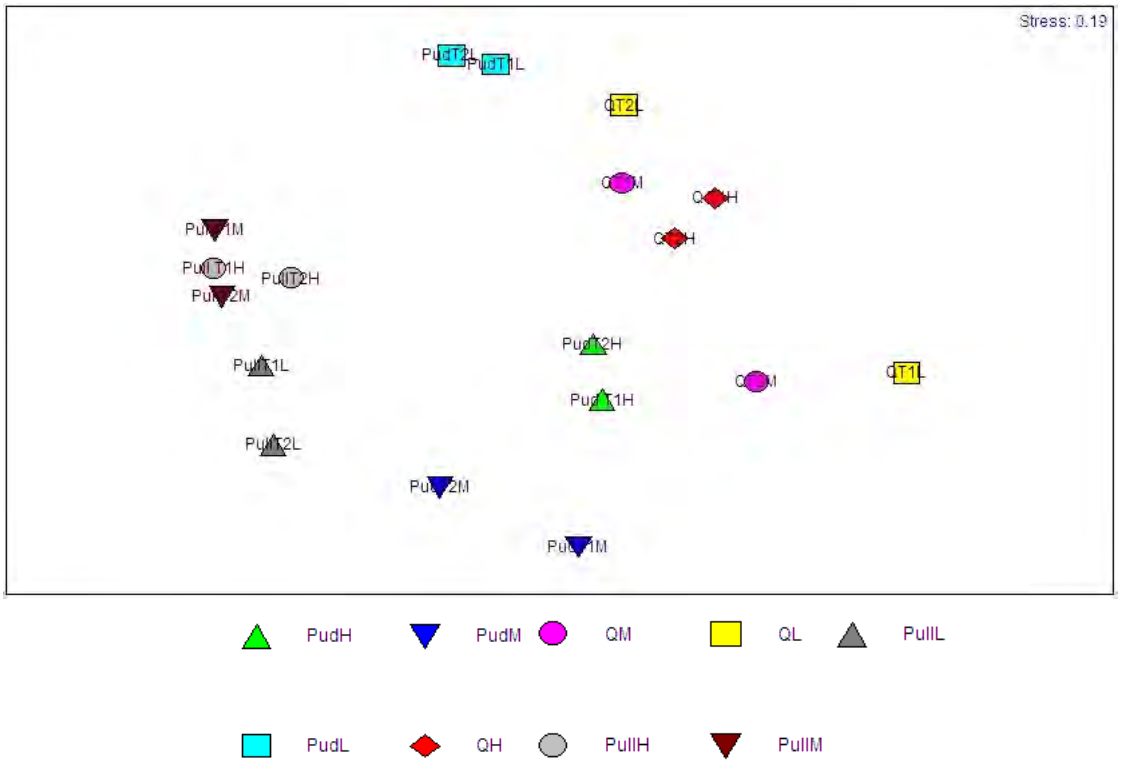


Figure 3.4.1. *Ordination plot for intertidal communities within quadrats at different rocky shore intertidal sites. Pud = Pudding Island; Q = Quarantine Island; Pull = Pulling Point.*

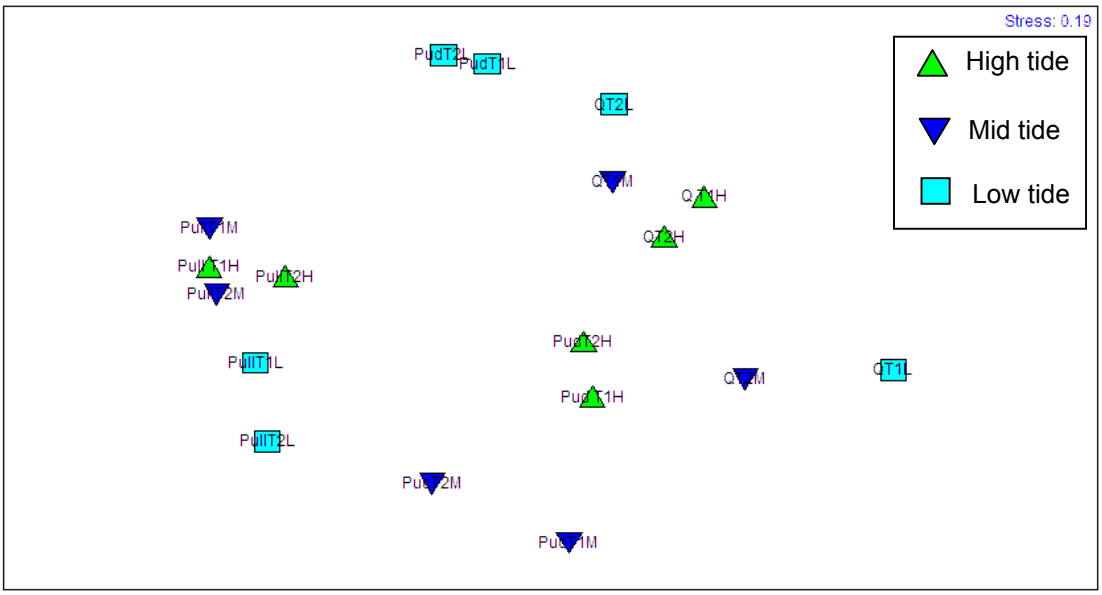


Figure 3.4.2. *Ordination plot for intertidal communities within quadrats at different rocky shore tide levels. Pud = Pudding Island; Q = Quarantine Island; Pull = Pulling Point.*

The dendrogram (Figure 3.4.3) shows relatively little compactness among clusters, once again suggesting differences in communities, with communities at Pulling Point being somewhat more different to other communities. This is likely due to the presence of numerous topshells.

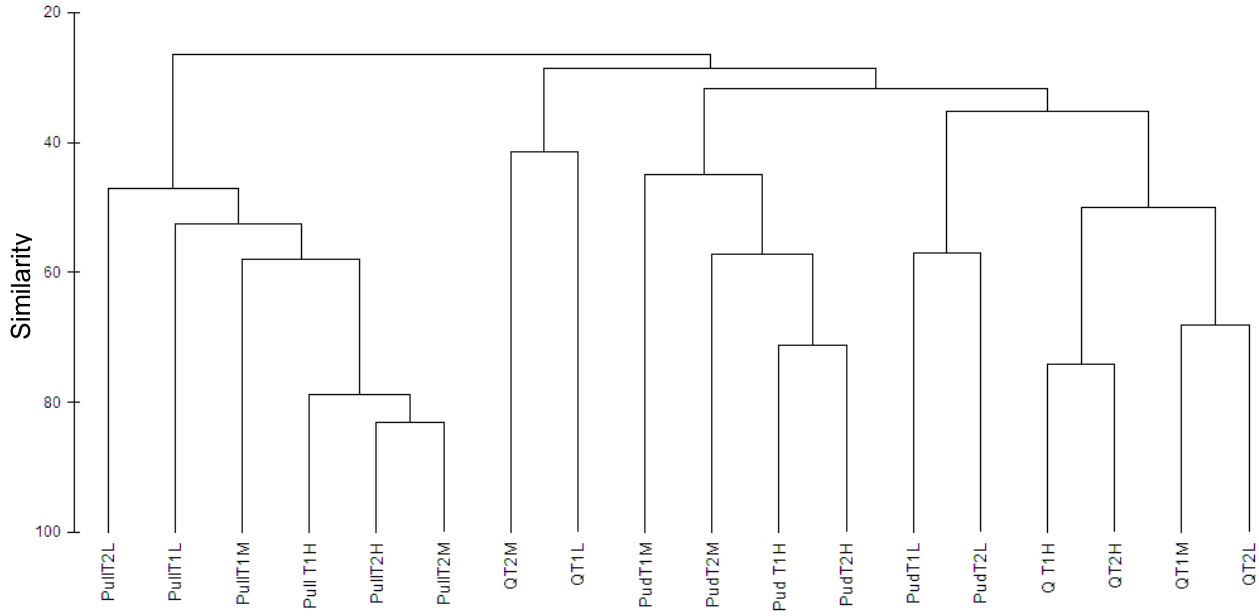


Figure 3.4.3. *Dendrogram showing the relationship among communities in different quadrats at intertidal rocky shore sites, Otago Harbour.*

Analysis of similarities (ANOSIM) among quadrats at different sites further supports the difference in community structure among quadrats and sites with R = 0.793 (p = 0.01). For different tide heights, however, R = 0.132 (p = 0.098) suggesting less difference when tidal zone is considered. Note once again that the nearer to zero the R value is, the more similar the samples are. Conversely, values for R close to 1.0 indicate samples that are very different in community composition.

Similarity percentages for quadrats at intertidal rocky shore sites show that some sites have very low similarities. Logically, low tide sites at Pulling Point have little similarity to high tide sites at Quarantine Island (Table 3.4.3). Quadrats within sites at the same tide height, however, generally have very strong similarities. This is reflected in the closer grouping of paired quadrat symbols in the ordination above (Figure 3.4.1).

Table 3.4.3. *Similarity percentages calculated for different quadrats at intertidal rocky shore assessment sites, Otago Harbour. A value of 100% would indicate that the communities at two locations are identical in terms of species present and the number of animals in each species.*

	PudH	PudM	PudL	QH	QM	QL	PullH	PullM	PullL
PudH	71.26								
PudM	49.59	51.04							
PudL	27.02	28.18	57.04						
QH	50.41	15.17	28.01	74.23					
QM	47.21	25.25	30.38	49.24	34.95				
QL	25.48	27.44	31.41	32.81	44.73	40.11			
PullH	33.77	21.45	30.37	35.48	26.25	18.97	78.17		
PullM	28.7	23.85	27.42	23.35	27.22	19.26	69.91	56.83	
PullL	29.42	40.01	30.03	15.01	23.82	21.00	50.11	48.26	52.04

It can be seen from values for the indices of multivariate dispersion that the highest variability was encountered in the mid-tide zone at Quarantine Island and the lowest at the high tide zone at Pulling Point (Table 3.3.4).

Table 3.4.4. *Indices of multivariate dispersion calculated for different quadrats at intertidal rocky shore assessment sites, Otago Harbour.*

Site	IMD
PudH	0.6
PudM	1.4
PudL	0.8
QH	0.4
QM	1.8
QL	1.6
PullH	0.2
PullM	1.0
PullL	1.4

Diversity indices calculated for each quadrat show a high degree of variability among quadrats with a range of 0.27 at mid-tide, Pudding Island, to 1.07 at mid-tide, Quarantine Island (Table 3.4.5).

Table 3.4.5. *Diversity indices calculated for each quadrat at intertidal rocky shore assessment sites, Otago Harbour.*

	PudH	PudM	PudL	QH	QM	QL	PullH	PullM	PullL
T1	0.424	0.272	0.83	0.639	1.075	0.728	0.535	0.627	0.897
T2	0.756	0.343	0.653	0.718	0.809	0.803	0.763	0.771	0.766

As suspected, 1 m^2 quadrats proved to be impractical for subtidal work due to limited visibility. Consequently 0.25 m^2 quadrats were photographed (Appendix 4). Quadrats along transects are labelled a-e with 'a' being shallowest and 'e' being deepest. Divers observed a good deal of diversity for flora but less so for fauna (Tables 3.4.7 and 3.4.8). In addition to the still photographs a video recording (included with this report) was made for each transect.

A total of 12 algal taxa were encountered along the rocky shore transects, with Pulling Point having the highest diversity (10 taxa). Algal cover in quadrats was variable, ranging from 0-33%, with the highest total cover being at Pulling Point. In video recordings *Undaria pinnatifida* was the visually most dominant species, with other large foliose species (*Carpohyllum* and *Cystophora*) also moderately common.

Table 3.4.6. *Percentage algal cover within 0.25 m^2 quadrats along subtidal transects at Pudding Island, Quarantine Island and Pulling Point, Otago Harbour.*

	PudT1a	PudT1b	PudT1c	PudT1d	PudT1e	PudT2a	PudT2b	PudT2c	PudT2d	PudT2e	QT1a	QT1b	QT1c	QT1d	QT1e	QT2a	QT2b	QT2c	QT2d	QT2e	PullT1a	PullT1b	PullT1c	PullT1d	PullT1e	PullT2a	PullT2b	PullT2c	PullT2d	PullT2e
Green Algae																														
Enteromorpha spp																							3							
Ulva lactuca	1									2		5			2	2	1	5	5						6	5			17	6
Red Algae																														
Callophyllis spp.			2		2	8		5	5	6			6	6	10	9	13		10	3	10		2	9	3					
Ceramium uncinatum																								9					3	
Coralina spp.											15												1							
Lenormandia spp.					15							2													5	4	18		16	4
Lithothamnion spp.	5	10			1						2		4				8				8	3	4	1	2	6		4	1	2
Brown Algae																														
Carpophyllum flexuosum	8								2		3																			
Cystophora torulosa											13												2							
Macrocystis pyrifera													3											1			5			
Petalonia fascia	1					2																								
Undaria pinnatifida	18	15												20				5	8	2					2	7			8	

Table 3.4.7. *Animals encountered within 0.25 m^2 quadrats along subtidal transects at Pudding Island, Quarantine Island and Pulling Point, Otago Harbour.*

	PudT1a	PudT1b	PudT1c	PudT1d	PudT1e	PudT2a	PudT2b	PudT2c	PudT2d	PudT2e	QT1a	QT1b	QT1c	QT1d	QT1e	QT2a	QT2b	QT2c	QT2d	QT2e	PullT1a	PullT1b	PullT1c	PullT1d	PullT1e	PullT2a	PullT2b	PullT2c	PullT2d	PullT2e
Molluscs																													
Dendrodoris citrina																										2			1
Scutus breviculus	4	3							1		2	2	3	1						1			1			2				
Sypharochiton pelliserpentis														1															
Anemones																													
Habrosanthus bathamae												7	6				1		1										
Sponges																													
Brown *Mycale* (%)															4		7	5	5	3				1		10			
Dactylia palmata																			4	9									
Orange *Mycale* (%)													6	4			5		2	5									
White *Mycale* (%)													2						2	1									
Yellow *Mycale* (%)														11	2			3									1		
Tethya spp.	5															2													
Crabs																													
Macrophthalmus hirtipes			1				2																						
Polychaete worms																													
Pomatoceros caerulus																									1				
Echinoderms																													
Allostichaster insignis														1															
Evechinus chloroticus																									1				
Tunicates																													
Orange *Didemnum*																			2										
Pyura pachydermatina												1								1									
Fish																													
Variable triplefin															1														
Number of taxa	2	1	1	0	0	0	1	0	1	0	1	3	4	5	3	1	3	2	6	6	0	0	1	1	0	4	2	0	0	1
Abundance per m^{-2}	36	12	4	0	0	0	8	0	4	0	8	40	68	72	28	8	52	32	64	80	0	0	4	4	0	56	12	0	0	4

Animals were less common than algal species, with relatively low abundance and diversity at both Pudding Island and Pulling Point (Table 3.4.7). In total, 18 taxa were encountered, with 13 of those being represented at Quarantine Island. Quadrats 1c and 2b at Pudding Island show a clear difference from other sites in the ordination (Figure 3.4.4) due to their having just burrowing crabs (*Macrophthalmus hirtipes*) present. Other sites all have a variety of sea squirts, sponges, polychaete worms and molluscs present, but no crabs. Video recordings echo the observations of the still photographs and also emphasise the presence of numerous burrows belonging to polychaetes and various crustaceans, and siphons, generally of cockles (*Austrovenus stutchburyi*). Areas of dead shell feature prominently in video recordings of transects at Pudding Island (*Maoricolpus roseus roseus*) and Quarantine Island (*Austrovenus stutchburyi*).

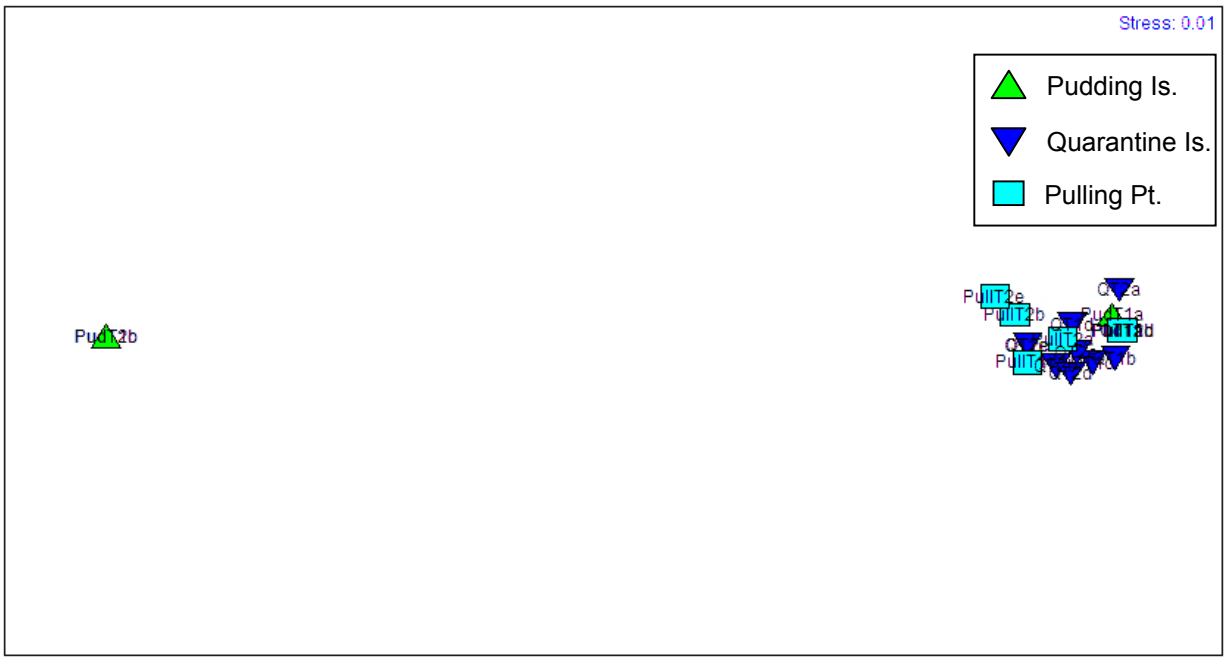


Figure 3.4.4. *Ordination plot for subtidal rocky shore communities within quadrats at different rocky shore intertidal sites. Pud = Pudding Island; Q = Quarantine Island; Pull = Pulling Point.*

The dendrogram for multidimensional scaling emphasises the difference in communities along the subtidal rocky shore transects, with Pudding Island T1a and T2b well separated from other groups and Pulling Point T2b and T2e also separated (Figure 3.4.5). The lack of compactness (i.e. how similar to one another the elements of a cluster are) is also quite marked. Note that any quadrats for which no animals were observed do not appear in ordinations or dendrograms.

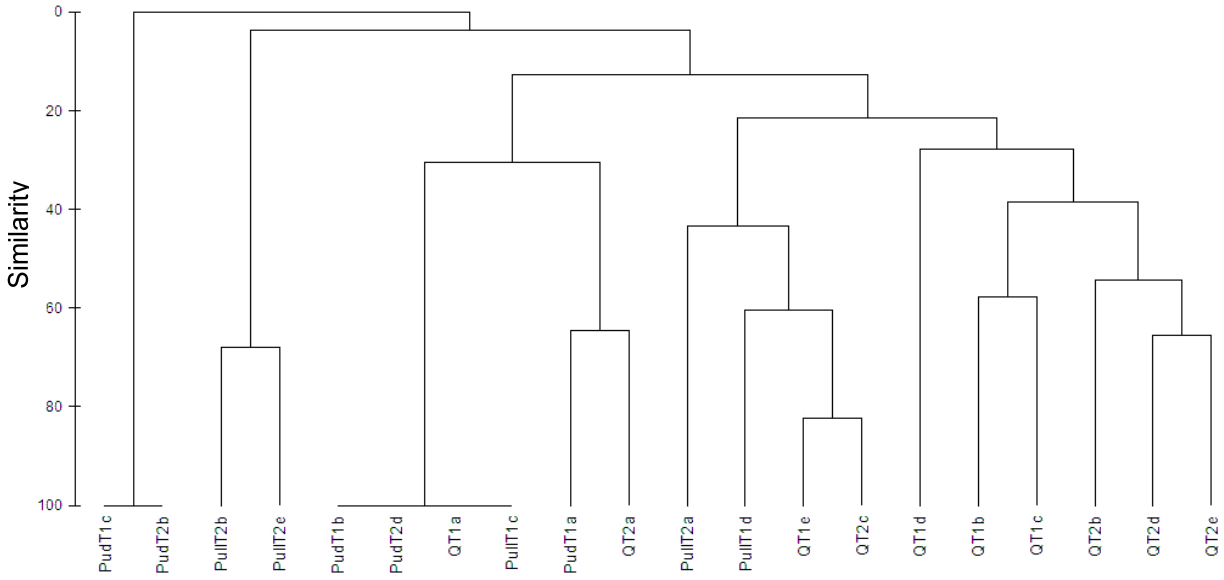


Figure 3.4.5. *Dendrogram showing the relationship among communities in different quadrats at subtidal rocky shore sites, Otago Harbour.*

Analysis of similarities (ANOSIM) among transects at different sites also suggest that differences, while reasonably low, are significant ($R = 0.198$, $p = 0.027$).

Similarity percentages for subtidal rocky shore sites show that similarities, both within sites and among sites, are quite low (Table 3.4.8).

Table 3.4.8. *Similarity percentages calculated for different subtidal rocky shore assessment site sites, Otago Harbour. A value of 100% would indicate that the communities at two locations are identical in terms of species present and the number of animals in each species.*

	Pudding	Quarantine	Pulling
Pudding	32.19		
Quarantine	13.43	23.29	
Pulling	14.35	16.91	15.38

It can be seen from values for the indices of multivariate dispersion that the highest variability was encountered at Pulling Point and the lowest at Quarantine Island (Table 3.4.9).

Table 3.4.9. *Indices of multivariate dispersion calculated for different quadrats at subtidal rocky shore assessment sites, Otago Harbour.*

	IMD
Pudding	0.973
Quarantine	0.965
Pulling	1.183

Diversity indices calculated for each quadrat show a high degree of variability with a range of 0.0 (no or just one animal species encountered) to 0.72 at Quadrat D, Quarantine Island (Table 3.4.10).

Table 3.4.10. *Diversity indices calculated for each quadrat at subtidal rocky shore assessment sites, Otago Harbour.*

H'	Pudding Island		Quarantine Island		Pulling Point	
Quadrat	T1	T2	T1	T2	T1	T2
A	0.298	0	0	0	0	0.389
B	0	0	0.348	0.39	0	0.276
C	0	0	0.562	0.287	0	0
D	0	0	0.485	0.722	0	0
E	0	0	0.415	0.625	0	0

3.5 Deep Channels

Deep channel sites were visited at low tide on 28th and 29th July 2013. GPS co-ordinates were recorded for the shallow and deep end for each Transect 1 surveyed (Table 3.5.1).

Table 3.5.1. *GPS locations of deep channel transect sites. Co-ordinates are expressed as NZMG. Also shown are depths at each end of each transect.*

Soft Bottom	Shallow	Deep
Swinging Basin	E2325953	E2325879
	N5485623	N5485696
	1.5m	13m
Pulling Point	Shallow	Deep
	E2327785	E2327708
	N5487315	N5487380
	1.4m	12.7m

Bottom sediment at the Swinging Basin site was generally quite clean and largely devoid of growing macroalgae. However, there were some very sparse clumps of *Lenormandia* and considerable drift algae, especially *Ulva lactuca.* Video recording along the Swinging Basin transect showed occasional burrows, likely those of burrowing crabs (*Macrophthalmus hirtipes*), ghost shrimps (*Callianassa filholi*) and mantis shrimps (*Squilla armata*), and polychaete worms. Surface dwelling crabs were also in evidence, including three cancer crabs (*Cancer novaezelandiae*), a camouflage crab (*Notomithrax* spp.) and a paddle crab (*Ovalipes catharus*).

At the Channel site there was very slightly increased algal diversity with very small clumps of what appeared to be *Gymnogrongus, Gracilaria, Ceramium* and *Lenormandia* evident. Animals too, were more diverse, with numerous burrows, cancer crabs, paddle crabs and nudibranchs all present. At about 50 m along the transect the substrate became more shelly, comprising mainly dead *Austrovenus stutchburyi* shell. This firmer substrate provided anchorage for scattered colonial hydroids, sea tulips (*Pyura pachydermatina*), and encrusting sponges.

Infaunal animals showed much more diversity than epifauna, with 15 taxa present at the Swing Basin Transect and 18 taxa at the Channel Transect (Table 3.5.2). Both transects were dominated by polychaete worms, although amphipods were also reasonably abundant. Bivalve molluscs were more common at the Swinging Basin Transect than in the Channel. However, oligochaetes were not as common as found by Paavo *et al.* (2008). This, of course, may be a function of sampling methodology, season (early June for Paavo *et al.*; late July for this study) and the time interval since the channel was last dredged.

Multi-dimensional scaling was once again used to plot ordinations showing similarities in the infaunal communities among sites at each transect. As before, invertebrate abundance data were first transformed (fourth root) to overcome the large number of zeros in the data.

Table 3.5.2. *Infaunal animals collected from cores at deep channel assessment sites. Diversity (number of taxa) and abundance m^{-2} are also shown.*

				Swinging Basin																
Phylum	**Order**	**Family**	**Genus/species**	S 1a	S 1b	S 1c	S 2a	S 2b	S 2c	S 3a	S 3b	S 3c	S 4a	S 4b	S 4c	S 5a	S 5b	S 5c	S 6a	S 6b	S 6c
Annelida	Oligochaeta			3	1	3				2	3	2									1
	Polychaeta	Glyceridae		8	17	12	5		12	26	11	14	7					1	1		1
		Nephtyidae		1		1				1	1	1	2						2		2
		Nereididae					1	1			2				2						
		Opheliidae		1			2	1			2		1	3	2	1	1			1	
		Spionidae		3	6	9	4	3	4	6	2	4						1	1		1
		Syllidae		2			4	4	2	2	1	2		4	1					1	
		Terebellidae																			
Crustacea	Amphipoda	Haustoriidae						1	1		2	1		2	7	5	6			5	
		Jassidae		1					1						3	1	1				
		Lysianassidae			2																
		Phoxocephalidae		3	4	5				3	7					3	1	1	1	1	
	Tanaidacea												1		2						
	Ostracoda															1					
Mollusca	Bivalvia		*Austrovenus stutchburyi*																		
		Nuculidae	*Nucula nitidula*	3	1			1			6	2		2							
		Ungulinidae	*Diplodonta* spp.	1	2	1			1		3							5	1	1	1
		Veneridae	*Paphies australis*																		
Pycnogonida																					
Colonial hydroid																					
			Number of taxa	10	7	6	5	6	6	6	11	7	4	4	6	5	4	4	5	5	5
			Abundance per core	26	33	31	16	11	21	40	40	26	11	11	17	11	9	8	6	9	6
			Abundance per m^{-2}	4581	5815	5462	2819	1938	3700	7048	7048	4581	1938	1938	2995	1938	1586	1410	1057	1586	1057
			Mean per site			5286			2819			6226			2291			1645			1233

Table 3.5.2. *Continued….*

				Channel																	
Phylum	**Order**	**Family**	**Genus/species**	C 1a	C 1b	C 1c	C 2a	C 2b	C 2c	C 3a	C 3b	C 3c	C 4a	C 4b	C 4c	C 5a	C 5b	C 5c	C 6a	C 6b	C 6c
Annelida	Oligochaeta			3																	
	Polychaeta	Glyceridae		5	2	1														1	
		Nephtyidae		1		1				1											1
		Nereididae				2		2	1	2		1	3	1		1	1				
		Opheliidae			1	2	1		1		3			2	1					1	1
		Spionidae		2	1				1									1	2	2	
		Syllidae				1						2									
		Terebellidae						1													
Crustacea	Amphipoda	Haustoriidae			1						2										
		Jassidae					1	1	1							1	1				
		Lysianassidae																	1		
		Phoxocephalidae		1	3		1			1	2		1			1	1	1	4	1	1
	Tanaidacea				1																
	Ostracoda																				
Mollusca	Bivalvia		*Austrovenus stutchburyi*			1	1		1	1	2	1									
		Nuculidae	*Nucula nitidula*		1		1						1	1					1		
		Ungulinidae	*Diplodonta* spp.																		
		Veneridae	*Paphies australis*											1							
Pycnogonida								1					1						1		
Colonial hydroid													1	1	1				1	1	1
			Number of taxa	5	7	6	5	4	5	4	4	3	5	5	2	3	3	2	6	5	4
			Abundance per core	12	10	8	5	5	5	5	9	4	7	6	2	3	3	2	10	6	4
			Abundance per m^{-2}	2114	1762	1410	881	881	881	881	1586	705	1233	1057	352	529	529	352	1762	1057	705
			Mean per site			1762			881			1057			881			470			1175

Overall, each transect forms a very loose grouping with the Swinging Basin mainly on the upper right and the Channel mainly on the lower left (Figure 3.5.1).

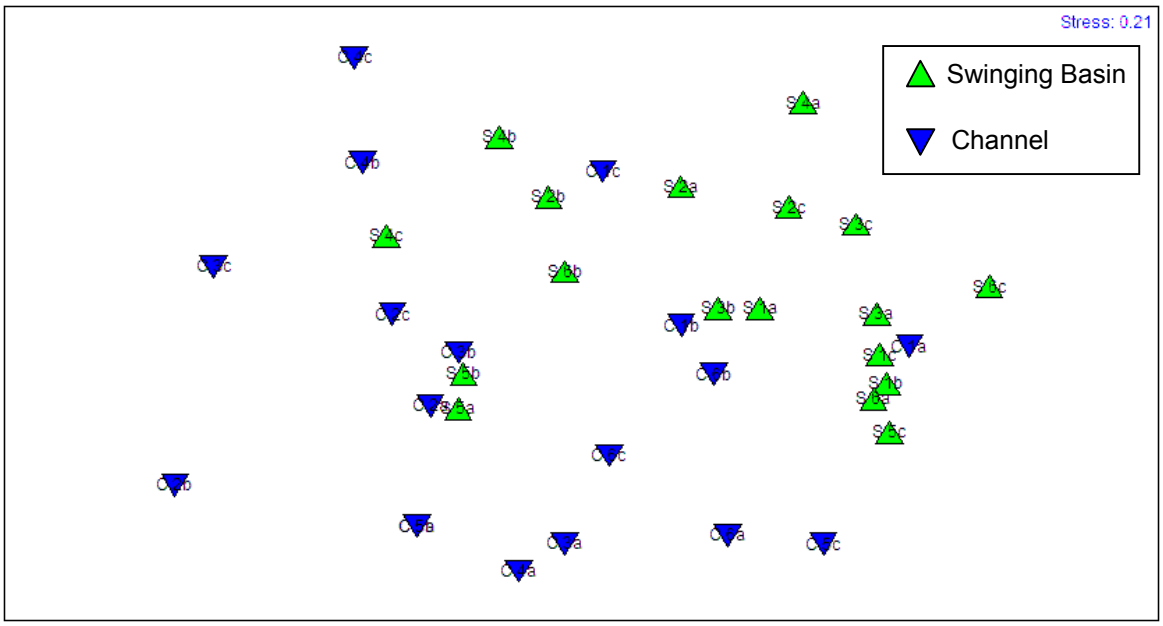


Figure 3.5.1. *Ordination plot for infaunal communities in cores collected along transects at the Port Chalmers Swinging Basin and across the Channel at Pulling Point.*

The dendrogram (Figure 3.5.2) shows moderate compactness among clusters, once again suggesting differences among transects and within transects.

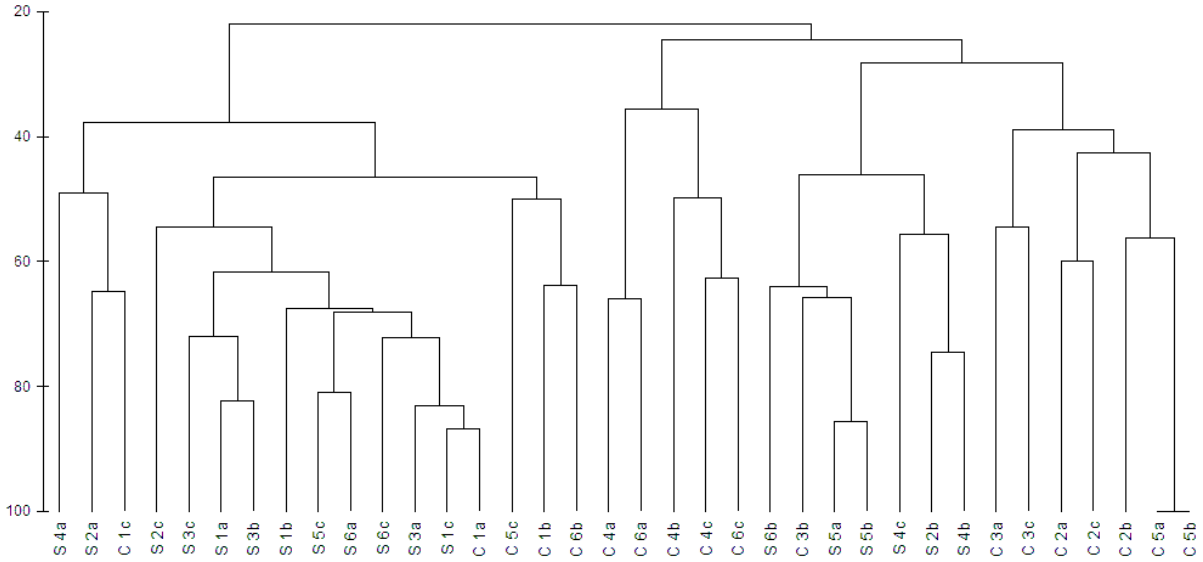


Figure 3.5.2. *Dendrogram showing the relationship among infaunal communities in cores collected along transects at the Port Chalmers Swinging Basin and across the Channel at Pulling Point, Otago Harbour.*

Analysis of similarities (ANOSIM) among cores at different sites further supports a moderate, but significant, difference in community structure among transects, with R = 0.295 (p = 0.001). Note once again that the nearer to zero the R value is, the more similar the samples are. Conversely, values for R close to 1.0 indicate samples that are very different in community composition.

Similarity percentages for transects across deep channel sites show that the differences between the two transects are only slightly greater than differences in cores within each transect (Table 3.5.3).

Table 3.5.3. *Similarity percentages calculated for different transects at deep channel assessment sites, Otago Harbour. A value of 100% would indicate that the communities at two locations are identical in terms of species present and the number of animals in each species.*

	Swing Basin	Channel
Swing Basin	41.94	
Channel	26.53	31.24

It can be seen from values for the indices of multivariate dispersion that the highest variability was encountered along the Channel transect (Table 3.5.4), a result that is equally true for epifauna, as borne out by the video recording.

Table 3.5.4. *Indices of multivariate dispersion calculated for two transects at deep channel assessment sites, Otago Harbour.*

	IMD
Swing	0.864
Channel	1.136

Diversity indices calculated for each quadrat show a moderate degree of variability with a range of 0.301 at Cores 4c and 5c on the Channel Transect to 0.919 at Core 3b on the Swinging Basin Transect (Table 3.5.5).

Table 3.5.5. *Diversity indices calculated for each quadrat at intertidal rocky shore assessment sites, Otago Harbour.*

Core	Swing Basin	Channel
1a	0.894	0.619
1b	0.634	0.797
1c	0.634	0.753
2a	0.647	0.699
2b	0.692	0.579
2c	0.562	0.699
3a	0.499	0.579
3b	0.919	0.594
3c	0.636	0.452
4a	0.449	0.641
4b	0.583	0.678
4c	0.692	0.301
5a	0.594	0.477
5b	0.436	0.477
5c	0.466	0.301
6a	0.678	0.699
6b	0.566	0.678
6c	0.678	0.602

3.6 Substrate Analysis

The intensity of the redox discontinuity layer (RDL) was extremely variable at different sites and also within sites (Figure 3.6.1, Appendices 2 and 3). At sites where substrate was relatively mobile the RDL was barely discernible (e.g. Te Rauone Beach sites, Appendix 3). However, this was also true for sites where Seagrass was abundant, where one would expect the substrate to be less mobile (Figure 3.6.1). For sites where the substrate was less mobile and where there was no seagrass the RDL varied from intensely discoloured and well defined (e.g. Saltmarsh sites Transect 1 Quadrat B and Transect 2 Quadrats A, B and C; Appendix 2) to pale and diffuse (e.g. Saltmarsh sites Transect 1, Quadrats C and D; Appendix 2). At no site was there a clear smell of hydrogen sulphide, a usual odour associated with heavily anoxic sediments.

Where present the depth of the RDL was also extremely variable, ranging from just a few millimetres below the surface to 100 mm down (Table 3.6.1).

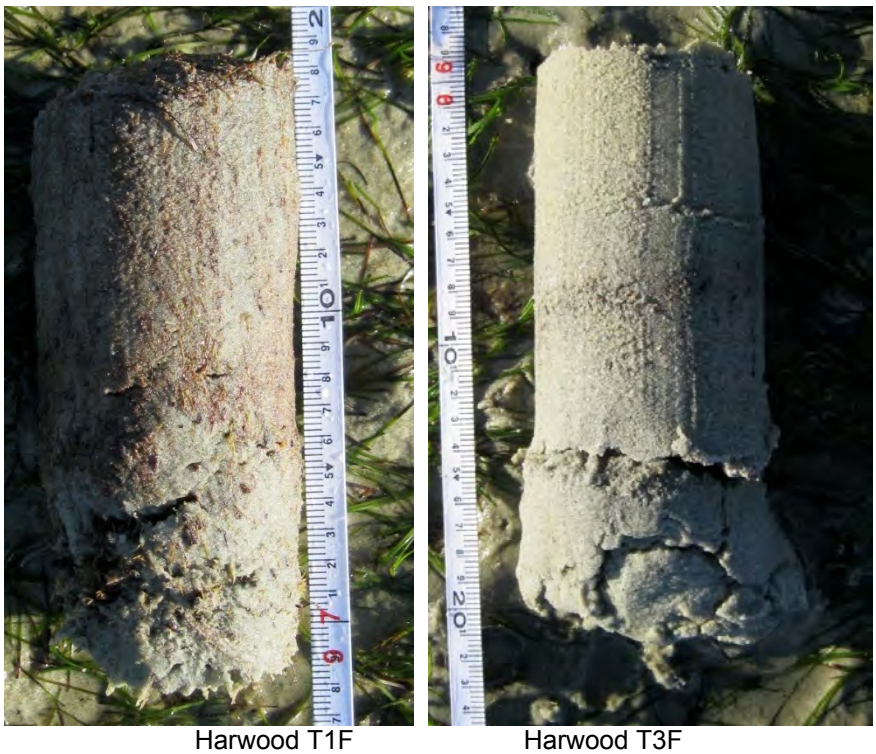


Figure 3.6.1. *Cores taken at Seagrass beds at Harwood.*

Table 3.6.1. *Characteristics of RDL at various sites within Otago Harbour.*

Site	Depth of RDL (mm)	Thickness of RDL (mm)	Nature of RDL
Harwood T1f	-	-	-
Harwood T3f	-	-	-
Saltmarsh 1a	30	110	Intense
Saltmarsh 1b	45	>200	Very intense
Saltmarsh 1c	30	>200	Very diffuse
Saltmarsh 1d	50	>200	Very diffuse
Saltmarsh 1e	40	60	Diffuse
Saltmarsh 2a	100	>200	Intense
Saltmarsh 2b	45	>200	Intense
Saltmarsh 2c	10	>200	Intense
Saltmarsh 2d	30	>200	Very diffuse
Saltmarsh 2e	30	>200	Diffuse
Saltmarsh 3a	2	>200	Very intense
Saltmarsh 3b	5	50	Intense
Saltmarsh 3c	40	>200	Intense changing to diffuse
Saltmarsh 3d	40	>200	Diffuse changing to intense
Saltmarsh 3e	90	>100	Irregular
Saltmarsh 4a	40	60	Very diffuse
Saltmarsh 4b	20	>200	Intense
Saltmarsh 4c	50	80	Very diffuse
Saltmarsh 4d	30	150	Intense
Saltmarsh 4e	10	>200	Intense
Cockle Bed 1	40	>200	Moderate
Cockle Bed 2	50	>200	Moderate-intense
Cockle Bed 3	60	>200	Moderate
Cockle Bed 4	60	>200	Moderate
Te Rauone Beach 1	60	50	Extremely pale
Te Rauone Beach 2	-	-	-
Aramoana 1	25	>200	Intense
Aramoana 2	40	>200	Moderate
Papanui 1	30	>200	Intense
Papanui 2	40	>200	Moderate-intense
Papanui 3	35	60	Moderate
Papanui 4	40	>200	Intense

Heavy metal contaminations at all sites was extremely low, and well below guideline trigger values set for marine sediments in the Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines (ANZECC 2000) (Table 3.6.2). These results are consistent with results of surveys carried out for the consent process (Hickey 2011).

Table 3.6.2. *Concentrations of metals in sediments from six sites within Otago Harbour.*

	As	Cd	Cr	Cu	Pb	Ni	Zn
	mg/kg dry wgt	mg/kg dry wgt	mg/kg dry wgt	mg/kg dry wgt	mg/kg dry wgt	mg/kg dry wgt	mg/kg dry wgt
ZosteraT1F	<2	<0.01	2	<2	0.5	<2	6
ZosteraT3F	<2	<0.01	3	<2	1.1	<2	9
SaltMarsh3B	<2	<0.01	4	<2	2.4	2	11
SaltMarsh4D	2	<0.01	2	<2	0.8	<2	6
Swinging Basin f	4	<0.01	7	3	2.6	5	21
Channel f	3	<0.01	6	2	2.1	4	15
ANZECC Low trigger value	20	1.5	80	65	21	50	200
ANZECC high trigger value	70	10	370	270	52	220	410

Particle size analysis shows that for all sites the highest percentage of all samples is fine sand (125µm - 500µm) (Table 3.6.3; Figures 3.6.2 and 3.6.3). However, the core at the deepest location of the Channel Transect had a higher percentage of silt than other sites (Figures 3.6.2 and 3.6.3). This was obvious to the diver collecting cores who indicated that cores from this location were very firm and the hole from which the core was taken held its shape rather than collapsing as it had at other sites.

Table 3.6.3. *Percentage composition for various particle sizes for substrate in cores taken at sites within Otago Harbour.*

% Composition	>2mm	>500µm	>250µm	>125µm	>63µm	<63µm
ZosteraT1F	3.53	9.20	78.07	9.08	0.06	0.06
ZosteraT3F	3.14	4.32	48.75	43.26	0.06	0.48
SaltMarsh3B	0.28	8.75	22.06	63.43	3.04	2.44
SaltMarsh4D	2.29	3.07	43.27	50.79	0.51	0.08
Swinging Basin 6	0.21	14.60	48.05	32.30	3.31	1.53
Channel 6	2.84	17.21	37.47	13.06	22.93	6.49

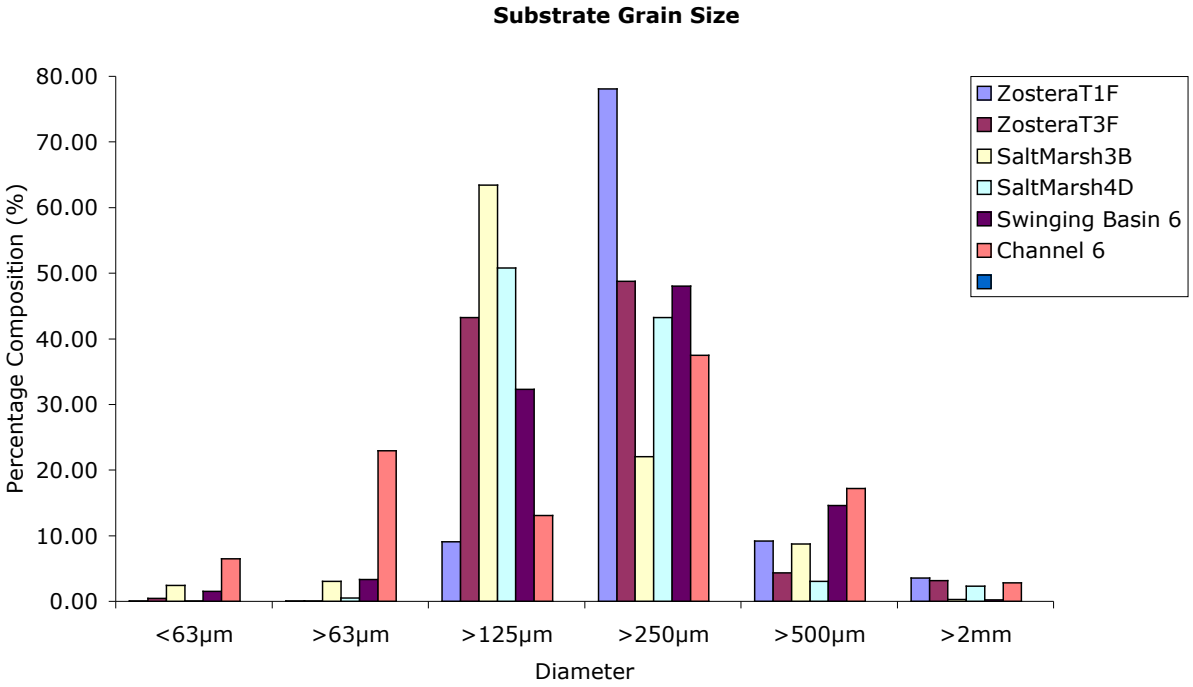


Figure 3.6.2. *Percentage composition for various particle sizes for substrate in cores taken at sites within Otago Harbour.*

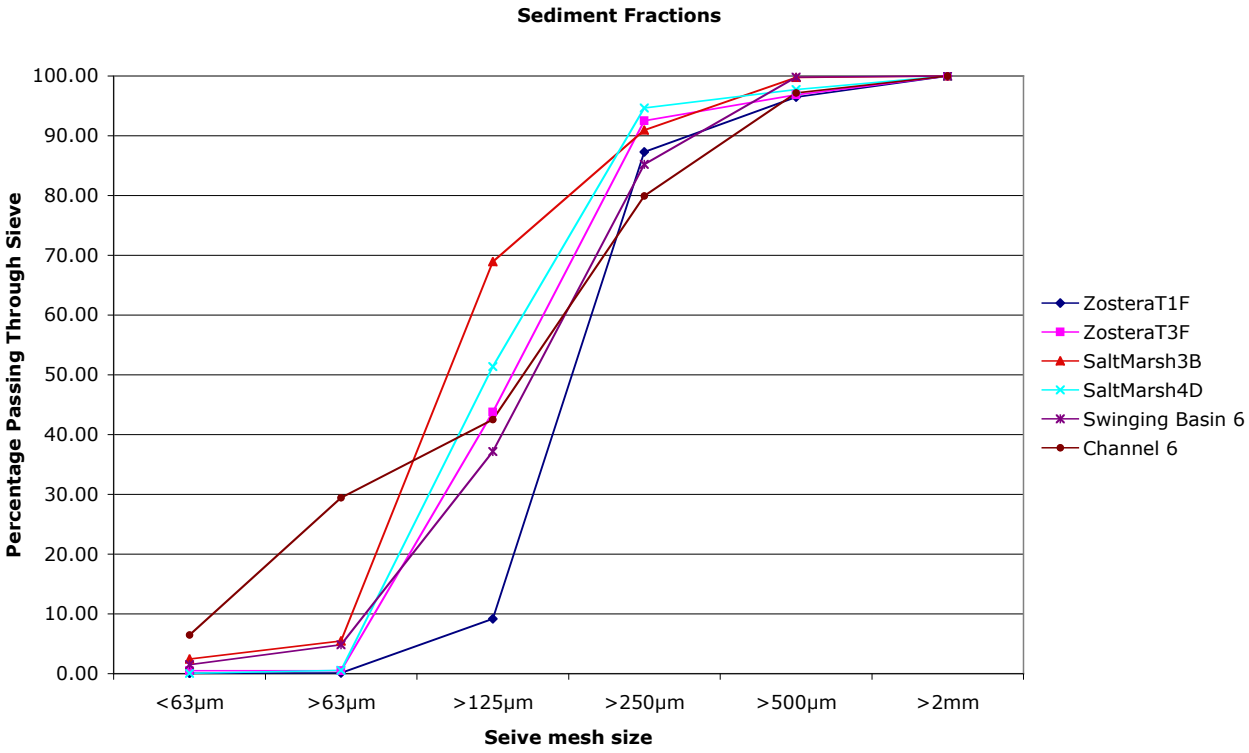


Figure 3.6.3. *Percentage of sediment passing through different mesh sizes for substrate in cores taken at sites within Otago Harbour.*

4. Discussion

This survey was designed to establish robust baseline data for different habitat types within Otago Harbour against which future surveys may be compared. It also serves as a comparator for surveys undertaken as part of the Port Otago Ltd consenting process. Paavo *et al*. (2008) contended that the soft sediment fauna in the lower Otago Harbour exist as a mosaic of different, but overlapping habitat types. The habitat classifications they used were:

- Sandy bottom with some shells present and sparse algal patches
- Sandy bottom free of attached algae and rippled by currents
- Extensive algal mats (bottom often not visible)
- Estuary-like areas with seagrass, ghost-shrimp mounds, and/or lugworm mounds and little algae
- Sandy to muddy areas with extensive mats of animal tubes, sparse algae, and few large shells
- Rocky areas with prominent sessile (attached) animals, such as sponges, hydroids, and tunicates, often mixed in with attached algae.

The current survey focused on five habitat types which fall within the above classification and which are perceived as significant due to their ecological, recreational, cultural or mahika kai importance.

Covering some 80 ha seagrass beds are moderately extensive within the harbour (Norhadi 2001). They are recognised as being ecologically significant in providing nursery grounds for a wide variety of intertidal invertebrates and fish and as feeding areas for birds and fish. Disturbance of *Zostera* beds should be avoided if at all possible as they are slow to re-establish if damaged and any disturbance may lead to destabilisation of quite large areas (Reed and Hovel 2006). Sampling of control and potential impact areas for this survey showed that the beds appeared to be in good health. Density of *Zostera* shoots at both sites was generally high, as was biomass. It is recognised that seasonal variations will play a significant role in the standing crop of seagrass (Norhadi 2001) and seasonal surveys of the beds are planned to quantify the differences. Other factors that will require consideration are storms and grazing by waterfowl. Locals at Harwood note that the Seagrass beds there are subject to quite heavy grazing by mainly geese and black swans from time to time (Mike Stuart, pers. comm.). Such grazing should not unduly affect shoot density but may affect cover, blade length and biomass from time to time.

As already stated, the saltmarsh area at Aramoana is recognized as being regionally important with high ecological and cultural values. Apart from very limited but obvious vehicle damage near the car park at the time of survey the Aramoana saltmarsh appears to be in good health.

The suite of organisms encountered reflected those found by Paavo *et al*. (2008). It should be pointed out that Paavo *et al*. (2008) encountered a higher number of infaunal taxa than the current study but, as Paavo (2009) rightly points out, no two surveys will be likely to produce the identical numerical results, given changes in weather and season. In addition Paavo *et al*. (2008) employed slightly higher taxonomic resolution when sorting samples and identifying specimens. For the purposes of this study, the level of taxonomic rigor employed is believed to be sufficient to adequately characterize the communities surveyed and provide a robust baseline against which similar future surveys may be compared (Bates *et al*. 2007), and has proved robust in similar surveys that compared marine biota in Otago Harbour over a long time-frame (e.g. Stewart 2008, 2011, 2013). We are confidant that any significant changes in community structure will be picked at the current level of sampling.

The cockle bed habitat is arguably the most studied of the soft bottom habitats included in this survey. The biomass of calms on the central sand banks within the harbour has been calculated on three separate occasions (Breen *et al*. 1999, Stewart 2008, 2013) and associated communities assessed in some detail, also on three occasions also (Paavo *et al*. 2008, Stewart 2008, 2013). Besides the current dredging programme, interest in the cockle beds stems from a source of mahika kai.

As for saltmarsh habitat, the communities associated with the cockle beds appear to be in good health and are similar to those observed by Paavo *et al*. (2008) and Stewart (2008, 2013). There are, however, some obvious differences. For example, anemones figured prominently in samples collected by Stewart (2103) but did not feature highly in results for Paavo *et al*. (2008) or this survey. Anecdotal evidence from harvesters and observations from previous surveys in Otago Harbour and in Waitati and Papanui Inlets (e.g. Stewart 2006, 2008) suggest that abundance of anemones varies with time of year and from year to year. In addition, lugworms and oligochaetes were much more common in the results of Paavo *et al* (2008) than in the current study. This may be due to seasonal differences but is more likely attributable to their using a different sampling technique. Paavo *et al*. (2008) used a grab deployed from a boat while this survey employed corers used at low tide. Thus, any animals that burrows deeply in response to exposure to air or those that retreat as a result of vibrational stimulus (as from an approaching person) will have been under sampled in the current survey. Once again, we are confidant that any significant changes in community structure will be picked at the current level of sampling. Cockle biomass, however, is as expected and ties in well with biomass calculated for much more extensive surveys.

Sheltered rocky shores within Otago are quite rare, with the majority of rocky substrate being on exposed coasts and other inlets having practically none (e.g. Stewart 2007). However, rocky

shores within Otago Harbour have been extensively studied. The existence of the Portobello Marine Laboratory directly across the harbour from Port Chalmers ensures a steady flow of both amateur and professional scientists keen to document what lives on the shore.

The communities encountered during this survey are flourishing and typical of those one would expect to find on sheltered rocky shores in southern New Zealand (Batham 1956, Morton and Miller 1973). The assemblages are very similar to those observed by Paavo (2009) and comprise largely foliose red and brown algae, sponges, ascidians, crabs and gastropod molluscs. As one would expect, there is a gradient of both diversity and abundance moving from the subtidal zone up to extreme high water. This is almost universal among rocky shores and well recognized (Clayton 1982, Raffaelli and Hawkins 1996, Ricketts 1997). What is not tested is the up-harbour gradient noticeable as one moves from Taiaroa Head to Vauxhall. However, it is believed that focus on rocky shores closest to the proposed dredging activity is most appropriate.

Organisms living on rocky substrate are particularly prone to smothering by fine material (Brosnan 1999, Stewart 2001). Consequently, the risk to such communities from any activity that generates fine sediments in the water column needs to be monitored. That being said, it also needs to be recognized that dredging activity is unlikely to be the only source of such sediments, nor the most significant source. Ongoing road improvements, property development, heavy rain events, the Water of Leith and land subsidence all contribute varying, and sometimes considerable, amounts of sediment to the harbour. The choice of widely separated sites, including intertidal and subtidal sites, and the use of control sites in the case of seagrass beds will assist in differentiating sources of sedimentation.

Deep channel communities will, of course, be the most affected by dredging activities. Unlike at other sites, they will be directly physically impacted and it is accepted that dredging will remove organisms from those parts of the harbour that are subject to excavation. The aim of this survey then, is to determine what suite of organisms currently inhabits the deeper channels and whether or not they are likely to re-colonise dredged areas. As in this study, Paavo *et al*. (2008) found the communities comprised mainly a variety of amphipod crustaceans and tube dwelling worms, both polychaetes and oligochaetes. Species encountered were not unique to the channels and most are common to soft bottoms in other parts of the harbour (Ralph and Yaldwin 1956, Grove 1995, Paavo *et al*. 2008).

In previous studies marine benthic communities have been found to re-establish within relatively short time frames of 30 days to 2 years (Brosnan 1996, Irwin 1999). It is expected that the organisms in deep channel Otago Harbour sites will do similar. Certainly the fact that a

moderately diverse community exists in the swinging basin when the site was dredged just 2-3 weeks prior to the survey is an indication of how quickly re-colonisation may take place.

Substrate analysis was not a required condition of the resource consent. However, it was felt that some analysis of the substrate would be useful to assist in tracking the fate of sediments disturbed during the dredging process and also provides a baseline for future comparisons. As has been found for other surveys of substrate within Otago Harbour the sediment comprises mainly fine sand with little in the way of large particles or silt (e.g. Stewart 2013a). Large particles, where they occur, tend to be dead shell and driftwood. Dredging may have some impact on the distribution of particles, particularly very fine sediment. However it is unlikely that it will have an effect on the depth of the redox discontinuity layer (RDL) at surveyed sites unless the amount of fine sediment released is particularly high. It is once again recognized, of course, that dredging will not be the only source of fine sediment released into the harbour. Current levels of heavy metal contamination in the surveyed area are very low, with more contaminated sites usually associated with stormwater outfalls or sites where historic industries were active (Stewart 2013b).

5. Conclusions

The level of sampling carried out during this survey is believed to be adequate to provide a robust baseline against which future surveys may be compared and any significant changes in community structure identified. The infaunal communities encountered during this baseline survey are typical of infaunal sandy communities in sheltered inlets and harbours around most of New Zealand (Morton and Miller 1973). Likewise, rocky shore communities are as one would expect for sheltered harbours in southern New Zealand (Morton and Miller 1973, Batham 1956). The invertebrate and macroflora assemblages encountered show considerable similarity to those observed in previous studies within Otago Harbour with minor differences attributable to differences in sampling techniques and taxonomic rigor (e.g. Ralph and Yaldwyn 1956, Rainer 1980, Grove 1995, Paavo and Probert 2005, Paavo *et al.* 2008, Paavo 2009, Stewart 2013).

It is reasonable to expect that these assemblages will remain essentially unchanged for the next survey, unless dredging, or some other extrinsic factor, has some discernible impact on the communities. The same applies to substrate. Ultimately, indices of multidimensional scaling, similarity percentages and diversity indices calculated for seagrass, saltmarsh, cockle bed, rocky shore and soft bottom communities will provide ready indicators of community health. Similar metrics for similarly conducted surveys in the future may be compared using a number of uni- and multivariate statistical tests that will reveal any changes in community structure.

It is acknowledged that any changes will be dependent on many factors, including scale and intensity of dredging, the type of substrate being dredged, time of year, and state of the tide and weather.

6. Acknowledgements

Ryder Consulting Limited would like to acknowledge the assistance of the following people and organisations: Murray Robertson and the team at New Zealand Diving and Salvage for spending much more time in the water in mid-winter than I'd like to; TL Survey Services Ltd for high quality aerial photographs; Murray Cumming for small boat hire, Jarred Arthur and Katie Blackwood for assistance in the field and in the laboratory and; Ruth Goldsmith for helpful reviews of this report.

7. References

Australian and New Zealand Environment and Conservation Council (ANZECC), (2000). Australian and New Zealand guidelines for fresh and marine water quality. Volume 2, Aquatic Ecosystems.

Bates, C.R., Scott, G., Tobin, M. and Thompson, R. (2007). Weighing the cost and benefits of reduced sampling resolution in biomonitoring studies: Perspectives from the temperate rocky intertidal. Biological Conservation 137(4): 617-625.

Batham, E.J. (1956). Ecology of southern New Zealand sheltered rocky shores. Transactions of the Royal Society of New Zealand, 84:447-465.

Breen P. A., Carbines, G. C. and Kendrick, T. H. (1999). Stock assessment of cockles in Papanui and Waitati Inlets, Otago Harbour, and Purakanui, Otago. Final Report for the Ministry of Fisheries research project COC9701 dated July 1999.

Brosnan, B.C. (1999). Recovery of terrestrial and marine communities in a New Zealand fiord after large-scale disturbances. Unpublished MSc thesis. Dept. of Marine Science, University of Otago. pp 137.

Clayton, S.M. (1982). A biologically defined wave exposure scale for the Otago Peninsula. Unpublished BSc (Hons) thesis. University of Otago.

Grove, S.L. (1995). Subtidal soft-bottom macrofauna of the upper Otago Harbour. Unpublished MSc thesis, University of Otago.

Hickey, C.W. (2011). Statement Of Evidence Of Christopher Wayne Hickey On Behalf Of Port Otago Limited. April 2011. Presented in relation to an application for resource consents for Project Next Generation before the Otago Regional Council.

Irwin, C.R. (1999). The effects of harvesting on the reproductive and population biology of the New Zealand Littleneck Clam (Austrovenus stutchburyi) in Waitati Inlet. Unpublished Msc thesis, University of Otago, Dunedin, New Zealand.

James, M., Probert, K., Boyd, R., and John, A. (2007). Summary of existing ecological information and scoping of further assessments for Port Otago dredging project. Report HAM2007-156 to Port Otago Limited, National Institute of Water & Atmospheric Research Ltd., Project number POL08201. 65 pages.

Kingsford, M. and Battershill, C. (1998). Studying temperate marine environments: A handbook for ecologists. Canterbury University press.

Mills, S. (2006). Benthic macrofauna assemblages of fragmented Seagrass (*Zostera capricorni*) beds in two southern New Zealand inlets. Unpublished MSc thesis, University of Otago, Dunedin.

Morton, J. and Miller M. (1973). The New Zealand Sea Shore. Collins, Auckland. 653 pp.

Norhadi, I. (2001). Ecology of eelgrass, *Zostera novazelandica* (Setchell), in Otago Harbour, Dunedin, New Zealand. PhD thesis, Otago University, Dunedin, New Zealand.

Paavo, B.L. (2009). Observations of Rocky Shore Habitats in Lower Otago Harbour. Report to Port Otago Ltd, 46 pp.

Paavo, B.L. and Probert, P.K. (2005). Infaunal assemblages in coastal sediments at dredge disposal sites of Otago, New Zealand. Report prepared for Port Otago Ltd. by the Department of Marine Science, University of Otago, Dunedin, New Zealand.

Paavo, B.L.; Probert, P.K.; James, M.R. (2008). Benthic habitat structures and macrofauna of Lower Otago Harbour. Report to Port Otago Ltd, 52 pp.

Plunket G.P. (2011). Statement Of Evidence Of Geoffrey Philip Plunket On Behalf Of Port Otago Limited. April 2011. Presented in relation to an application for resource consents for Project Next Generation before the Otago Regional Council.

Probert P.K. and Jillett, J.B. (1998). Proposed Vauxhall redevelopment: Marine environmental aspects. A report for Incite Ltd, Dunedin. pp. 11.

Rainer S.F. (1981). Soft-bottom benthic communities in Otago harbour and Blueskin Bay, New Zealand. N.Z. Oceanographic Inst. Memoir 80: 38pp.

Raffaelli, D. and Hawkins, S.J. 1996. Intertidal Ecology. Chapman and Hall, London. pp.356.

Ralph, P.M. and Yaldwyn, J.C. (1956). Seafloor animals from the region of Portobello Marine Biological Station, Otago Harbour. Tuatara 6(2): 57-85.

Reed, B.J, and Hovel, K.A. (2006). Seagrass habitat disturbance: How loss and fragmentation of eelgrass *Zostera marina* influences epifaunal abundance and diversity. *Marine Ecology Progress Series*: 326:133-143.

Ricketts, E.F., Calvin, J., Hedgepeth, J.W. and Phillips, D.W. (1997). *Between Pacific Tides*. 5th edition. Stanford University Press. pp.652.

Robertson, B.M.; Gillespie, P.A.; Asher, R.A.; Frisk, S.; Keeley, N.B.; Hopkins, G.A.; Thompson, S.J.; Tuckey, B.J. (2002). Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

Robinson, J. (2010). Otago Harbour Survey of *Pumilus antiquates* for Port Otago. Unpublished report. University of Otago Department of Geology.

Stewart B.G. (2001). Assessment of Effects of Sediment Discharge from Excavation of the Proposed Deepwater Basin Marina on the Biota within Milford Sound. Report prepared for Tyndall and Hammond Ltd.

Stewart B.G. (2005). Peninsula Road Improvements Projects: Ecological Impact Assessment. Report prepared for OPUS International Consultants Ltd by Ryder Consulting Ltd.

Stewart, B. (2006). Stock assessment of cockles (*Austrovenus stutchburyi*) in Papanui and Waitati Inlets, Otago 2004. Final report for the Ministry of Fisheries Research Project COC2004/02. 54p.

Stewart B. (2007). Mapping of the Waikouaiti and Shag River Estuaries: Otago Regional Council State of the Environment Report. Prepared for the ORC by Ryder Consulting Ltd. pp. 55.

Stewart B.G. (2008). Clam (*Austrovenus stutchburyi*) resource and habitat survey in Otago Harbour (COC3), Otago, 2008. Report prepared for Southern Clams Ltd by Ryder Consulting.

Stewart, B.G. (2011). *Warrington Treated Sewage Discharge: Waitati Inlet ecological survey, 2011*. Report prepared for the Dunedin City Council by Ryder Consulting Ltd.

Stewart B.G. (2013a). Investigations into the Effects of Commercial Harvest of Clams (*Austrovenus stutchburyi*) in Otago Harbour (COC3), Otago: Report on Phase II Harvesting, 2012. Prepared for MPI and Southern Clams Ltd.

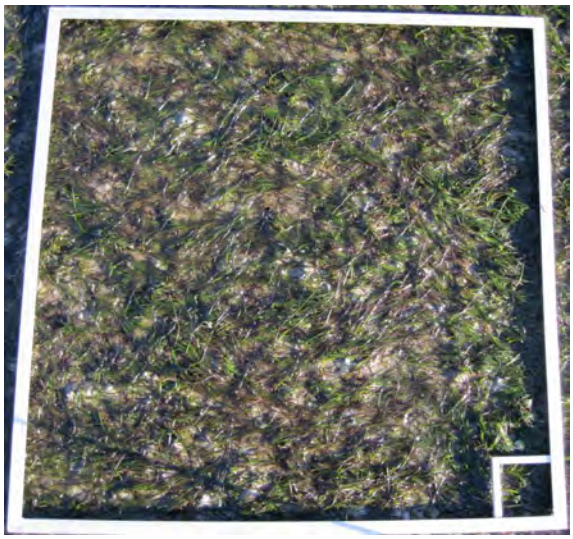
Stewart B. (2013b). Compliance Monitoring 2013: Stormwater discharges from Dunedin City (ORC Resource Consents 2002.080-2002.110 and 2006.222). Report to the DCC prepared by Ryder Consulting Ltd.

Warwick, R.M. and Clarke, K.R. (1993). Increased variability as a symptom of stress in marine communities. Journal of Experimental Marine Biology and Ecology 172: 215-226.

Zar, J.H. (1996). Biostatistical Analysis. Third Edition. Prentice Hall International Inc.

Appendix 1 – Seagrass Sites

Harwood: Transect 1 (Quadrats are 1 m x 1 m. Small square is 10 cm x 10 cm)



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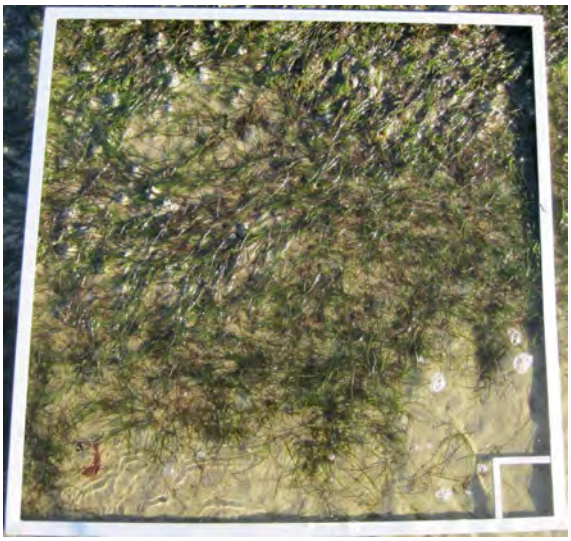

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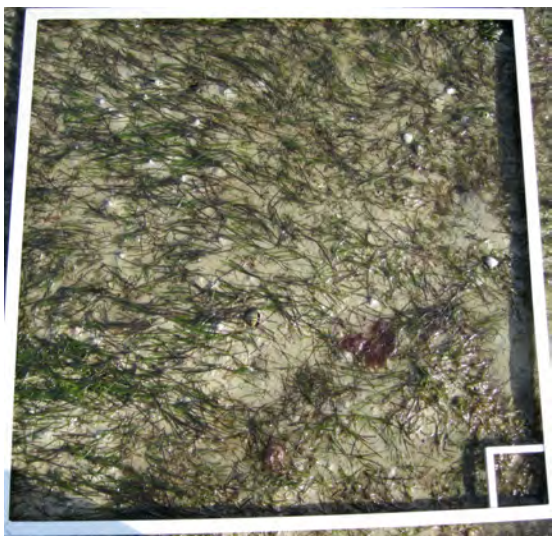
Quadrat D

Quadrat E

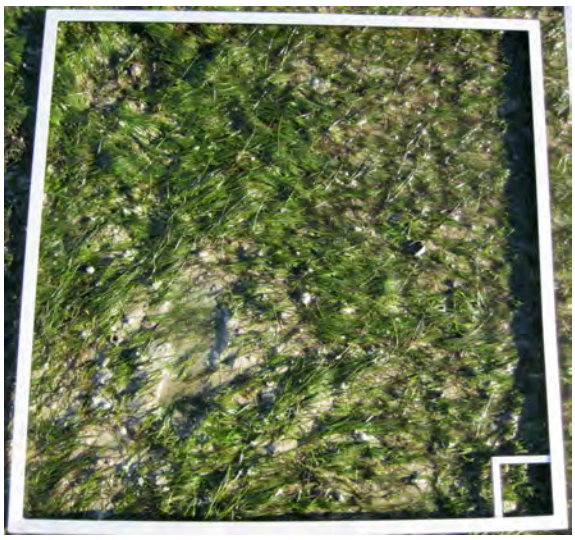


Quadrat F

Harwood: Transect 2

Quadrat A

Quadrat B



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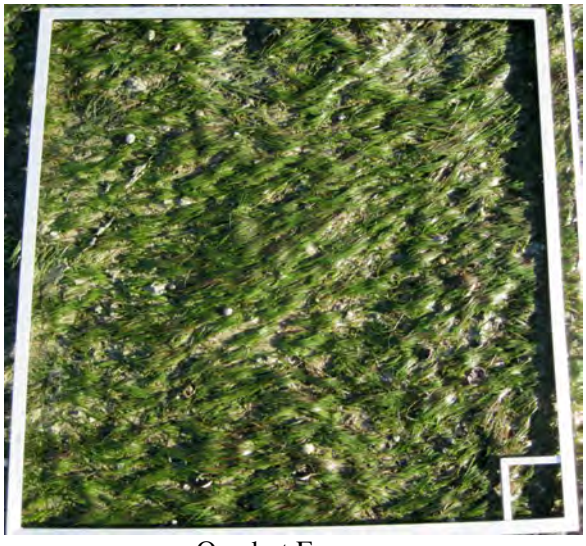


Quadrat E

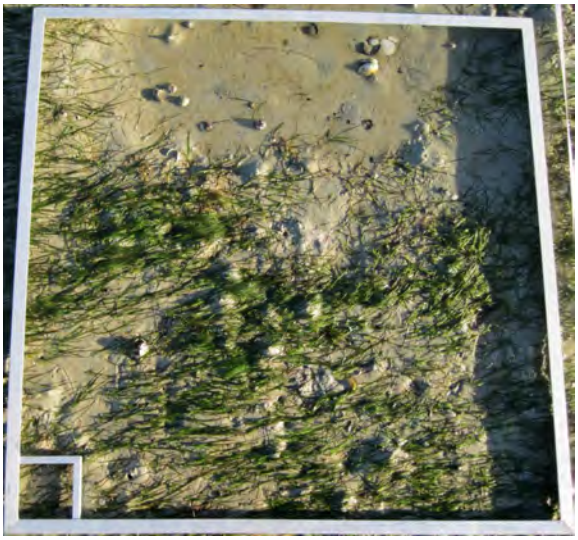
Quadrat F

Harwood: Transect 3

Quadrat A

Quadrat B

Quadrat C



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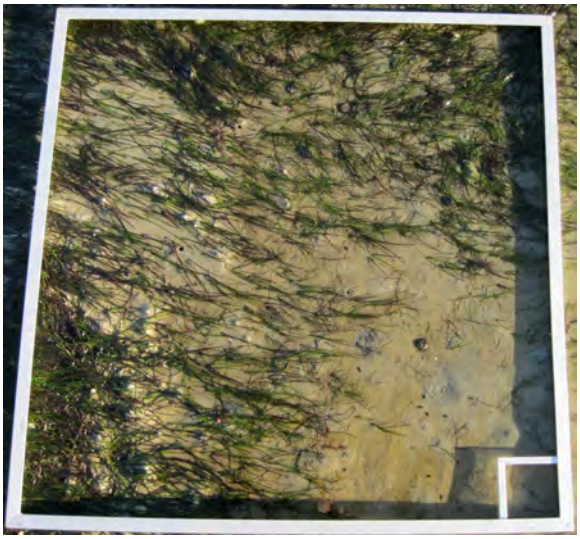


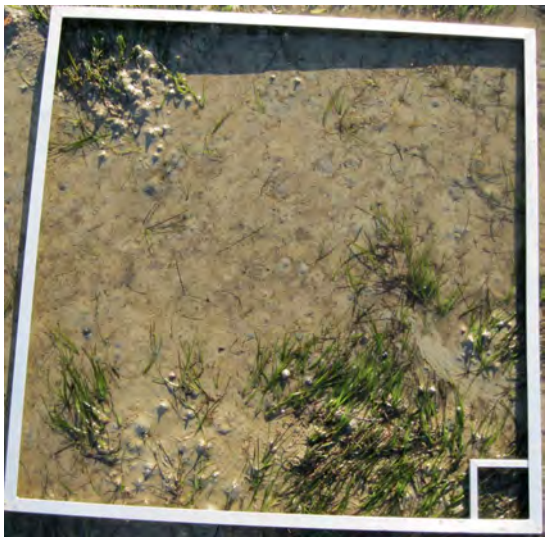
Quadrat E

Quadrat F

Harwood: Transect 4

Quadrat A

Quadrat B



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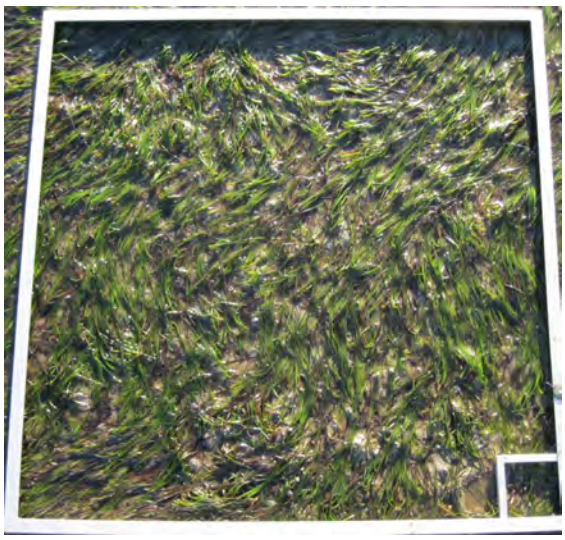
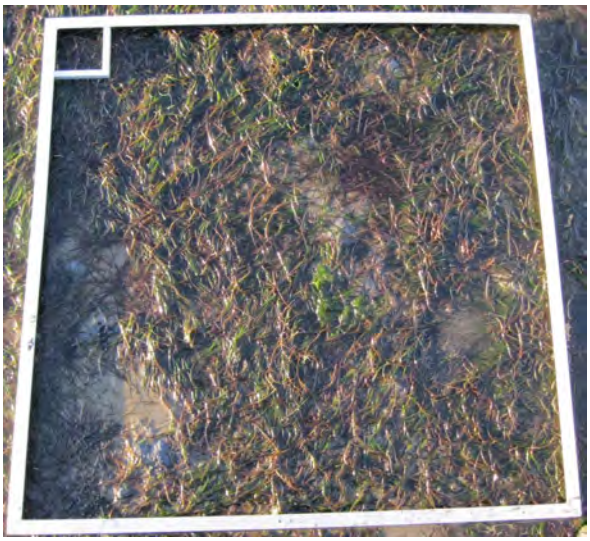


Quadrat F

Papanui Inlet: Transect 1



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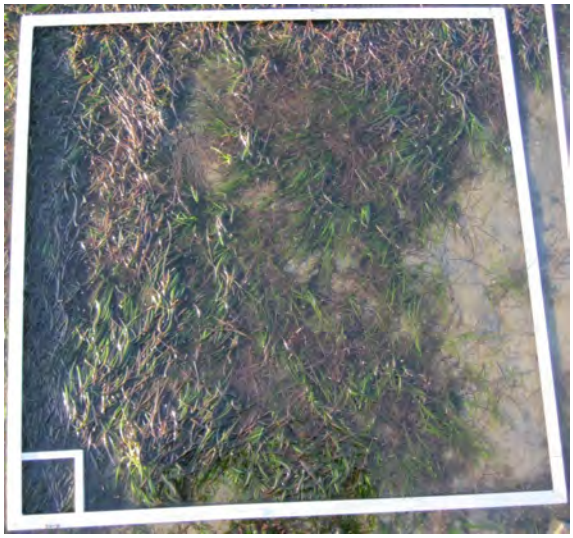

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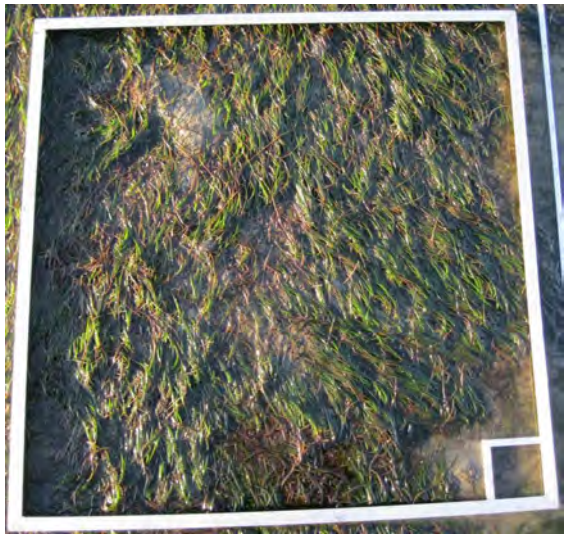

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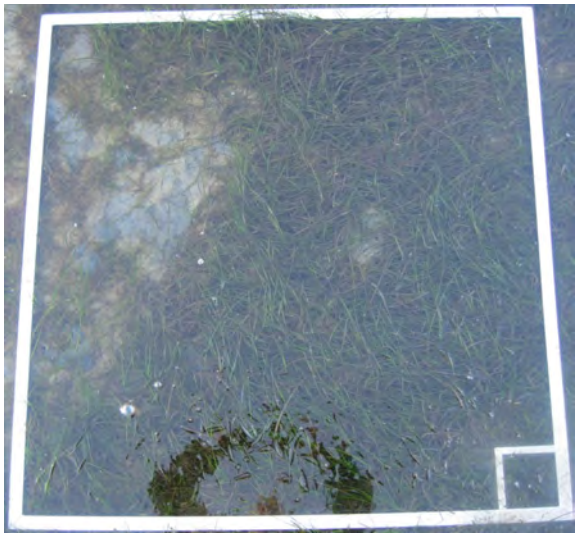

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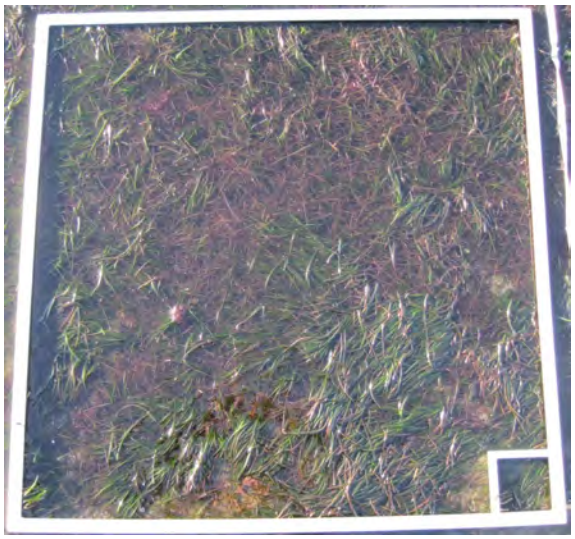
Papanui Inlet: Transect 2



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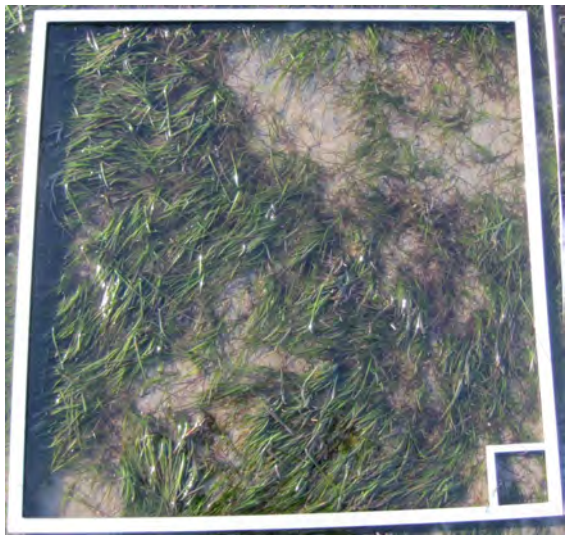

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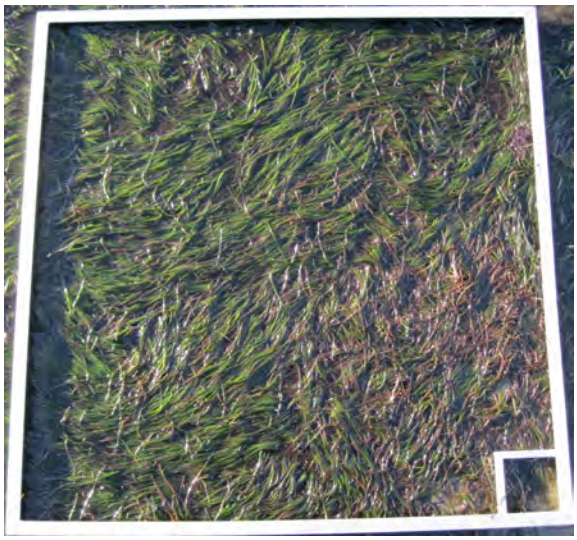
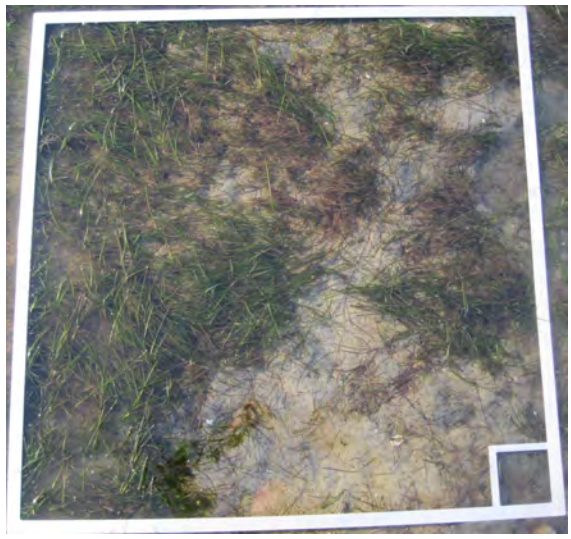


Quadrat C

Quadrat D

Quadrat E



Quadrat F

Appendix 2 – Saltmarsh Sites

Aramoana: Transect 1 (Quadrats are 1 m x 1 m. Small square is 10 cm x 10 cm)

Quadrat A

Core A

Quadrat B

Core B

Quadrat C

Core C

Quadrat D

Core D

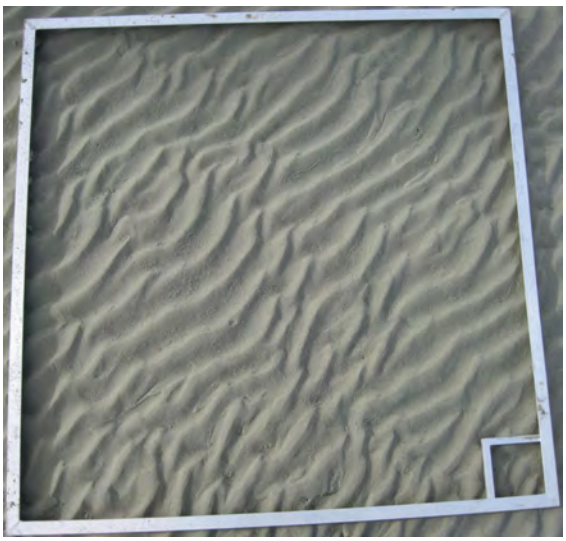
Quadrat E

Core E

Transect 2

Quadrat A

Core A



Quadrat B

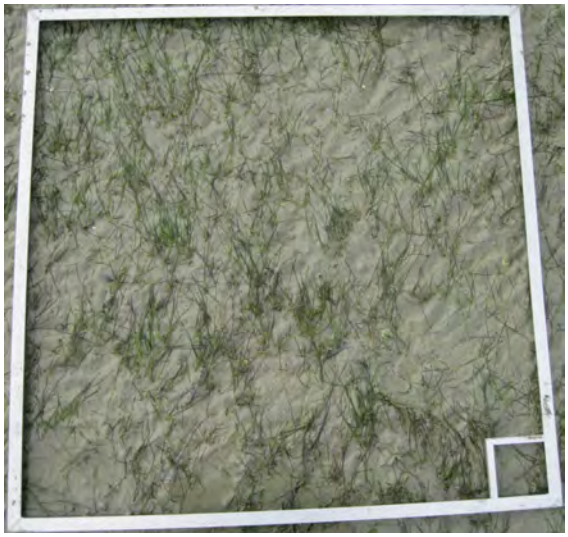
Core B

Quadrat C

Core C

Quadrat D

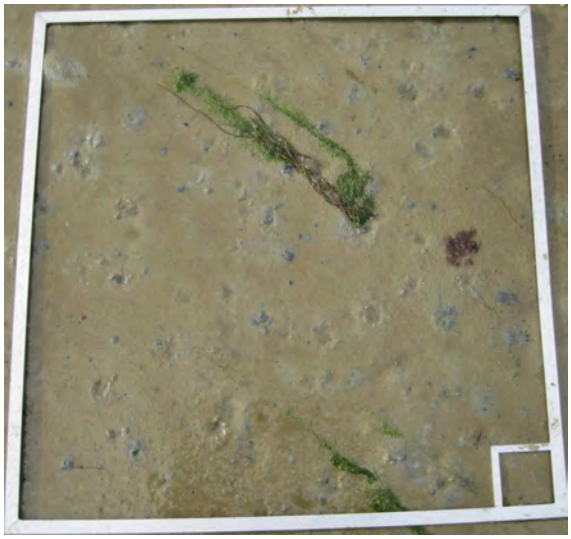
Core D



Quadrat E

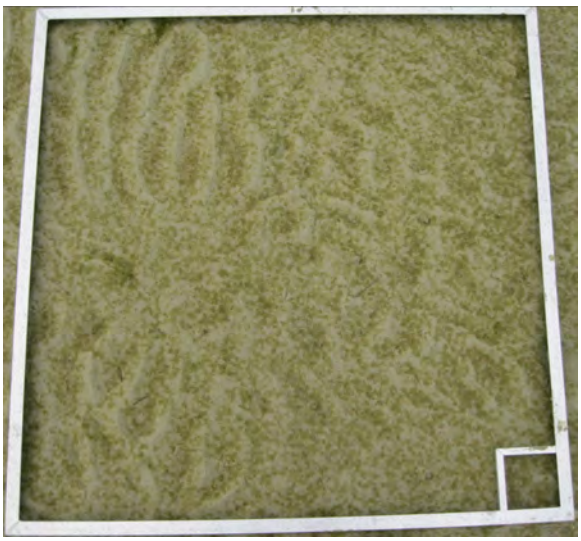
Core E

Transect 3



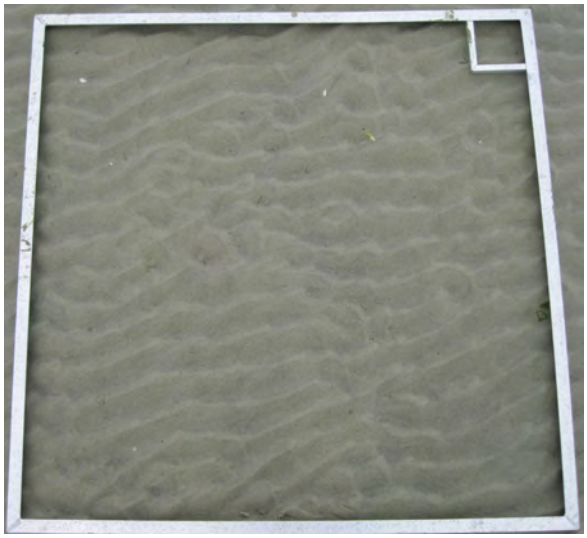
Quadrat A

Core A



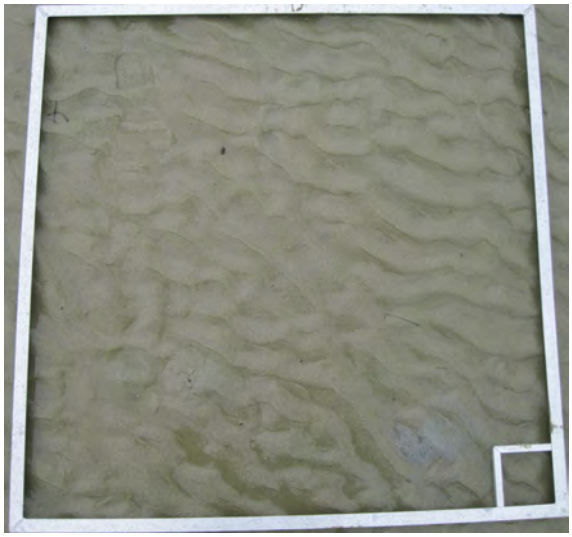
Quadrat B

Core B



Quadrat C

Core C



Quadrat D

Core D

Quadrat E

Core E

Transect 4

Quadrat A

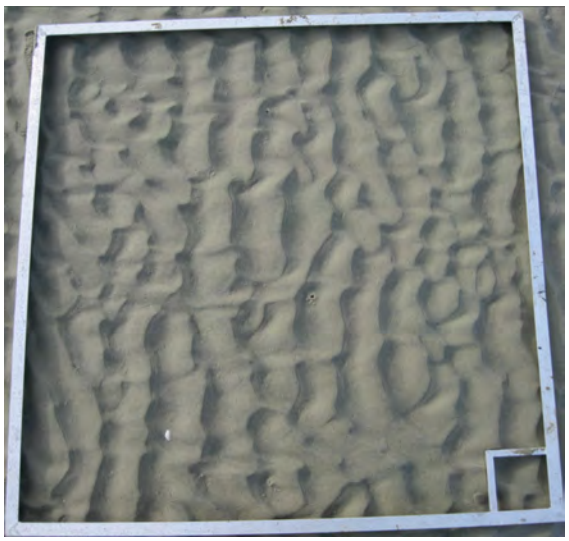
Core A

Quadrat B

Core B

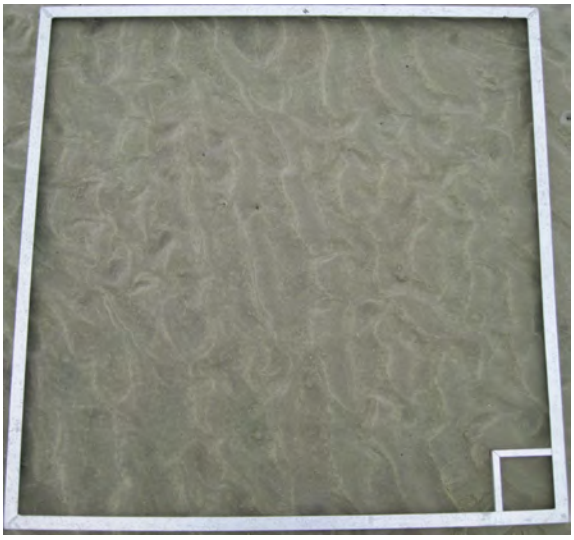
Quadrat C

Core C



Quadrat D

Core D

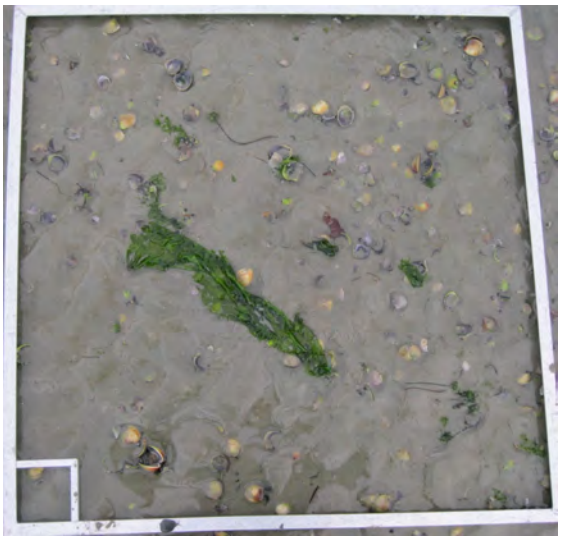


Quadrat E

Core E

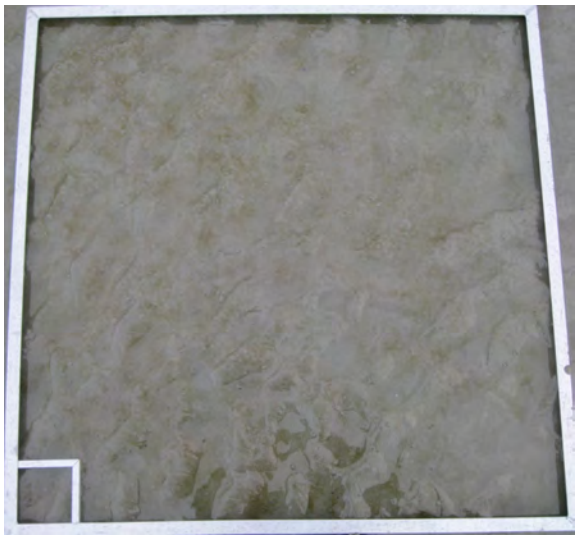
Appendix 3 – Clam Bed Sites

Bed Opposite Pulling Point Sites (Quadrats are 1 m x 1 m. Small square is 10 cm x 10 cm)



Site 1

Core 1



Site 2

Core 2

Site 3

Core 3


Site 4


Core 4

Te Rauone Beach Sites


Site 1


Core 1


Site 2


Core 2

Aramoana Sites

Site 1

Core 1

Site 2

Core 2

Papanui Inlet Control Sites

Site 1

Core 1

Site 2

Core 2

Site 3

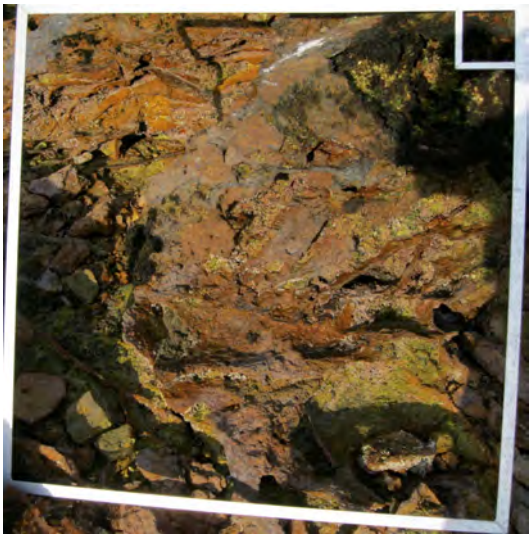
Core 3

Site 4

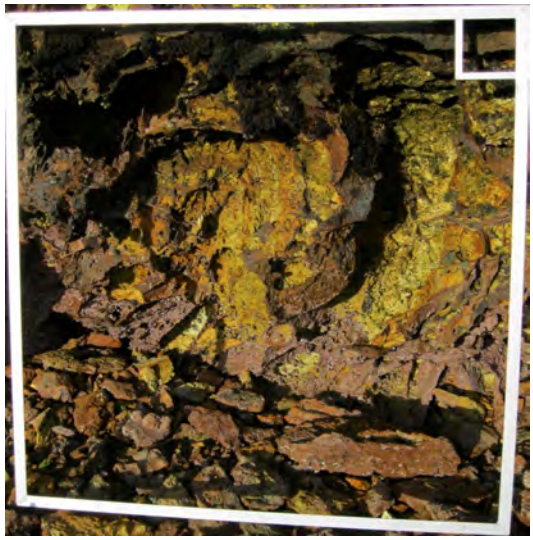
Core 4

Appendix 4 – Rocky Shore Intertidal Sites

Pudding Island Sites (Quadrats are 1 m x 1 m. Small square is 10 cm x 10 cm)



Transect 1 High tide



Transect 2 High tide

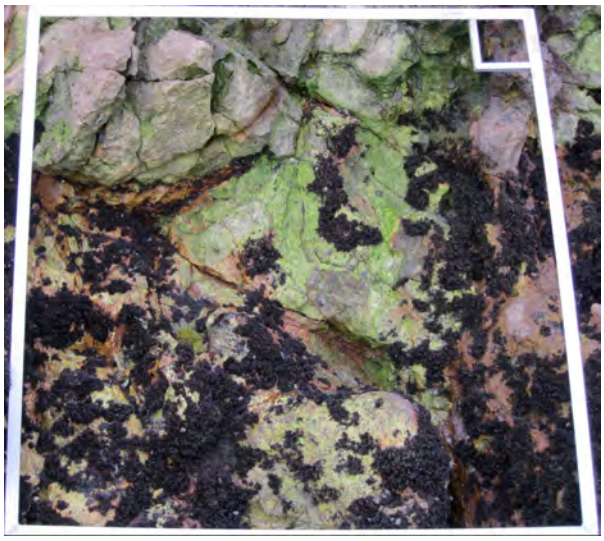
Transect 1 Mid tide

Transect 2 Mid tide

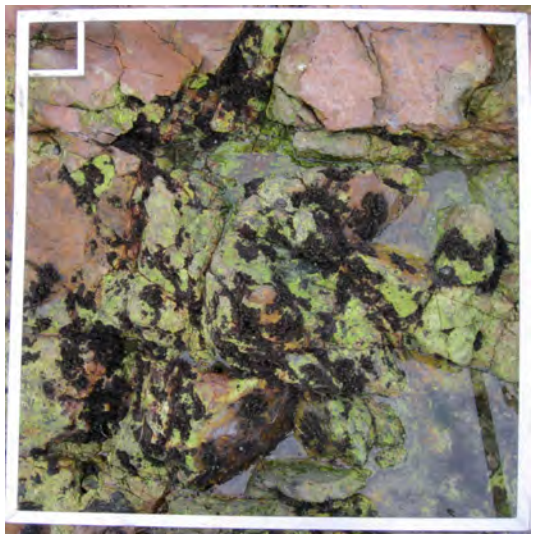
Transect 1 Low tide

Transect 2 Low tide

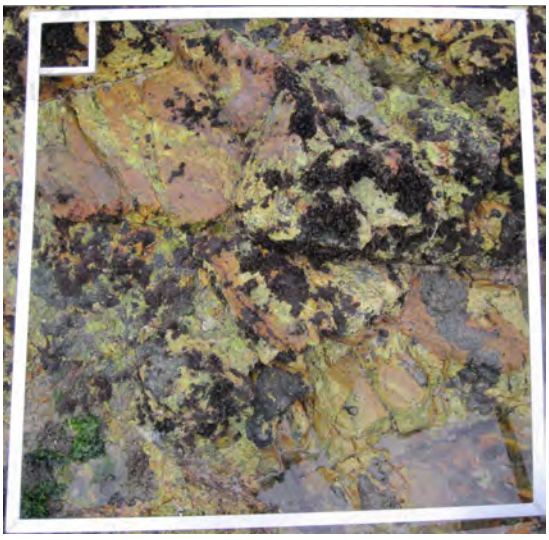
Quarantine Island Sites (Quadrats are 1 m x 1 m. Small square is 10 cm x 10 cm)



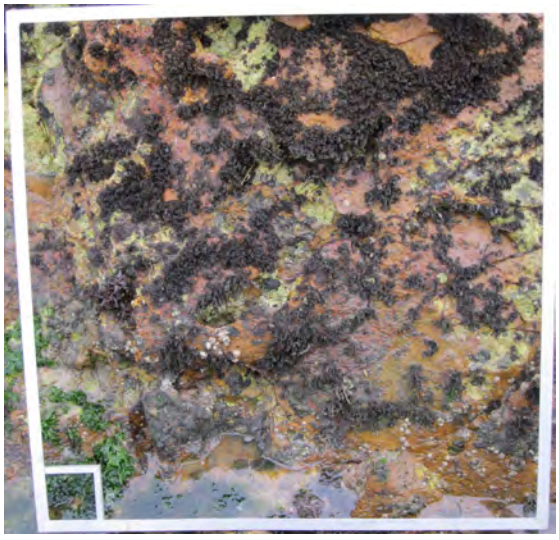
Transect 1 High tide



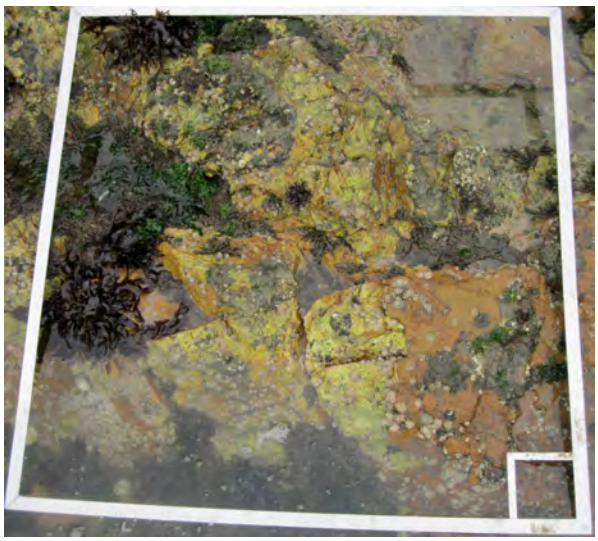
Transect 2 High tide



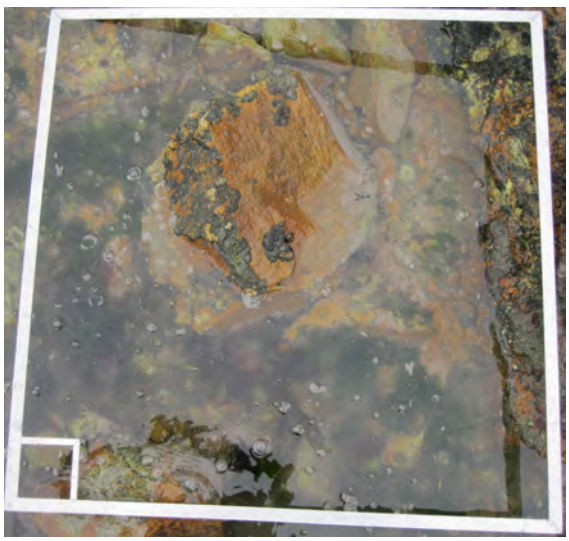
Transect 1 Mid tide



Transect 2 Mid tide



Transect 1 Low tide



Transect 2 Low tide

Pulling Point Sites (Quadrats are 1 m x 1 m. Small square is 10 cm x 10 cm)

Transect 1 High tide

Transect 2 High tide

Transect 1 Mid tide

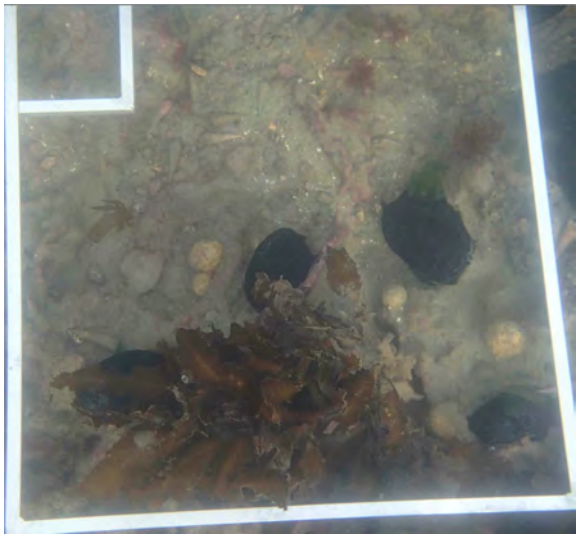
Transect 2 Mid tide

Transect 1 Low tide

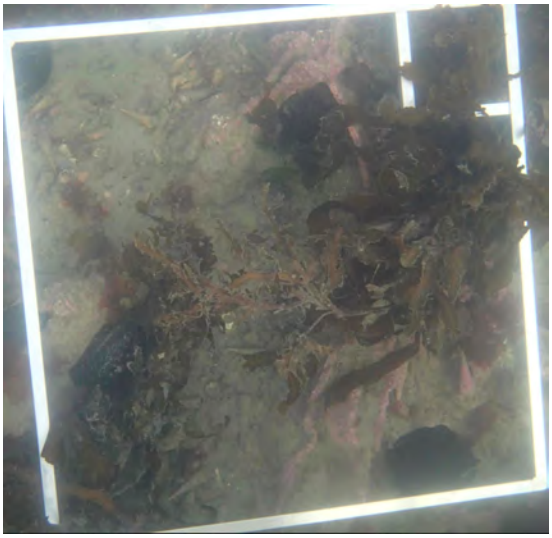
Transect 2 Low tide

Appendix 4 – Rocky Shore Subtidal Sites

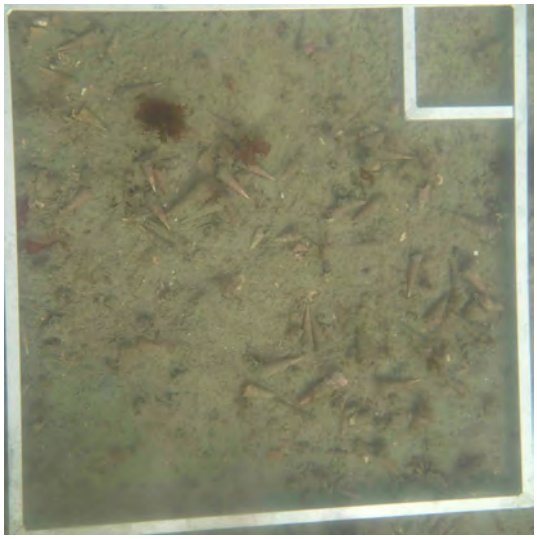
Pudding Island Sites (Quadrats are 0.5 m x 0.5 m. Small square is 10 cm x 10 cm)



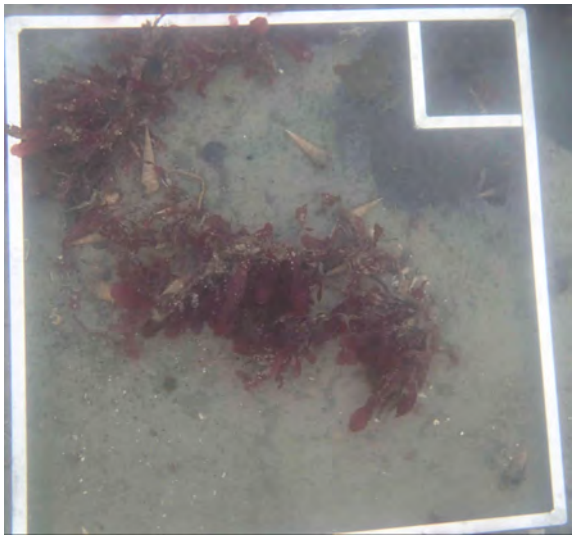
Transect 1Qa



Transect 1Qb

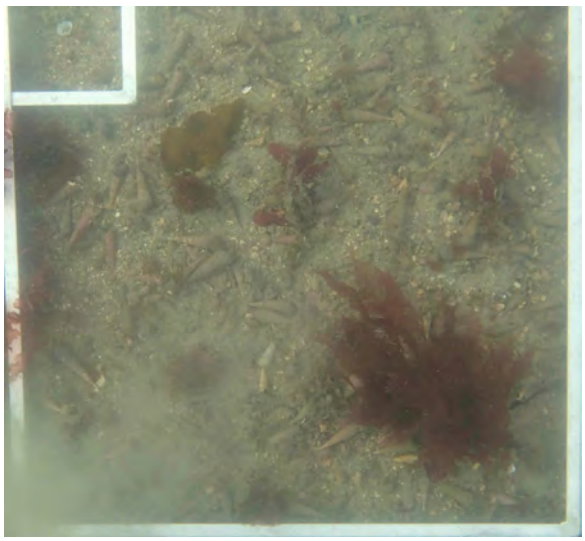


Transect 1Qc

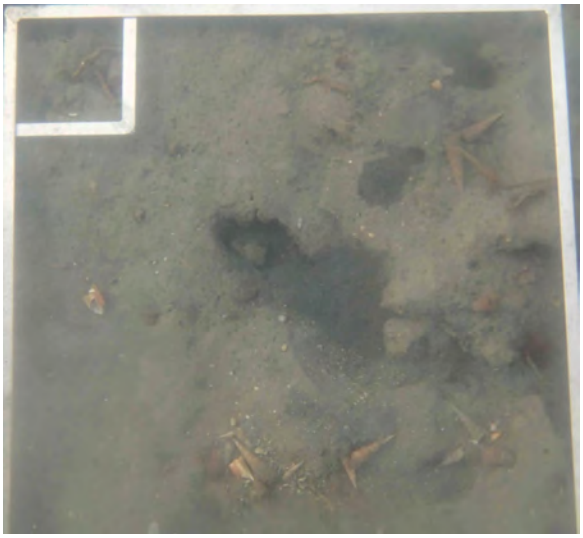


Transect 1Qd

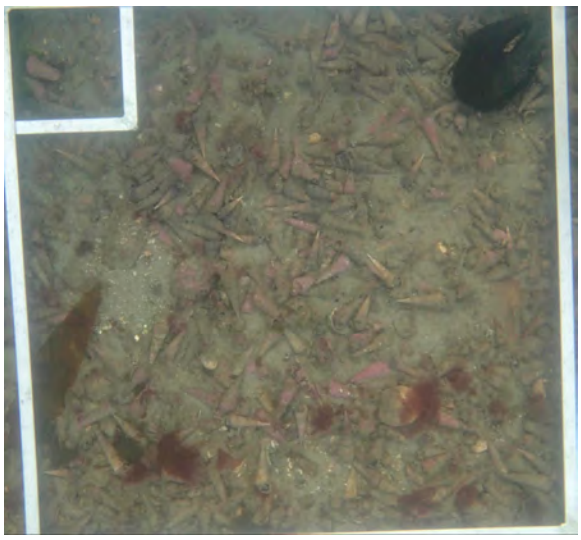
Transect 1Qe



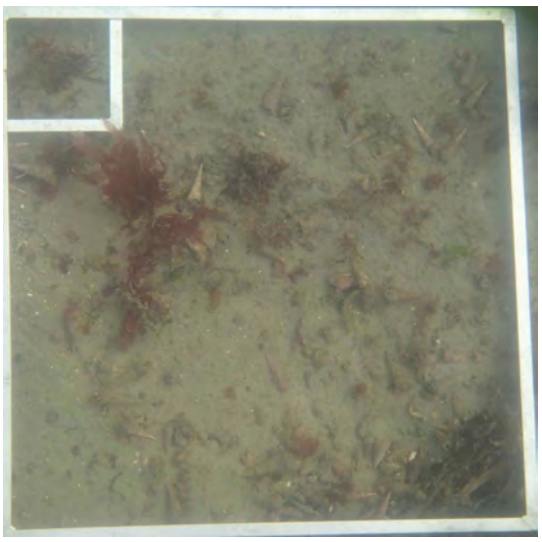
Transect 2Qa



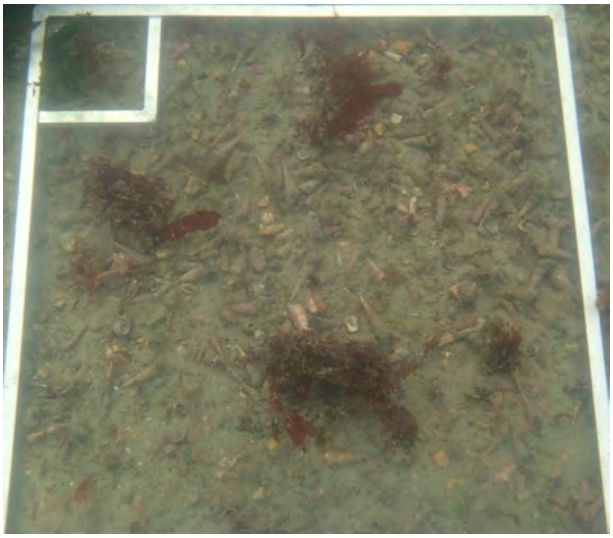
Transect 2Qb



Transect 2Qc

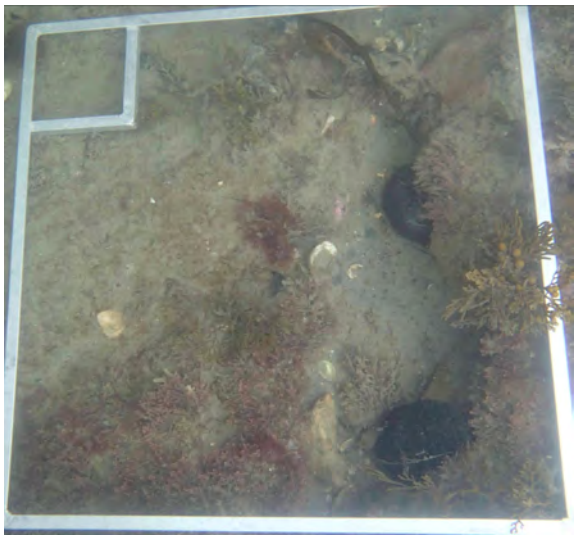


Transect 2Qd

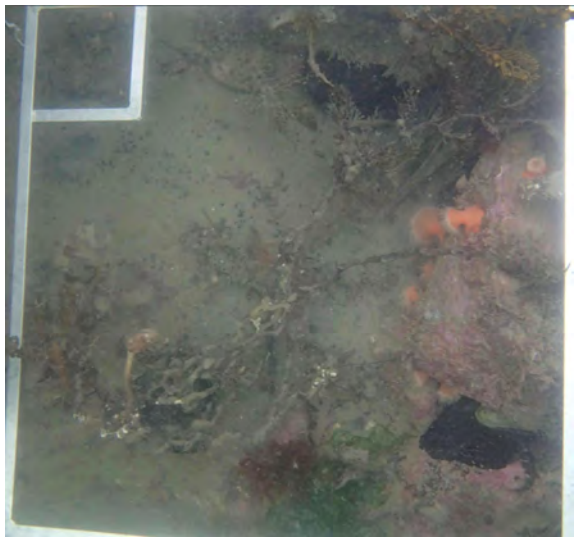


Transect 2Qe

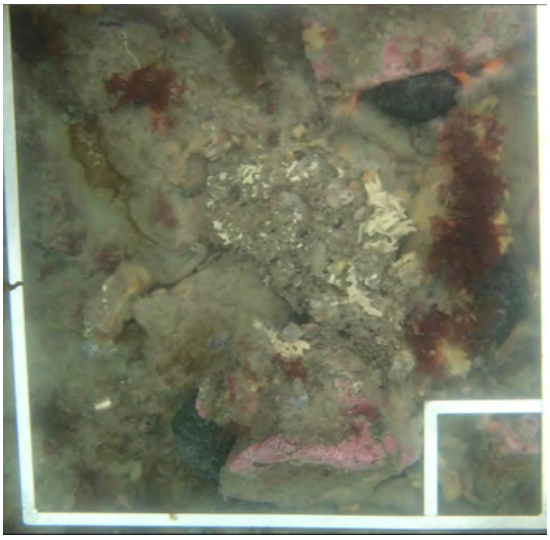
Quarantine Island Sites (Quadrats are 0.5m x 0.5m. Small square is 10cm x 10cm)



Transect 1Qa

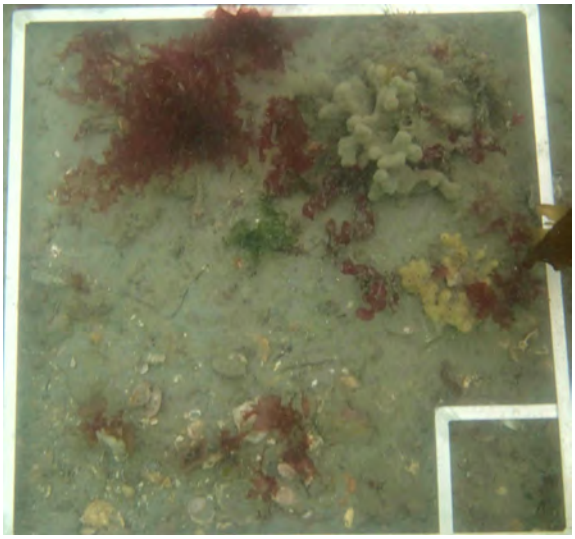


Transect 1Qb

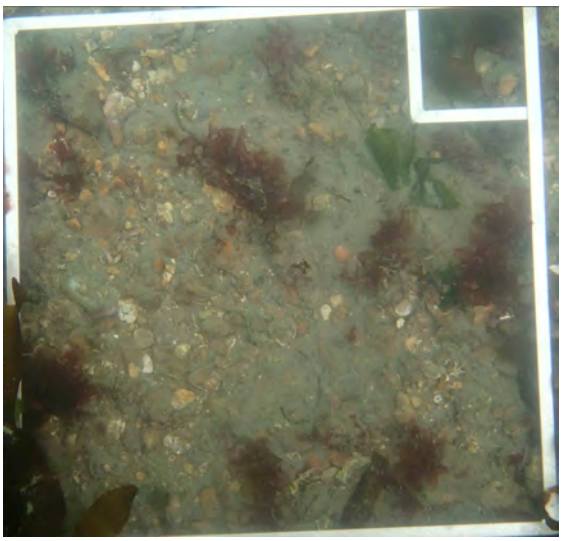


Transect 1Qc

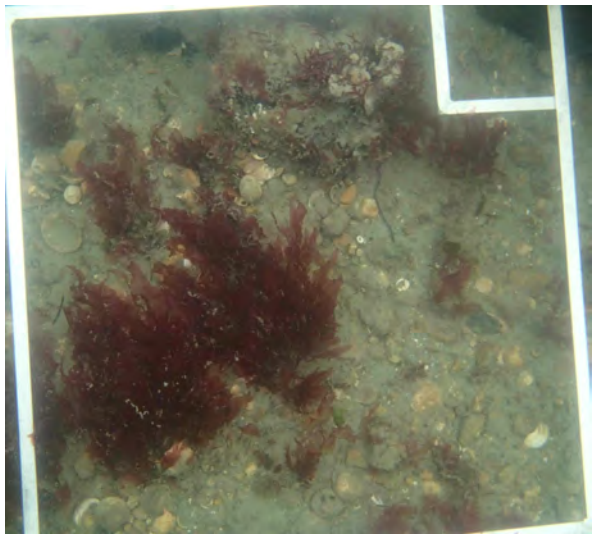
Transect 1Qd



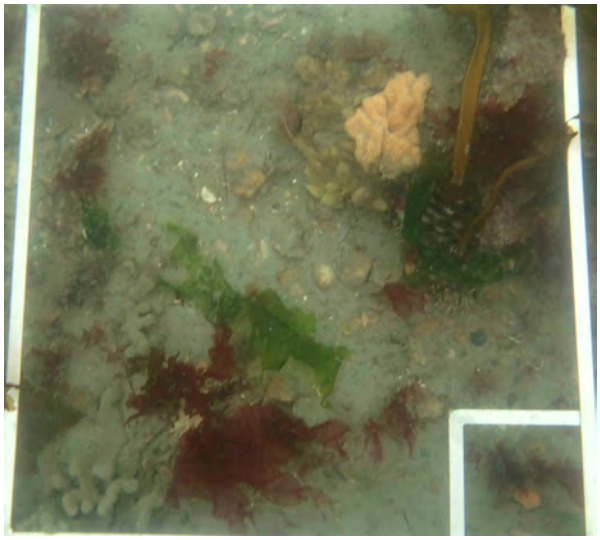
Transect 1Qe



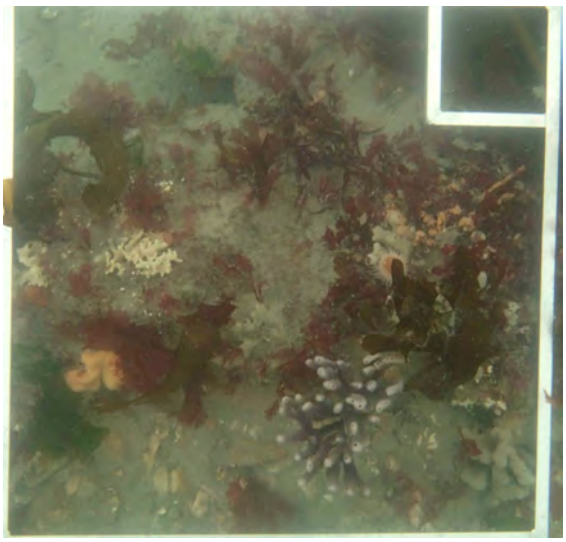
Transect 2Qa



Transect 2Qb



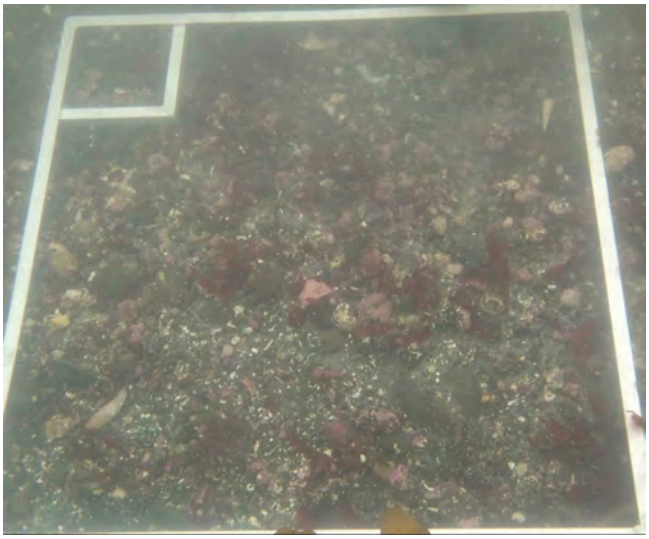
Transect 2Qc



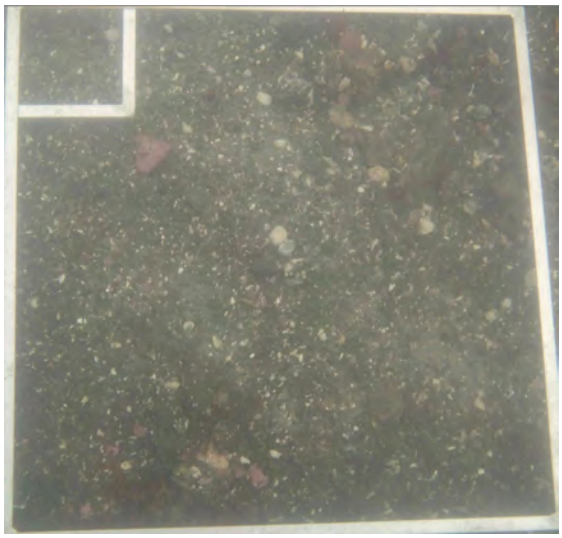
Transect 2Qd

Transect 2Qe

Pulling Point Sites (Quadrats are 0.5 m x 0.5 m. Small square is 10 cm x 10 cm)

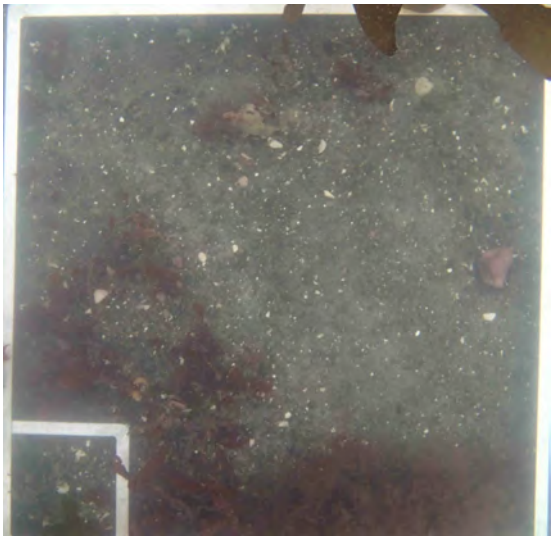


Transect 1Qa

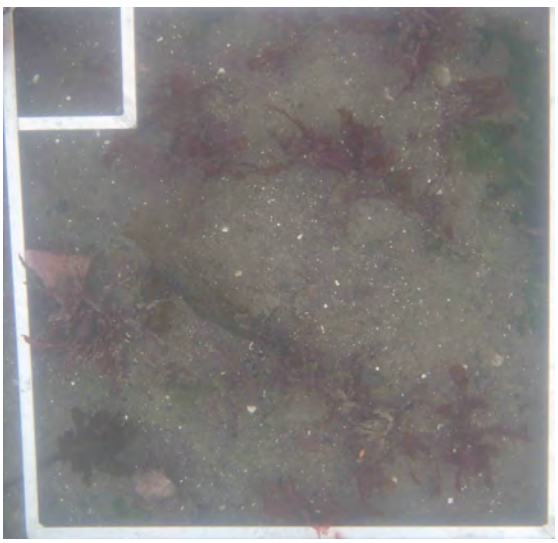


Transect 1Qb

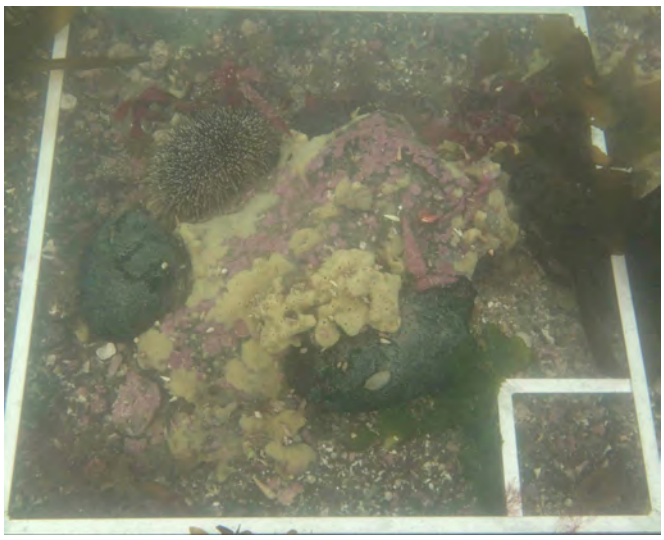
Transect 1Qc



Transect 1Qd

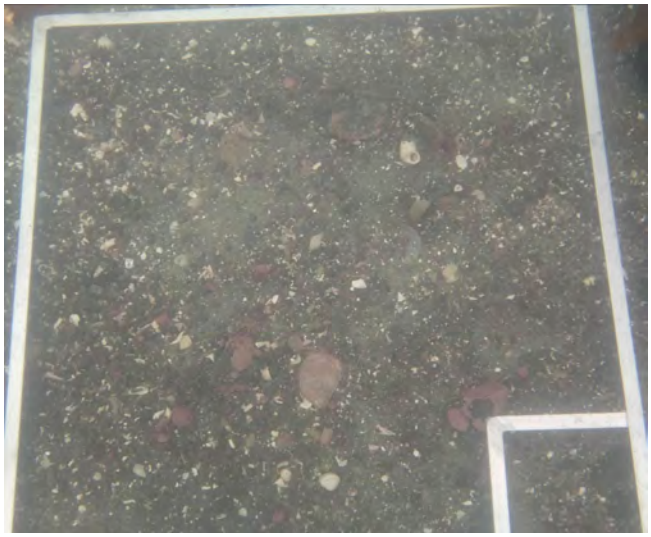


Transect 1Qe

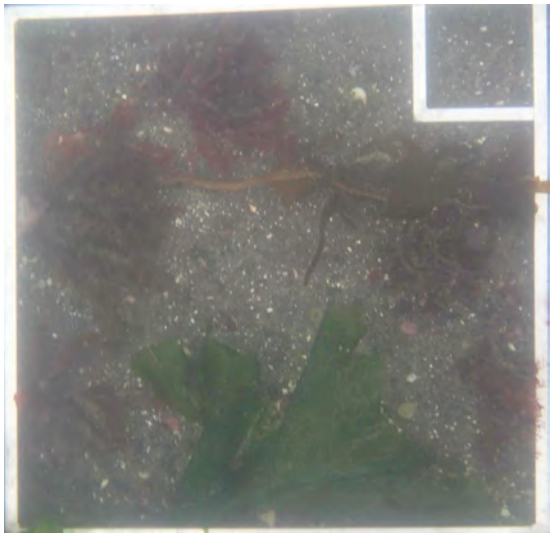


Transect 2Qa

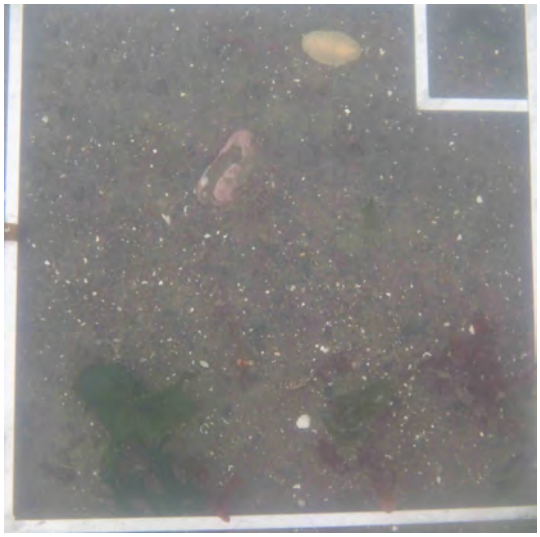
Transect 1Qb



Transect 2Qc



Transect 2Qd

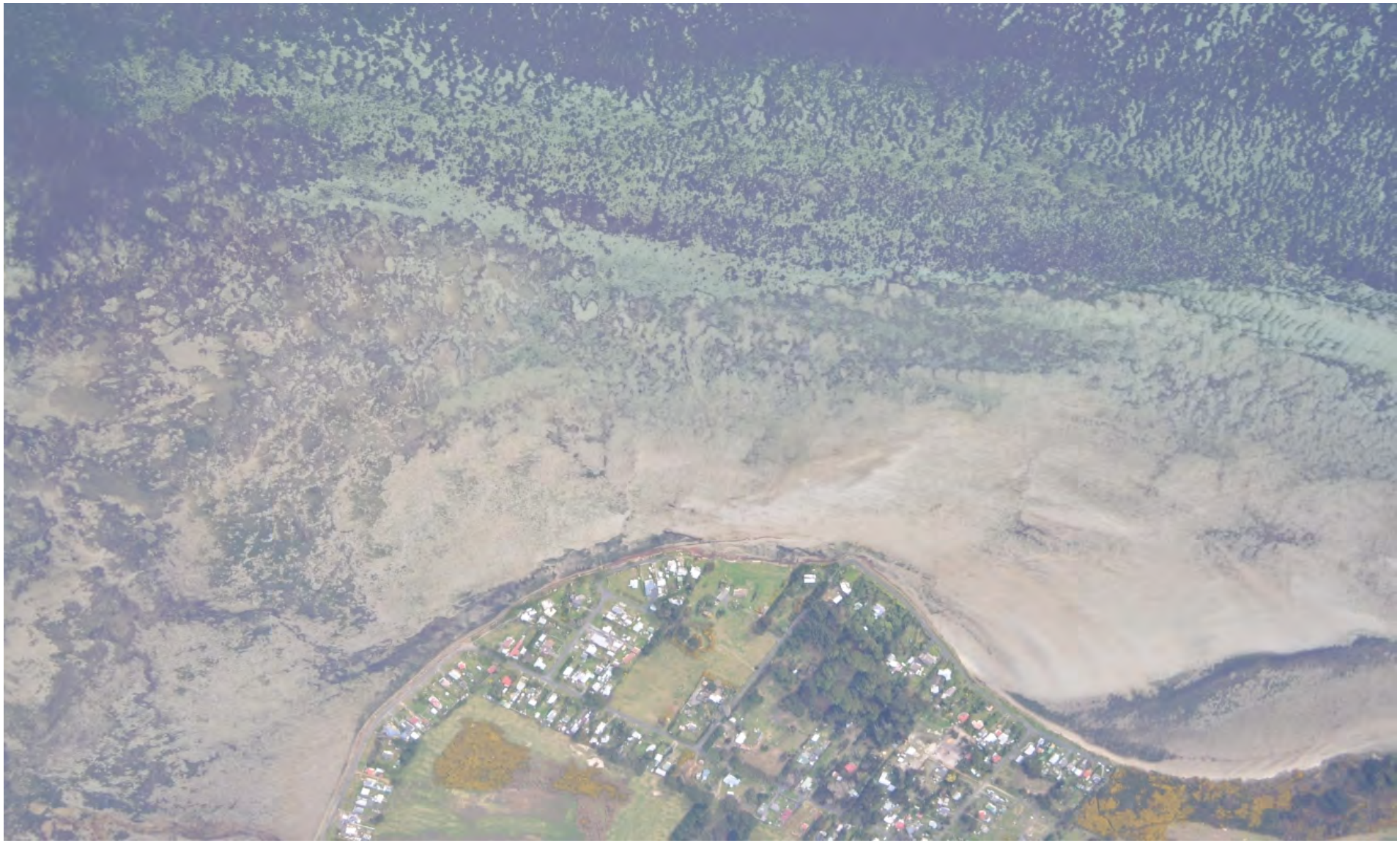


Transect 2Qe

Appendix 5 – Aerial Photographs

Seagrass Beds – Papanui Inlet

Seagrass Beds – Harwood



Aramoana Saltmarsh