Adelaide Desalination Plant
Intertidal Monitoring Winter 2012

November 2012

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1. Executive Summary

This report presents data from intertidal rocky shore monitoring undertaken as a requirement for the environmental monitoring program proposed by the South Australian Water Corporation in conjunction with Adelaide Desalination Plant/Adelaide Aqua. This report covers the monitoring period of winter 2012. The objectives of this study were to monitor the invertebrate and algal communities of rocky shore habitats within the Port Stanvac exclusion zone and within two reference zones to the north and south, in order to ascertain baseline data as a reference for future monitoring.

A total of 20 sites were sampled, with four at the northern reference zone, six at the southern reference zone and ten within the construction zone. As in previous intertidal monitoring, photoquadrats and video transect methods were used to assess the structure of flora and fauna communities within the intertidal rocky shores of all three zones.

Overall, the Port Stanvac exclusion zone had higher biodiversity, greater individual abundances of invertebrates and higher percent cover of algae. A total of 20 species from four phyla were identified across sites in the photoquadrats. Variation in distribution and individual abundances of the barnacle *Chthamalus antennatus* and the mollusc species *Cellana tramoserica* and *Siphonaria diemenensis* accounted for most of the variability observed in the Port Stanvac exclusion zones. Polychaete tubeworms accounted for the greatest percent cover of sessile organisms identified in quadrat surveys, but their distribution was highly variably and was most prevalent within the Port Stanvac exclusion zone.

This monitoring programme has established a solid spatial and temporal data set on the rocky shore communities along the Fleurieu Peninsula that will be valuable for any future assessment of potential environmental changes. The survey has also revealed the beneficial effects of protection, with the restricted access zone at Port Stanvac emerging as a biodiversity hotspot for rocky shores on the Fleurieu Peninsula coastline. Some recommendations for future monitoring design are given.

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2. Introduction

2.1 Rocky Shores and the Gulf St. Vincent

The coastline along the Fleurieu Peninsula in South Australia's Gulf St. Vincent, is comprised of rocky intertidal reef habitats that support complex algal and invertebrate communities (Benkendorff and Thomas 2007; Benkendorff *et al.*, 2008). Port Stanvac was once a working petroleum refinery, which has been closed off from public access for the last two decades. The intertidal reefs at Port Stanvac appear to be ecologically significant on a regional scale with large populations of invertebrate predators indicating a healthy reef system (Dutton and Benkendorff, 2008). Preliminary surveys by Dutton and Benkendorff (2008) indicate that the fenced off reefs at Port Stanvac may provide a biodiversity hotspot for intertidal molluscs and red algal species. Further, a review of Southern Australian herbarium collections by Scott *et al*. (2009) indicates that the Port Stanvac area is a hotspot for vulnerable macroalgal species, based primarily on the work of Prof. Brian Womersley (1988).

2.2 Potential desalination effects on marine rocky-shore flora and fauna

Many putative impacts of desalination plants onto the marine environment have been suggested (Winters *et al.*1979; Einav *et al.* 2002; Miri and Chouikhi 2005; Younos 2005); however, few peer reviewed and published studies present empirical data supporting claims for direct or indirect effects, leaving it unclear whether such impacts are really corroborated by science (Roberts *et al.* 2010). The intertidal rocky shores along the Fleurieu Peninsula are heterogeneous environments with varying levels of connectivity to other coastal ecosystems (Benkendorff *et al*. 2008); hence shifts in the rocky shore community structure may occur from anthropogenic activities in surrounding marine and terrestrial habitats. Impacts on intertidal rocky shore can also influence other larger scale ecosystem level processes, such as primary productivity, detritus supply and water quality, in other communities (Thompson *et al.* 2002). In the longer term, during the desalination plant operation phase, intertidal reefs could be affected by larval entrainment in the intake pipe reducing local recruitment of species with planktonic larvae (Lattemann and Hopner 2008). Also, there is a possibility for intertidal communities to be subjected to salinity stress if the dense brine plumes do not sufficiently flush from the outlet pipe, particularly in the warmer seasons where minimal flushing by open ocean water occurs (Samarasinghe *et al*. 2003; Kämpf *et al*. 2009).

2.3 Use of rocky shore flora and fauna as indicators of human impacts

An understanding of the spatial and temporal variation of species diversity and composition on intertidal reefs is essential to achieve appropriate management solutions (Underwood 1994). The intertidal zone is characteristically complex, with interactions between oceanographic and ecological processes as well as anthropogenic influences (Castilla and Duran 1985; Ruis et al. 2006). To be able to differentiate natural from anthropogenic influences, the assessment of intertidal biodiversity essentially has to incorporate various measures to understand all interconnecting influences.

Intertidal reefs support a variety of flora and fauna which are found within a mosaic of habitats (Schoch and Dethier 1996) and intertidal communities can vary over different scales of time and space (Underwood 1998; Olabarria and Chapman 2002) and many researchers focused their studies on identifying which processes influence variability. The distribution, abundance and interactions between organisms or with their environment require an understanding of the hierarchy of scales at which processes act. Differences in biodiversity can occur within and across patches of habitat, across habitats and on a biogeographical scale (Whittaker 1975; Gray 1997). Similarly, changes on a temporal scale can occur within days, months or years.

Marine algae are classified into three major groups: Chlorophyta (green algae), Phaephophyta (brown algae) and Rhodophyta (red algae). Marine algae enhance the heterogeneity of a rocky shore by providing increased surface area for attachment, shelter, sediment traps and a source of food for invertebrate species (Chemello and Milazzo 2002). Additionally, macroalgae are important for the possible utilisation as a food resource and also as pollution indicators (Womersley 1984; Phillips 2001). Algal species assemblages are dynamic, as their structure, composition and abundances vary temporally (Underwood and Chapman 1998). Temporal and spatial differences within algal assemblages have been attributed to biogeographical and seasonal effects, activities of grazers, disturbances and recruitment (Underwood and Chapman 1998). Changes in macroalgal density are a useful indicator as algal beds may change quickly in response to disturbances (Ward *et al*., 1998). The effects of trampling can often be seen through a reduction of algal cover on the shore resulting in the loss of habitats for invertebrates (Keough and Quinn 1998). Additionally, macroalgae respond rapidly and predictably to a wide range of pollutants and as such they are useful in providing early warning signals of deteriorating conditions, such as the influx of pollutants (McCormick and Cairns 1994).

Rocky shore invertebrate communities have been utilised to assess the effects of human disturbances, for example trampling, fishing or collecting, and pollution (Kingsford *et al.* 1991; Underwood, 1993). These disturbances have been shown to reduce species richness and abundance of some species, which has a flow on effect to the entire intertidal community (Keough and Quinn 1998, 2000). A reduction in numbers of key animal and plant species from communities in marine systems is a good indicator of human-induced changes to environmental conditions (Scheltinga *et al*., 2004). Yet, abundances will not only change due to human impacts, but also naturally.

2.4 Design of environmental monitoring studies

Monitoring plays an important role in a major development, like the Port Stanvac desalination plant, and requires well planned ecological studies that can provide an assessment of the variability in natural communities at two spatial scales; 1) within the development site and 2) between different sites of similar environmental conditions inside and outside the development zone, to provide a reference for benchmarking any changes detected in subsequent monitoring surveys. Underwood (1991, 1992) recommends replicated before/after, control/impact (beyond BACI) studies in order to detect anthropogenic effects over and above the natural variability in local communities. Such designs are beneficial in assessment of environmental impacts on marine systems, in order to detect anthropogenic effects exceeding the natural variability in local communities (Underwood 1991; 1992; Morrisey *et al.* 1992). Therefore, BACI experimental design principals were followed for this monitoring. Suitable reference locations should be situated at sites with similar habitat, at varying distances from the impact source.

The marine environment off Port Stanvac contains numerous habitat types including rocky reefs, soft sediment, shell grit habitat, macroalgae and seagrass (Benkendorff *et al*. 2008; Bryars *et al.* 2008; Edyvane 2008; Fotheringham and Coleman 2008; Loo and Drabsch 2008; Loo *et al.* 2008; Turner and Collings 2008). Suitable reference locations with a similar range of habitat are situated to the north (Marino Rocks and Hallett Cove) and south (Carrickalinga, Second Valley and Fisheries Beach) of the Port Stanvac desalination plant exclusion zone. For the intertidal survey the design included sampling at sites within the Port Stanvac exclusion zone and the northern and southern reference zones.

2.5 Study rational and scope

An EIS prepared by SA Water identified a potential for a negative effect of the construction and operation of a desalination plant at Port Stanvac on the rocky intertidal flora and fauna (SA Water 2008). As a condition of licence to construct and operate the desalination plant, the Environment Protection Authority ordered that the company in charge of construction of the plant, Adelaide Aqua, must meet strict ecological monitoring requirements including surveying intertidal macrofauna and algae, at 20 sites, including 10 reference locations (EPA Licence; available at URL: http://www.epa.sa.gov.au/xstd_files/Water/Other/desal_licence.pdf; accessed 18/08/2011).

Communities on intertidal reefs have been shown to be variable between reefs and also over time (Creese and Kingsford, 1998; Chapman, 2002). Sampling design for monitoring needs to be optimised across all sites and standardised in both time and space to facilitate comparison of data sets (Benkendorff, 2003). In addition, samples must have sufficient replication in order to reduce the amount of intrinsic variation, and increase the ability to detect changes in the data (Underwood and Chapman, 2002).

Here we report on the last sampling of a seasonal rocky intertidal survey programme that commenced in May 2009 during the establishment of a desalination plant at Port Stanvac. Intertidal flora and fauna were monitored along 100 transects (representing the sites required by the EPA licence), 50 line intercept transects within the Port Stanvac exclusion zone and a further 50 transects from two reference zones, consisting of a total of five reference sites. To obtain an indication of the spatial variation in flora and fauna communities, sites were selected from Marino Rocks and south to Fisheries Beach on the tip of the Fleurieu Peninsula. This report presents the results of the winter 2012 survey, several months after the plant started producing desalinated water in late 2011.

2.6 Study aims and design

This investigation was strictly monitoring, with scope to test for potential mechanisms for disturbance of the desalination plant on the marine benthos by way of spatial comparisons.

The goal was to determine any impact of construction on the rocky intertidal habitat at Port Stanvac relative to natural levels of background spatial and temporal variation in these habitats along the Fleurieu Peninsula. Thus, this montoring programme aimed to:

- determine the spatial and temporal pattern of distribution and abundance of rocky intertidal communities to be used as a baseline data set for future monitoring programmes on potential disturbances resulting from the desalination plant operations at Port Stanvac, relative to background spatial and temporal variation, measured at nearby reference locations.

To achieve this aim, the monitoring programme included sampling of rocky intertidal communities at Port Stanvac and at nearby reference sites using photoquadrats and video transects. Sampling on multiple spatial and temporal scales allowed quantification of the natural variation of the rocky intertidal communities. This design allowed to detect disturbance of construction at Port Stanvac, if any, over natural background levels of variation, in a beyond-BACI type design (Underwood 1992). This report details the results obtained for the spatial variation of flora and fauna communities across five reference sites and five sites within the Port Stanvac exclusion zone for winter 2012.

3. Methods

3.1 Sampling locations, sites and dates

Sites along the Fleurieu Peninsula were selected according to comparable rock strata type and topography. Five locations within the Port Stanvac fenced area were sampled, with reference locations located to the North at Marino Rocks and Hallett Cove and to the South at Carrickalinga, Second Valley and Fisheries Beach (Figures 1). These sites have been surveyed for this monitoring since autumn 2009. Please note; as the desalination plant has moved to an operational phase, the construction zone, as per previous reports, is now referred to as the Port Stanvac exclusion zone.

Two 20 x 20 m plots, placed roughly 100 m apart, were surveyed within the intertidal zone at each location, thus generating data from 20 specific sites. GPS coordinates were taken from the middle of each plot. All sites were surveyed during low tides throughout January 2012 (Table 1), using the methods outlined below.

3.2 Invertebrate abundance

Photoquadrats were used to assess invertebrate abundance, species diversity and species richness. This method can be rapidly applied in the field and provides a permanent record for future reference. Ten replicate 0.25 m^2 quadrats were haphazardly placed within each 20 m x 20 m plot. Each quadrat was divided into quarters, with one high resolution photograph taken of each quarter, as well as one encompassing the whole quadrat, using an Olympus Model µ 1030SW digital camera (see Dutton and Benkendorff, 2008), generating a total of 1,200 high resolution photos. Photographs were later downloaded onto a computer and analysed using Paint.NET v3.36 imaging software. All visible mobile fauna was identified and counted to a minimum of family level, with identification to species level where possible. Organisms which were unable to be identified to the family level (due to heavy erosion of the shell or algal/invertebrate encrustation etc.) were marked as unidentified species. All field work was conducted during tides below 0.7 m.

3.3 Percent cover of sessile organisms

A line intercept transect method (e.g. Benkendorff and Thomas, 2007; Dutton and Benkendorff, 2008) was used to assess the percent cover of sessile invertebrates (e.g. black mussels *Limnoperna pulex* (formerly *Xenostrobus pulex*) and polychaete tube worms (*Galeolaria caespitosa and Pomatoceros taeniata*), as well as percent algal cover from the low to high tide zones. The method was adapted to include the use of video recording in which footage was taken of each replicate transect using an Olympus Model Tough8000 digital camera. This ensured that transects were completed during low tides on the same day at each location. Transects were filmed by walking slowly along a tape measure, showing distance covered in centimetres. The camera was set at a rate of 30 frames per second and held approximately 10 cm from the substrate to ensure that the footage was captured at a high resolution. Taxa identified along video transects were classified into functional groups to minimise the time taken for the survey analysis and also due to the complexity of identifying certain algae species. Functional groups were chosen according to morphology or broad taxonomic group (e.g. foliose green, encrusting brown/red/green, brown turfing, red foliose etc.) such as those used in Reef Watch surveys (Reef Watch, 2007). Using a functional grouping approach is useful for understanding broader generalizations on the ecology of rocky shores as well as predicting changes in community structure. In regions where there was an overlap of sessile and algal communities, 'mixed community' categories were established to represent and identify the presence of multiple species. The percent of bare substrate and sediment cover was also recorded along these transects.

Video transects were analysed using VLC Media software, with regular pausing along transects to identify sessile organisms and to allow accurate recording of distance intervals. At the start of each transect, the type of organism cover was recorded and then transition from one type of organism cover to another recorded along each transect to a resolution of 1 cm. Total percent cover for each category, organism or substrate was subsequently calculated from the summed total distance covered, divided by the total length of the transect (20 m). Means and standard deviation were generated from 5 replicate transects in each plot. However, transects of 20 m were not always obtained (at Second Valley during high swell). In these cases, percent cover was calculated by dividing the summed distance of organisms by the total transect distance, thus giving a proportional cover comparable to that of other shoreline transects.

3.4 Data analyses

To determine the diversity and evenness of invertebrate species composition at all sites, three different diversity indices were calculated (Shannon-Wiener index and Pielou's evenness) based on the shares of the individual numbers of each taxon on the total number of individuals (*N*). The Shannon-Wiener index identifies greater species diversity the higher the index value. Pielou's index identifies the equitability of species presence at each site where a larger number indicates higher evenness (Clarke and Warwick 2001).

Abundances of each taxonomic group were statistically analysed using PERMANOVA to determine if there were significant differences between Zones and Sites nested within Zones. PERMANOVA utilises permutations based on dissimilarities and does not assume a normal distribution for the original variables, making it a useful tool for analysing ecological community datasets (Anderson *et al*. 2008). Further pair-wise tests were also conducted to detect which group differences contributed to any significant result using PERMANOVA. Monte Carlo tests were undertaken in the pair-wise test function in PERMANOVA if low permutations were obtained. The Monte Carlo (*P)* value is better suited and more reliable when there are not enough possible permutations (i.e. < 100) (Anderson *et al*. 2008).

Analyses of invertebrate community composition for each of the seasons were undertaken on quadrat abundance data to determine if there were similarities between sites and zones. A square root transformation was performed on the abundance data for sites and zones. Principle Co-ordinates

Analysis (PCO) was employed to provide a visual pattern of invertebrate community structure, as it preserves original dissimilarities between points (Anderson *et al*. 2008). In addition, vector overlays were superimposed onto PCO plots to determine the strongest associations of variables (species) at both the site and zone level using Spearman Rank correlations. In order to distinguish the dissimilarities between invertebrate communities a design incorporating the factors of zone, and sites nested within zone, was used. To detect which group differences contributed to any significant result, further pair-wise permutation tests were carried out using PERMANOVA, with a Monte Carlo test if low permutations resulted. All univariate and multivariate analyses were performed using the PRIMER version 6.0 with PERMANOVA + add on programme.

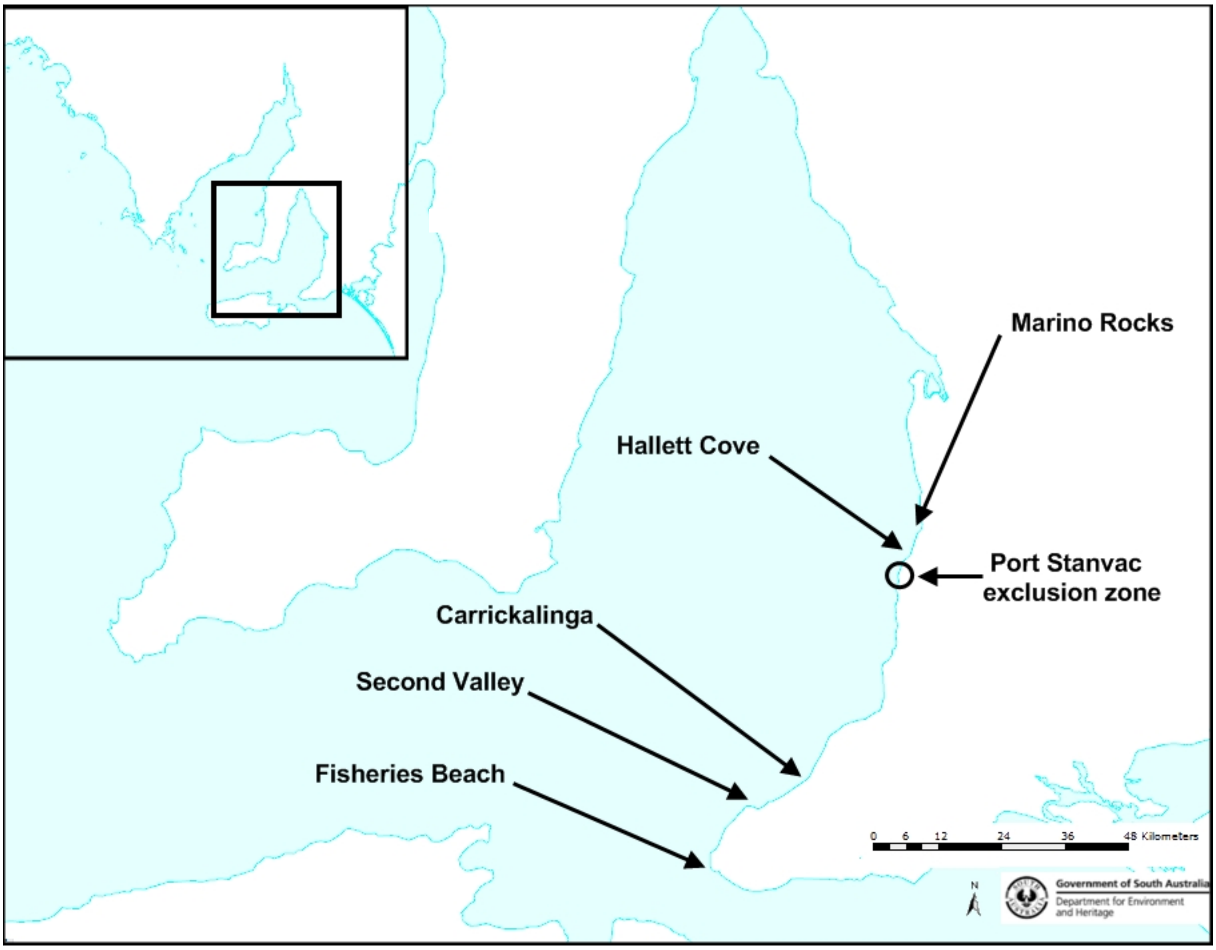


Figure 1: Intertidal sampling sites; Port Stanvac exclusion zone; Northern Reference Zone (Marino Rocks and Hallett Cover); and the Southern Reference Zone (Carrickalinga, Second Valley and Fisheries Beach), during winter 2012. Maps adapted from Nature Maps, Department of Environment and Heritage, Government of South Australia, www.naturemaps.sa.gov.au

Table 1: Sampling dates and GPS co-ordinates for the intertidal study sites sampled during winter 2012.

		GPS Co-ordinates				
Location	**Abbreviation**	**South**	**East**	**Season**	**Date**	**Tidal Height (m)**
Marino Rocks	MR	S 35°02'45.6"	E 138°30'27.6"	Winter	20/08/2012	0.44
Hallett Cove	HC	S 35°05'06.2''	E 138°29'31.5"	Winter	20/08/2012	0.44
Port Stanvac 1	PS1	S 35°06'48.8"	E 138°28'13.5"	Winter	3/09/2012	0.39
Port Stanvac 2	PS2	S 35°06'28.4"	E 138°28'20.0"	Winter	3/09/2012	0.39
Port Stanvac 3	PS3	S 35°06'15.4"	E 138°28'31.8"	Winter	21/08/2012	0.46
Port Stanvac 4	PS4	S 35°06'12.4"	E 138°28'34.4"	Winter	21/08/2012	0.46
Port Stanvac 5	PS5	S 35°06'25.7"	E 138°28'20.7"	Winter	21/08/2012	0.46
Carrickalinga	CC	S 35°25'09.0"	E 138°19'25.2"	Winter	8/08/2012	0.63
Second Valley	SV	S 35°30'36.3"	E 138°12'54.2"	Winter	6/08/2012	0.54
Fisheries Beach	FB	S 35°37'58.5"	E 138°06'49.4"	Winter	4/09/2012	0.39

4. Results

4.1 Photoquadrats

4.1.1 Invertebrate Species Diversity

A total of 20 taxa were recorded on the rocky intertidal shore across all sites during the 2012 winter survey, the majority of which were molluscs represented by 14 taxa, followed by four crustaceans and one taxa each of annelids and bivalves (Figure 2, Appendix 1). Twenty taxa were recorded within the Port Stanvac exclusion zone, compared to 13 taxa found in the northern reference zone, and 12 taxa within the southern reference zones, Consistent with previous baseline recordings (Baring et al. 2010; Cantin et al. 2011), the greatest number of macroinvertebrate species found were located within the Port Stanvac exclusion zone and more specifically at sites Port Stanvac 1B and Port Stanvac 4B (S=14). In general, lower species numbers were recorded across the southern reference zone, being lowest at sites Carrickalinga 1 and Fisheries Beach 1 (S=5) (Figure 2). Mollusc species were present at each site within the three zones (Figure 2). Similarly, Crustacea were recorded at most sites, with the exception of Hallett Cove site and Fisheries Beach site 1 where no Crustacea species were recorded (Figure 2).

Species density was variable within the intertidal zone, with significant differences between zones ($F_{2,180}$= 36.237, $P < 0.001$), and site(zone) ($F_{17,180}$= 1.7021, $P < 0.05$). A *post hoc* pair-wise analysis revealed significant differences in species densities between the Port Stanvac exclusion zone and both the northern and southern reference zones ($P < 0.001$), as well as between the northern and southern reference zone ($P < 0.01$).

Pielou's index for species evenness (J') was calculated for all sites and was found to be lowest at Port Stanvac 5B and Carrickalinga 2 (Figure 3a), indicating numerical dominance of a particular species at these sites. Species evenness was variable throughout the Port Stanvac exclusion zone, with low evenness at Port Stanvac sites 4B and 5B, predominantly due to the dominance of the barnacle, *Chthamalus antennatus*. Generally, sites within the northern reference zone had higher J' values indicating more even abundances across all species (Figure 3a). The Shannon-Wiener diversity index (H') was also calculated for all sites and diversity varied significantly between the three zones ($F_{2, 180}$, 24.836, P < 0.001) but was not different for sites(zones) ($F_{17, 180}$, 1.3827, P > 0.05), with *post-hoc* pairwise tests indicating higher diversity in the Port Stanvac exclusion zone and the northern reference zone, in comparison to the southern reference zone (Figure 3b). However, two sites within the southern reference zone, Second Valley site 1 and Fisheries Beach site 2, had higher than average H' values indicating greater species diversity (Figure 3b). These sites also displayed high values for evenness and the higher diversity values are likely due to the relatively low abundance of individuals at both these sites compared to the number of species identified. While these sites on the southern Fleurieu coastline are important as rocky intertidal reference locations when establishing a baseline, caution should be exercised when using sites with low individual abundances to measure diversity, as this can lead to a misrepresentation of biodiversity in that region.

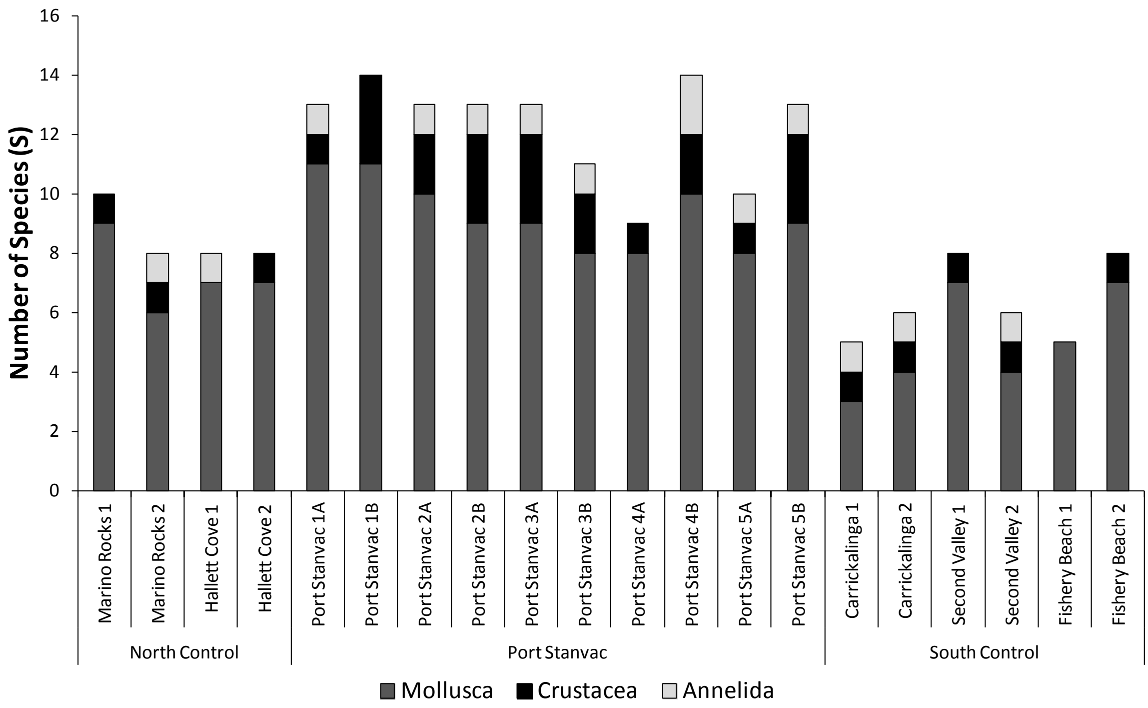


Figure 2: Total species number per phyla identified in photo quadrats during the winter 2012 intertidal surveys for all sites encompassing three Zones; Northern Reference Zone, Construction Zone and Southern Reference Zone.

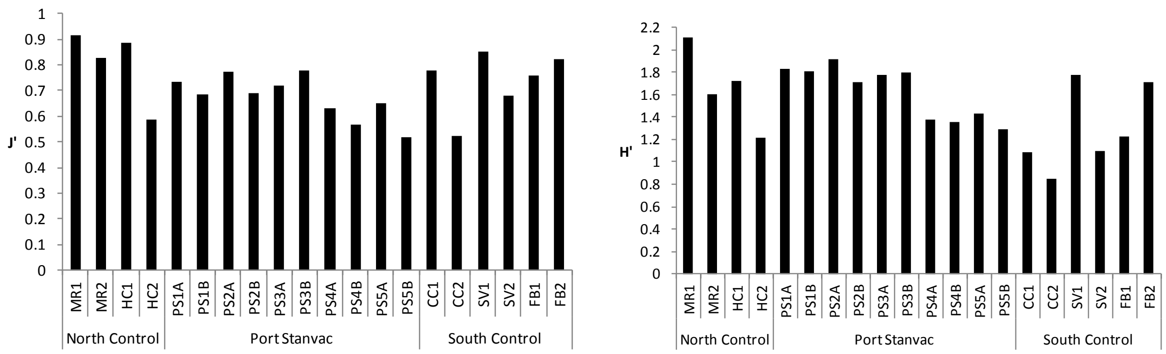


Figure 3: Diversity of invertebrates during winter 2012 survey; based on (a) Pielou's index of evenness (J'), (b) Shannon-Wiener diversity index (H'). Refer to Table 1 for site abbreviations.

4.1.2 Invertebrate Abundance

Invertebrate abundance and species distribution varied between the three zones and sites within each zone, with highest average abundances recorded within the Port Stanvac exclusion zone and lowest abundances in the southern reference zone (Figure 4a). Mollusca were abundant across survey sites, with the highest average abundance occurring within the Port Stanvac exclusion zone (Figure 4b). Crustacea were also most prevalent within the Port Stanvac exclusion zone, however, occurred in patchy distributions within this zone (see large standard deviations in Figure 4c). PERMANOVA test results indicated significant differences between zones and sites nested within zones for total benthic abundances as well as for molluscs and crustaceans (Table 2). Subsequent *post hoc* pairwise analyses showed significant differences between the Port Stanvac, northern reference and southern reference zones for all phyla and Crustacea (Table 3). Test results also showed significant differences between the Port Stanvac exclusion zone and both the northern and southern zone for molluscs, however, their abundances were not significantly different between the northern and southern reference zone (Table 3).

Percent cover of polychaete tube worms and *Limnoperna pulex*, the only annelid and bivalve recorded in this survey, were highly variable. Polychaete tube worms were found in all three zones, but did not occur at every individual site (Figure 5). The mussel *L. pulex* was recorded at only one site throughout the winter survey, occurring at Port Stanvac site 4b.

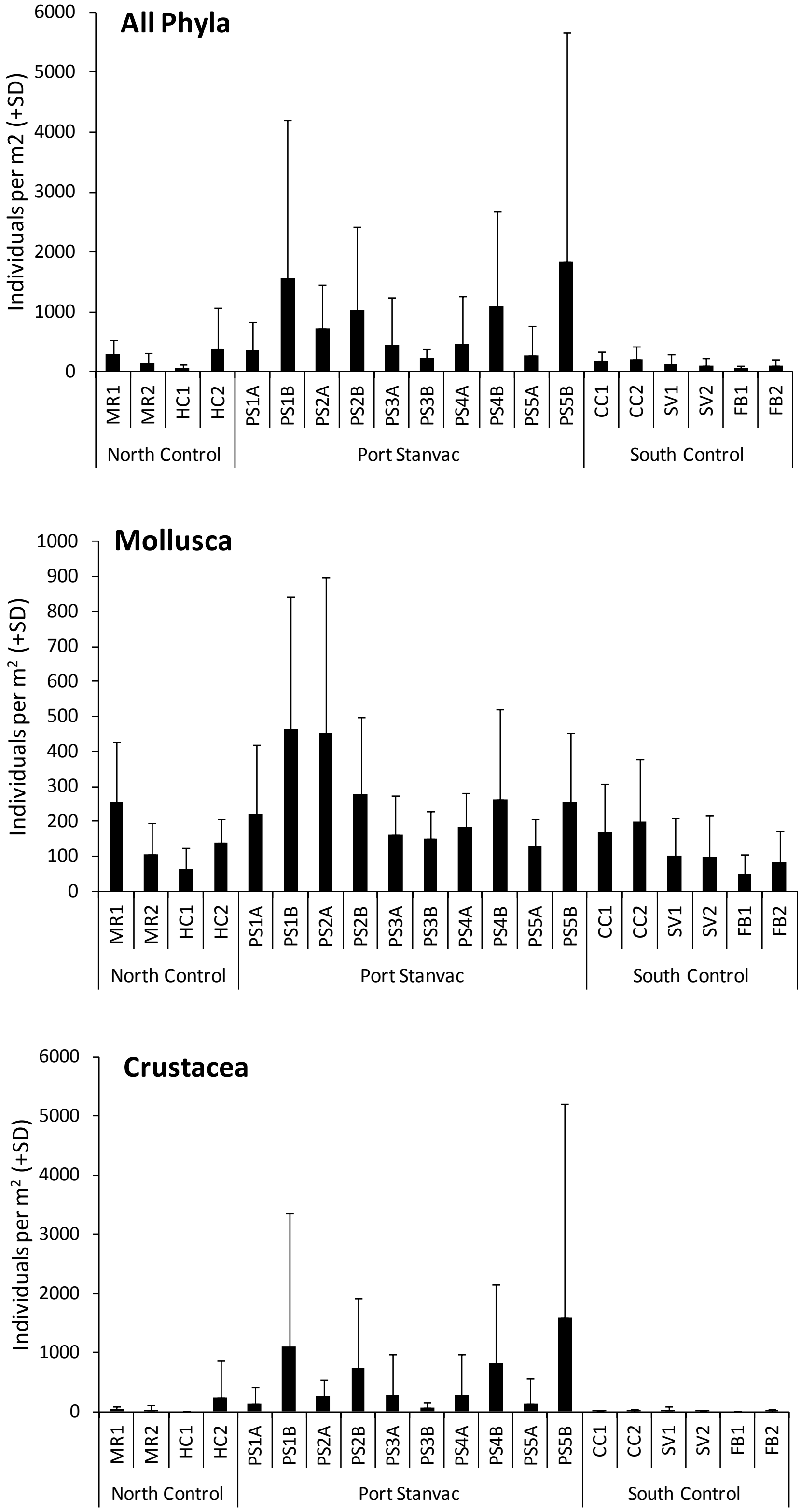
Table 2: Results from PERMANOVA test showing differences between zones (Port Stanvac, northern reference and southern reference zone) and sites nested within each zone for abundances of all phyla, Mollusca and Crustacea; Significant *P*-values are highlighted in bold.

Source	df	All phyla *P* (perm)	Mollusca *P* (perm)	Crustacea *P* (perm)
Zone	2	**0.0001**	**0.0001**	**0.0001**
Site(Zone)	7	**0.0003**	**0.008**	**0.0014**
Residual	190			

Table 3: PERMANOVA Pair-wise test results for term ‘Zone’ for abundances of all phyla, Mollusca and Crustacea; Significant *P*-values are highlighted in bold.

Term 'Zone'	All phyla *P* (perm)	Mollusca *P* (perm)	Crustacea *P* (perm)
Northern Reference, Port Stanvac	**0.0001**	**0.0007**	**0.0005**
Northern Reference, Southern Reference	**0.0271**	0.0999	**0.0022**
Port Stanvac, Southern Reference	**0.0001**	**0.0001**	**0.0001**

a)



b)

c)

Figure 4: Mean abundances (+SD) for a) all phyla, b) Mollusca and c) Crustacea from the winter 2012 intertidal survey encompassing three zones; Northern Reference Zone, Port Stanvac Exclusion Zone and Southern Reference Zone.

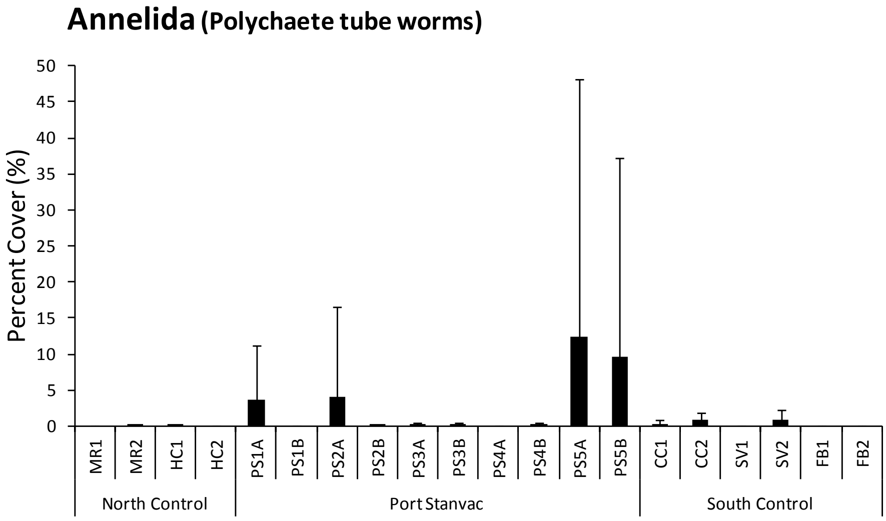


Figure 5: Percentage cover of Annelida from the winter 2012 intertidal survey encompassing three zones; Northern Reference Zone, Port Stanvac Exclusion Zone and Southern Reference Zone.

4.1.3 Community Analysis

The Principle Coordinate Ordination (PCO plot) of the winter 2012 intertidal data shows a difference between the three zones based on invertebrate assemblages, with both axes explaining 63.5 % of the observed total variation (Figure 6). A vector overlay illustrates that a higher diversity characterised the rocky shore community at Port Stanvac, with several species influencing the distinction of this assemblage (*Siphonaria diemenensis, Patelloida latistrigata, Chtalamus antennatus, Elminius modestus, Notoacmea flammea, Chamaesipho tasmanica*, as well as *Cellana tramoserica* and *Bembicium vittatum*) (Figure 6a). The rocky shore assemblage at the Port Stanvac exclusion zone was clearly distinct from the northern and southern exclusion zones (Figure 6a), with PERMANOVA identifying significant differences between zones ($F_{2,180}$= 13.787, P < 0.001).

Two sites of the southern reference zone (Carrickalinga and Second Valley) had distinct rocky shore assemblages, due to higher abundances of the snail *Austrolittorina unifasciata* (Figure 6a). The distinction of rocky shore assemblages from both the northern (Hallett Cove and Marino Rocks) and southern (Fisheries Beach) reference zones to the Port Stanvac exclusion zone was mainly driven by *Notoacmea* spp. (Figure 6a). Some sites within the northern reference zone had a slightly similar rocky shore assemblage to the Port Stanvac exclusion zone.

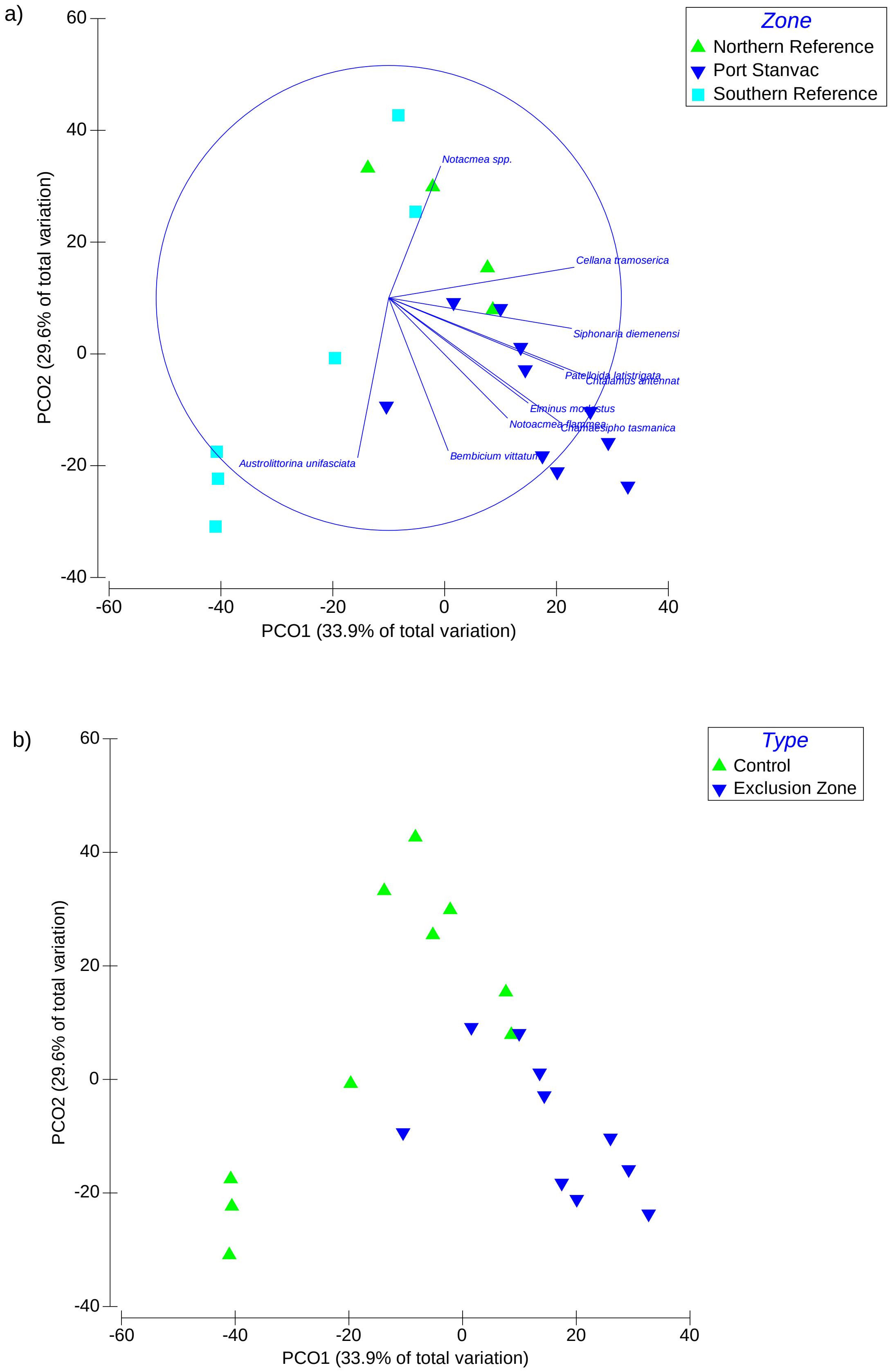


Figure 6: Principle Coordinate Plots (PCO) of invertebrate communities from quadrat surveys using Bray-Curtis resemblance matrices. Data are presented in two ways by; (a) Zone, with vector overlay displaying strongest species correlations using Spearman Ranks (0.5); and (b) Type, displaying sites within the Port Stanvac exclusion zone and a common grouping of sites from the northern and southern reference zones.

Data were also analysed by type (control *versus* exclusion zone) to further examine the possible distinction of rocky shore assemblages within the Port Stanvac exclusion zone compared to either of the surrounding regions (Figure 6b). The PCO plot illustrates the spread of sites with a denser clustering of sites from the Port Stanvac exclusion zone compared to the rocky intertidal sites located outside of this exclusion zone (Figure 6b). This distinction was supported by PERMANOVA results indicating a significant difference between the Port Stanvac exclusion zone and the control zones ($F_{1,180}$= 18.368, P < 0.001).

4.2 Transect Data

4.2.1 Percent of Substrate Cover

During winter 2012, the highest proportion of bare rock occurred within the northern reference zone, with an average of 88 % bare rock across all sites, while the Port Stanvac exclusion zone had an average of 76 % bare rock cover across all at sites. Sand cover occurred at only 4 sites across the three zones and accounted for less than 1 % of total substrate cover (Figure 7). Beach wrack had accumulated and covered parts of the rocky intertidal shore at Second Valley. Algal and sessile fauna cover was highest within the Port Stanvac exclusion zone, particularly at site Port Stanvac 1b and at Fisheries Beach site 2 (Figure 8).

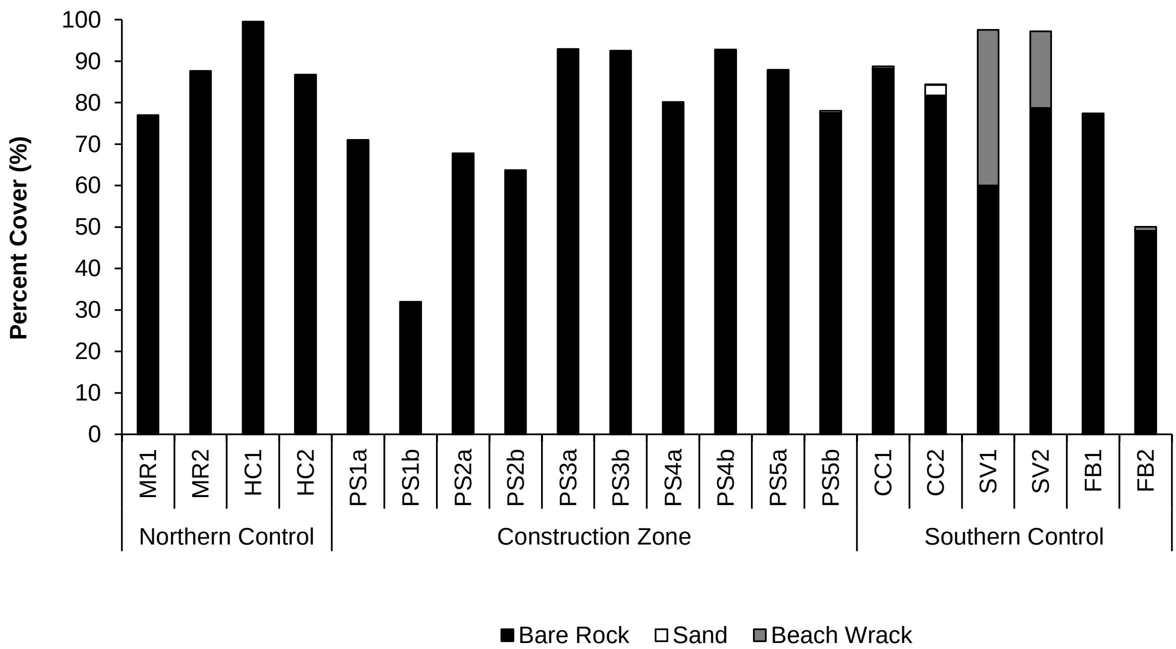


Figure 7: Mean percent cover of intertidal reefs, split into bare substrate and sand, based on intertidal reefs at all sites, across three Zones; Northern Reference Zone, Construction Zone and Southern Reference Zone during the winter 2012 survey.

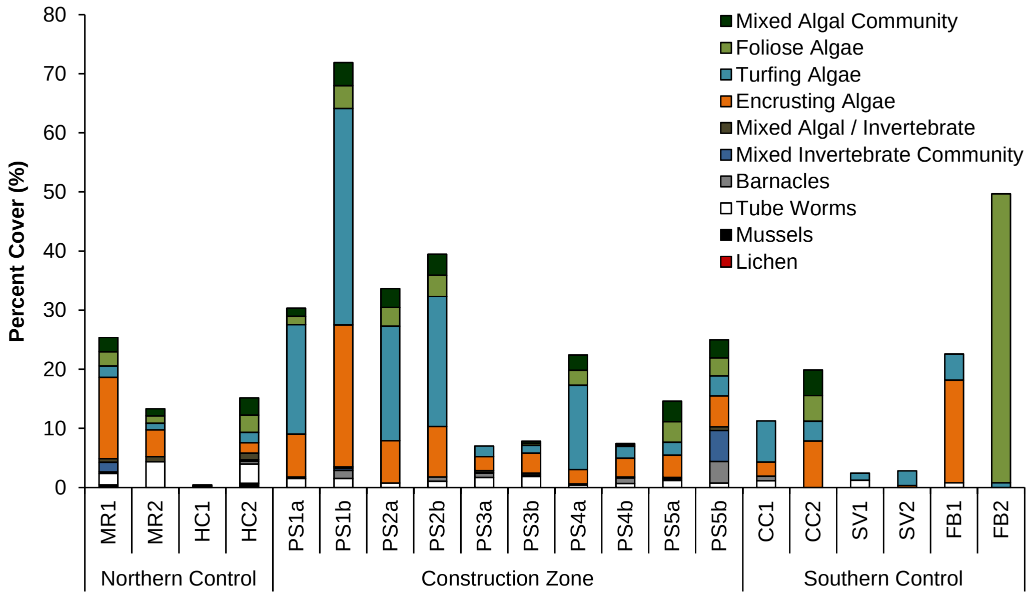


Figure 8: Mean percent cover of algal and fauna on intertidal reefs quantified from transects. Based on intertidal reefs at all sites, across three Zones; Northern Reference Zone, Construction Zone and Southern Reference Zone during the winter 2012 survey.

4.2.2 Community Analysis of Substrate Cover

Based on the substrate cover, the rocky intertidal was significantly different between zones (PERMANOVA, $F_{2,\,80}$, 22.608, P < 0.001) and site(zone) ($F_{17,\,80}$, 10.455, P < 0.001), with further *post hoc* pair-wise tests revealing significant differences between all zones and sites nested within zones indicating high variability within the dataset. A PCO plot of substrate cover illustrated a greater similarity of sites from all three zones, with combined axes explaining 69.6 % of the variation (Figure 9). The PCO plot revealed outliers, based mainly on sites in the southern control zone where the rocky shore was dominated by beach wrack that had accumulated in large quantities at Second Valley (Figure 9a). The second outlier was Fisheries Beach site 2, which was distinct because of a high level of cover by foliose green algae occurring near a runoff from a nearby farm and thus constituting an anomaly within the dataset for this survey. For the remaining sites, the assemblages based on substrate cover were characterised by mixed algal communities, encrusting algae and, especially at the Port Stanvac sites 1 and 2, also turfing algae. These particular substrate covers at the sites also accounted for a significant difference in the assemblage between types (Control versus exclusion zone) ($F_{1,80}$= 28.644, P < 0.001) (Figure 9b).

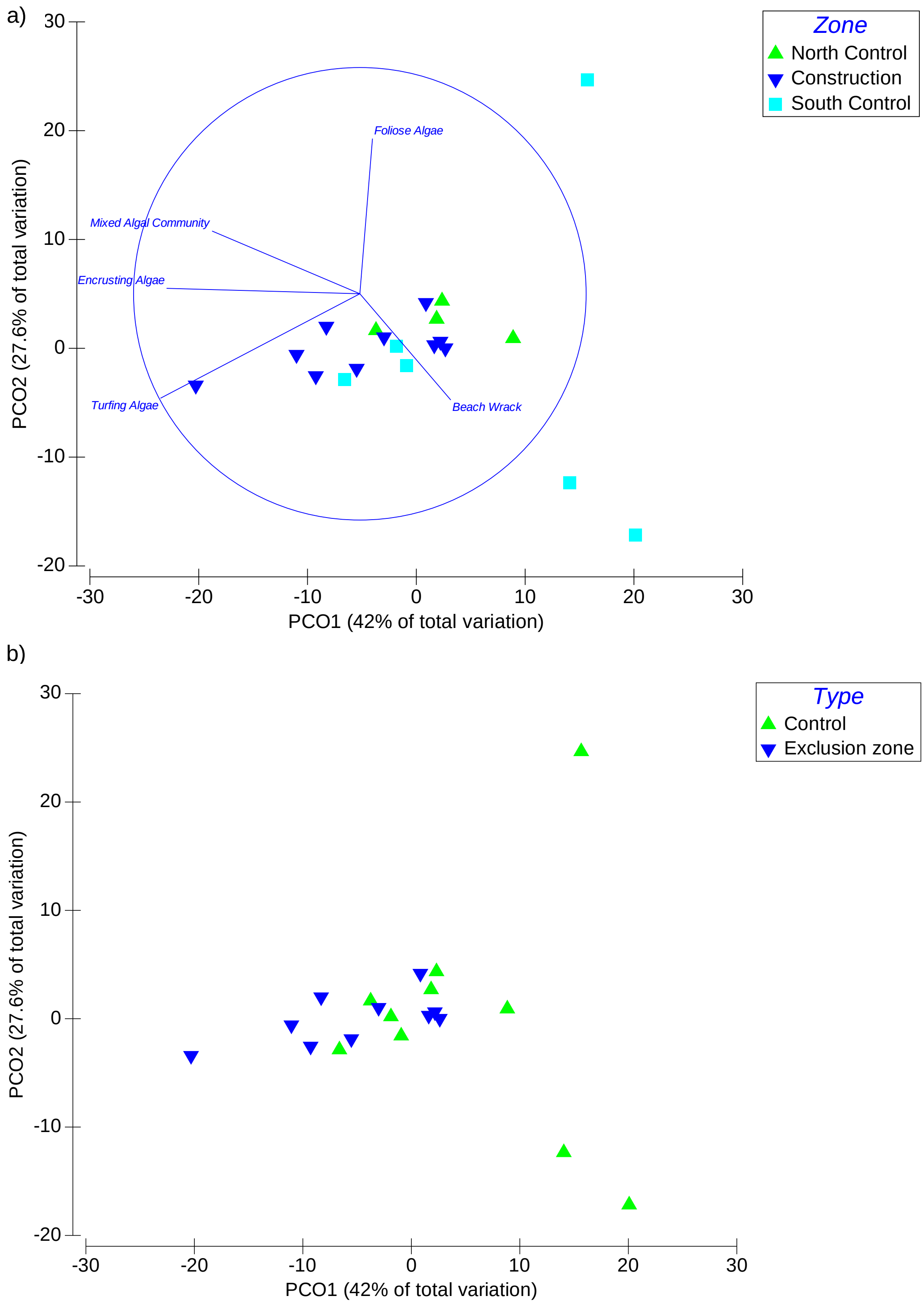


Figure 9: Principle Coordinate Plot (PCO) of substrate cover (flora and fauna) cover from video transect surveys, presented two ways for interpretation by (a) Zone, and (b) Type, using Euclidean resemblance matrices.

5. Discussion

The intertidal survey undertaken in winter 2012 was a continuation of previous research as part of an ongoing environmental monitoring program during the establishment of the Adelaide Desalination Plant. The general observations and patterns observed within this survey were consistent with those seen in previous intertidal surveys for the Port Stanvac exclusion zone and the northern and southern reference zones (Dutton and Benkendorff 2008, Baring et al. 2010; Cantin et al. 2011). The commencement of small-scale desalination in late 2011 with the associated discharge of small volumes of brine had no apparent effect on the rocky shore communities so far. Differences in the rocky shore between the Port Stanvac and control zones were much more driven by restrictions of public access.

Total species numbers and abundances, as well as abundances of individual phyla were greatest within the Port Stanvac exclusion zone, which has previously been identified as a region rich in biodiversity (Womersley 1988; Dutton and Benkendorff 2008, Cantin et al. 2011). Complex habitats, such as boulder zones occurring throughout the Port Stanvac exclusion zone, provide protection from predation, shelter and habitats for egg mass deposition (Chapman 2002; Benkendorff and Davis 2004), and can account for the high abundance and numbers of intertidal species seen throughout this zone. In addition, the coastline adjacent to the Port Stanvac Exxon Mobil oil refinery, bordering Marino Rocks and O'Sullivans beach, has been publically inaccessible for the past two decades, creating an exclusion zone and providing an intertidal marine sanctuary. Previous studies on the intertidal coastline have highlighted the role that exclusion zones play in determining population sizes and dynamics (Moreno et al. 1986), as well as the negative impact that human recreational activities have on intertidal species (Castilla and Duran 1985; Ruis et al. 2006).

Variable densities of Crustacea and Mollusca from quadrat data indicated a patchy distribution of individuals across all sites within the three zones. Such variability can originate from the interaction between organisms and various environmental parameters such as tide, exposure and habitat (Underwood and Chapman 1995). High levels of spatial variability are expected in heterogeneous intertidal habitats, with macrofauna often displaying variable patterns of distribution and abundance along rocky shores (Chapman and Underwood 1996; Chapman 2005). Highly variable distribution of substrate cover was also evident across all sites and zones with the greatest algal cover occurring within the Port Stanvac exclusion zone. This may again be attributed to the restricted access of the public to the Port Stanvac coastline, as algae are susceptible to human trampling (Keough and Quinn 1998) and algal cover increases at sites which are protected from physical disturbance such as human activity (Moreno et al. 1984).

Species diversity was proportionally higher at two sites located within the southern reference zone despite the greatest number of species and highest individual abundance being found at sites within the Port Stanvac exclusion zone. This illustrates that a diversity index value alone may not necessarily best indicate a region of high biodiversity. While the assessment of the southern sites (Carrickalinga, Second Valley and Fisheries Beach) has been valuable for establishing a local and regional baseline of rocky intertidal organisms, their function as reference sites in future monitoring has to be evaluated.

Future monitoring efforts should be concentrated on the Port Stanvac exclusion zone, as well as the closest neighbouring rocky shores; Marino Rocks and Hallett Cove Beach, to better determine any effects that may occur as a result of the desalination plants activity. Due to the high variability that exists in environmental datasets, particularly when working on rocky intertidal shores, consistency in maintaining a balanced experimental design, including high level of replication, will allow for more accurate temporal and spatial comparisons. For a balanced design, an additional site in the northern reference zone near Marino Rocks and Hallett Cove can be considered if sites in the southern zone should be discontinued, as well as a reduction by one site within the Port Stanvac exclusion zone.

While more frequent surveys will provide a greater understanding of seasonal variation, the shift in recent years from seasonal monitoring to biannual monitoring of the rocky intertidal shores has not hampered the understanding of species diversity and abundance between the three zones. However, routine monitoring is still recommended to ensure that sufficient data is collected to asses any environmental impacts that may result from the operation of a desalination plant at Port Stanvac. This baseline monitoring programme has succeeded in establishing a solid data base on spatial and temporal patterns that can be used for future reference.

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Appendix 1

List of species recorded in photoquadrats on the rocky shore sites in the winter 2012 survey. See Table 1 in the report for site acronyms.

Taxa	Species	MR 1	MR 2	HC 1	HC 2	PS 1A	PS 1B	PS 2A	PS 2B	PS 3A	PS 3B	PS 4A	PS 4B	PS 5A	PS 5B	CC 1	CC 2	SV 1	SV 2	FB 1	FB 2
Annelida	*Galeolaria/Pomatoceros*		✓	✓		✓		✓	✓	✓	✓		✓	✓	✓	✓	✓		✓		
Mollusca	*Limnoperna pulex (%)*												✓								
	Notoacmea flammea	✓				✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓		
	Notacmea spp.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓		✓	✓
	Patelloida latistrigata	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓			✓			✓
	Scutellastra peronii					✓															
	Cellana tramoserica	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓	✓
	Cellana solida	✓					✓	✓													
	Nerita atramentosa	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Austrocochlea rudis						✓														
	Austrocochlea constricta			✓	✓	✓		✓	✓	✓		✓	✓	✓	✓					✓	✓
	Austrolittorina unifasciata			✓	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓		✓		
	Bembicium nanum	✓		✓	✓	✓	✓	✓		✓		✓									
	Bembicium vittatum	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Siphonaria diemenensis	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	Siphonaria zelandica					✓															
	Unidentified gastropod	✓	✓		✓	✓	✓	✓	✓	✓			✓						✓		
Crustacea	*Chtalamus antennatus*	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Chamaesipho tasmanica						✓	✓	✓	✓	✓		✓		✓						
	Eliminus modestus						✓		✓						✓						
	Catomerus polymerus														✓						