Adelaide Aqua Desalination Plant Infauna Survey 2017

Final Report

December 2017

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May be cited as:

Dittmann S., Baring R., Jessup-Case H., Lam O. (2017) *Adelaide Aqua Desalination Plant; Infauna Survey 2017. Final Report December 2017*, Flinders University, Adelaide

Content

Executive summary

This reports presents the findings from two infauna surveys carried out for Adelaide Aqua Pty Ltd. In compliance with the EPA Licence 39143 for the operation of the desalination plant. The two infauna surveys were conducted in autumn and winter/spring 2017 in the vicinity of the Port Stanvac Desalination Plant, as well as in two control locations to the north and south. Samples were obtained using a box corer and subsamples for sediment, meiofauna and macrofauna were taken from each box core sample. A total of 400 samples each were analysed for sediment, meiofauna and macrofauna across both surveys.

The monitoring revealed no significant differences in sediment or infauna between the Central Port Stanvac Desalinisation Plant, and the Northern and Southern Controls during either of the two surveys. Some site specific spatial and temporal variability was found during the two surveys, but no effects could be attributed to the vicinity of the desalination plant.

Sediments across sites in all locations (Port Stanvac Desalination Plant, north and south control locations) were mainly coarse sands and poorly sorted, with slightly coarser sediment near the desalination plant, but overall very little variation in grain size between the two surveys and locations. In comparison with previous monitoring, sediment compositions were mostly unchanged.

Meiofauna diversity varied between the two surveys, but not between the locations. Abundances of several meiofauna taxa were higher in the control zone than the desalination plant, however, spatial and temporal variability was high, as found in previous monitoring. The lower abundances near the desalination plant could be attributed to the coarser sediment present this year compared to earlier monitoring. Meiofauna communities varied more over time between the two surveys in 2017 than between zones or locations. The patterns for meiofauna diversity and communities appeared comparable between the current surveys and previous monitoring.

Macrofauna diversity was high and comparable across the locations and two surveys, with little site specific temporal variability. Macrofauna abundances showed more seasonal than spatial variation, with higher abundances found in the autumn than winter/spring survey 2017. For single taxa, site specific spatial and temporal variability was high, as found in previous surveys. High temporal variability was also found in previous monitoring and the variability in macrofaunal communities across locations over the surveys found in the current monitoring aligns with past monitoring.

Overall, the infaunal communities found in this study are most likely affected by the spatial, and temporal variation of benthic habitats, rather than by the brine discharge from the Port Stanvac Desalinisation Plant. Natural changes in sediment composition and seasons appear to be the main drivers for infaunal communities. Some recommendations are given to enable more quantitative comparisons of infauna over time.

1. Introduction

1.1 Background and Rationale

The Adelaide Aqua desalination plant at Port Stanvac along the metropolitan Adelaide coastline was completed in 2012. During the construction and running in phase from 2009 to 2013 monitoring occurred for a baseline assessment and potential effects on benthic condition in adjacent coastal waters (Ramsdale et al. 2011a, Loo et al. 2014). Since the completion of the desalination plant, Adelaide Aqua was issued with an EPA licence for the operation of the desalination plant. The EPA licence sets strict requirements for compliance that includes marine environmental monitoring and more specifically, benthic infauna and condition monitoring. Licence conditions for infauna monitoring requires two surveys to be conducted once every three years. This report provides the final report and assessment of benthic infauna and sediment conditions from two surveys conducted in March and August/September 2017.

Since the inception of benthic monitoring of the Adelaide Aqua desalination plant in 2009, survey methods have changed from box coring, dredges and suction sampling (2009 to 2011) by Flinders University to HAPS coring (2012 to 2013) by SARDI Aquatic Sciences. The review of the Adelaide Aqua desalination plant monitoring by Cheshire (2014a, b) advised that comparable surveys in future assessments of benthic condition are essential. For comparison of previous with the current surveys in 2017, we used the original box corer method to sample macrofauna and sediment condition. The box coring method allows for direct comparison with the early 2009 to 2011 surveys (i.e. during the construction and early running-in phase of the desalination plant) and the standardised macrofauna data to individuals per m^2 allows for comparison with the later 2012 to 2013 surveys. At all three locations, the sites for the 2017 surveys were adjusted so that they were located within the complete site perimeters from the early (2009 to 2011) and more recent surveys (2012 to 2013). The northern control location was modified slightly (as discussed with Adelaide Aqua) to include sites from all previous surveys and some new sites in between for better comparison of data from the current survey with surveys from 2009 to 2013. These slight modification of sampling methods and localities will ensure that the 2017 data will be comparable to the quite separate surveys from 2009 to 2011 and 2012 to 2013. The approach implemented in the 2017 infauna monitoring will also enable the standardisation of scientific evaluation from this point forward in future monitoring surveys as part of the EPA licence conditions for the Adelaide Aqua desalination plant operations.

1.2 Aims and Approach

The overall aim of this project was to provide an assessment of the benthic condition of coastal waters adjacent to the Adelaide Aqua desalination plant near Port Stanvac and at comparative northern and southern control locations. Benthic condition was based on assessment of macrofauna, meiofauna, and sediment condition at the desalination plant location and the two control locations. The assessment of benthic infauna and sediment was a component of the monitoring program for the Adelaide Aqua desalination plant as a requirement of the EPA licence conditions associated with operation of the plant.

This final report provides a description, analyses and reporting of the benthic macrofauna and sediment condition of the desalination plant and control locations from the Autumn (March) and Winter/Spring (August/September) surveys conducted in 2017. Site and species specific results are provided in the appendix, with the main part of the report focussing on the major patterns between zones and locations. Findings of this monitoring report for two surveys conducted in Autumn and Winter/Spring 2017 can also be compared to baseline surveys conducted between 2009 to 2013. A detailed data analysis comparing surveys over time was not part of the contract for this infauna survey, but recommendations are given on the approach for such analysis.

2. Methods

2.1 Sampling sites

Sampling was undertaken across three separate locations of the Adelaide metropolitan coastline in Gulf St. Vincent during Autumn and Winter/Spring 2017. Locations consisted of the Adelaide Aqua Desalination Plant inlet and outlet pipe near Port Stanvac (PSDP; 35°05'S, 138°28'E), a Northern Control (NC) location at Glenelg (34°59'S, 138°26'E) and a Southern Control (SC) location at Port Noarlunga (35°09'S, 138°26'E) (Figure 1). The zones compared were the desalination plant (PSDP) and control areas (NC and SC).

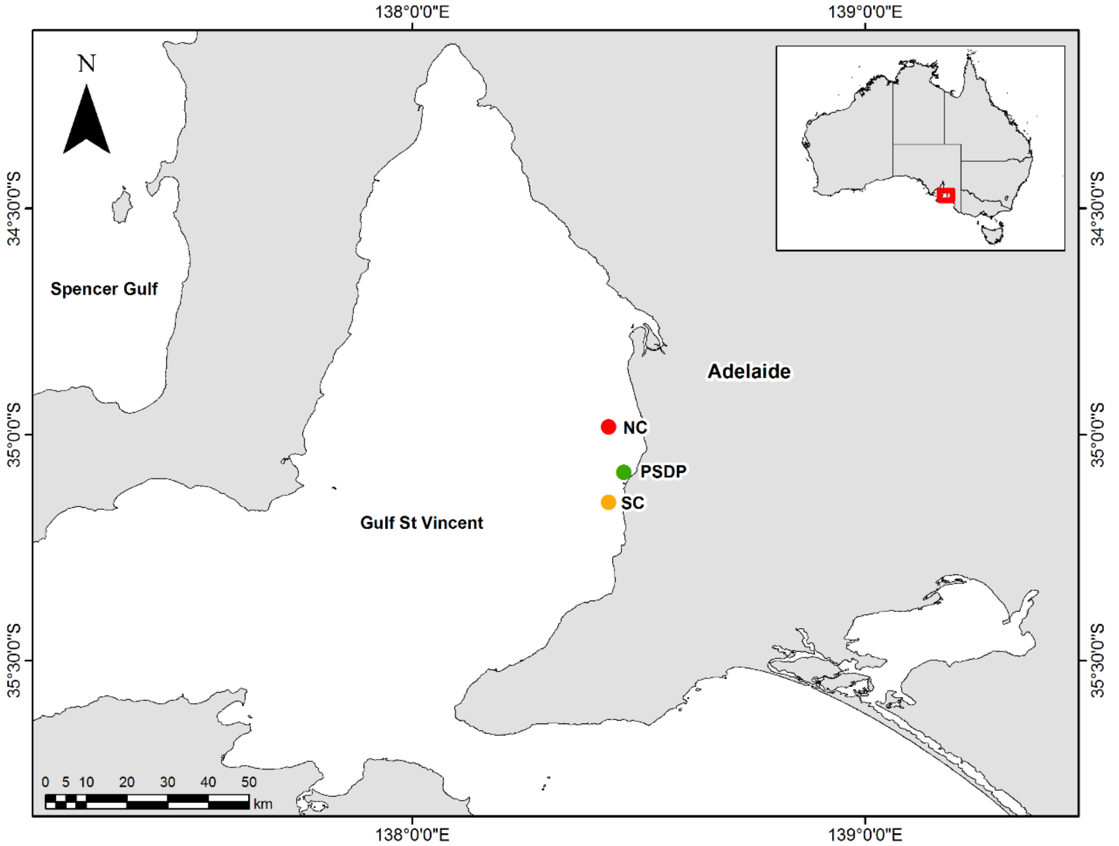
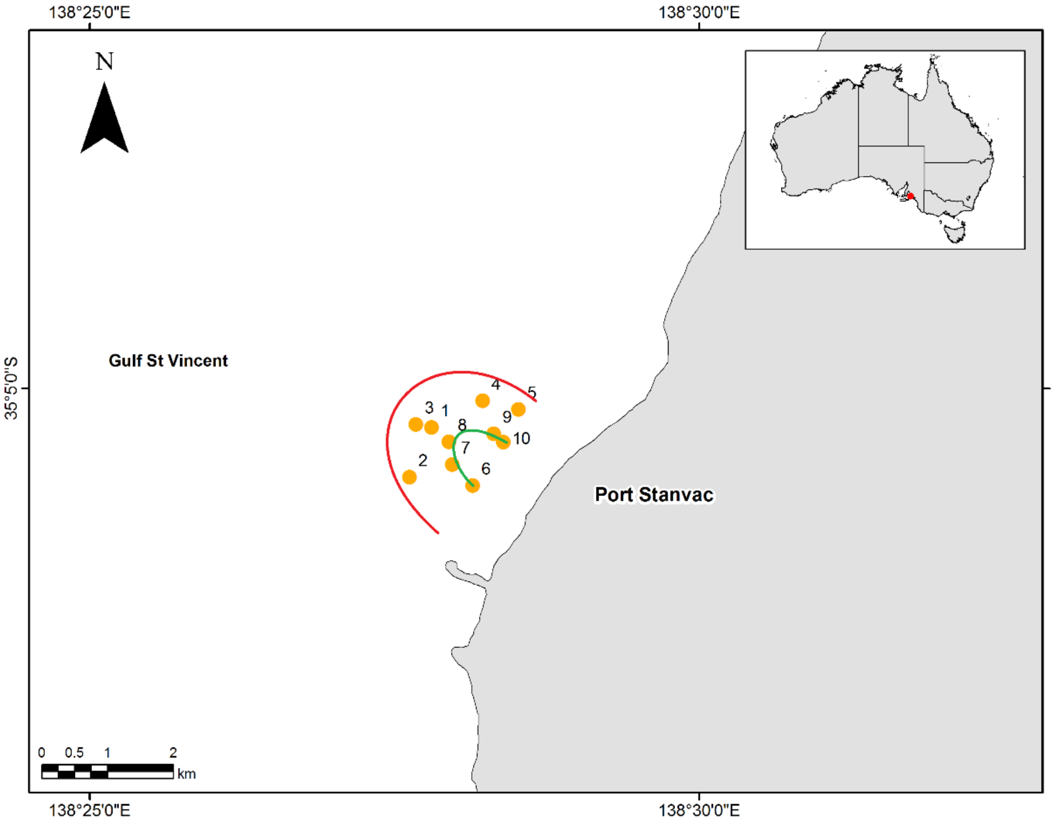


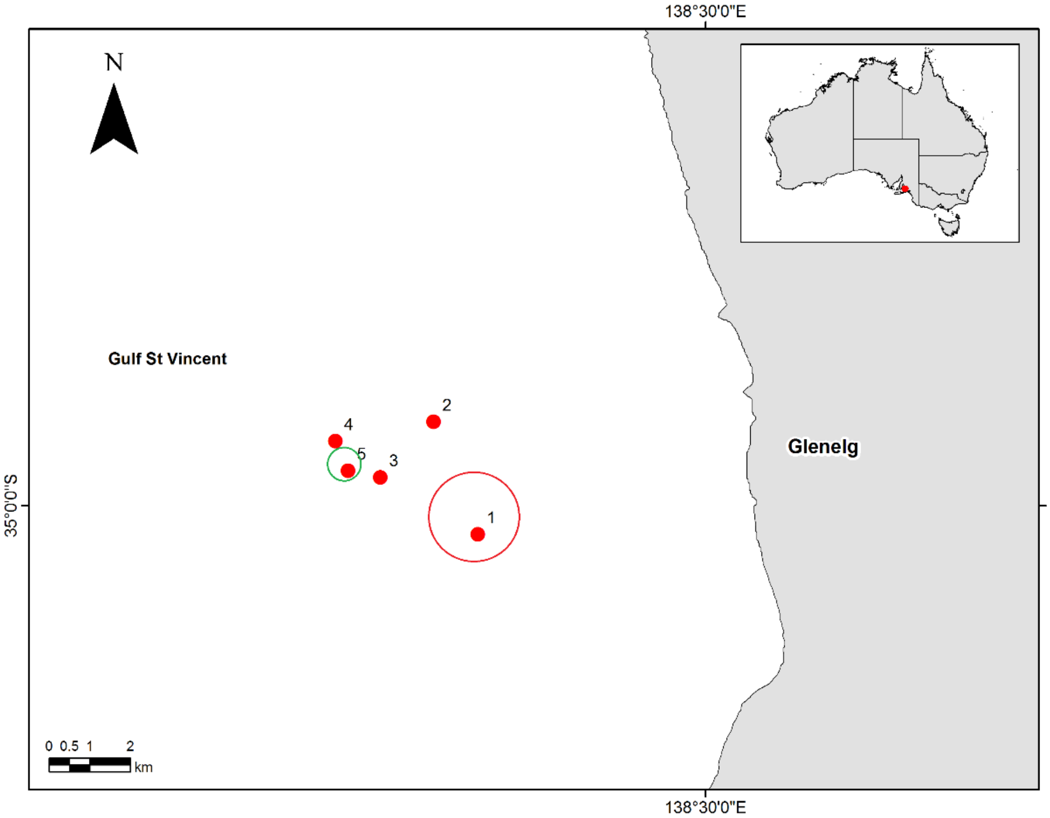
Figure 1: Map of the Port Stanvac Desalination Plant (PSDP), North Control (NC) and South Control (SC) infauna survey locations surveyed in Autumn and Winter/Spring 2017.

In 2014, an independent review of previous monitoring programs by Flinders University (Ramsdale et al. 2011a) and SARDI Aquatic Sciences (Loo et al. 2014) from 2009 to 2013 pointed out that changes to control site locations made comparisons between the two sampling programs difficult (Cheshire 2014). To improve the consistency of areas sampled at all locations and across the two previous monitoring programs, ten sites at the PSDP location and five sites at each of the two control locations (NC & SC) were selected within the complete perimeter boundary of both previous monitoring programs (Figure 2). Only one site (NC, site 2) was shifted further north to avoid a large area of hard bottom seafloor that was encountered with multiple deployments of sampling equipment. However, the new North Control site was kept along the same depth contour as the previous Flinders University

(a)


138°25'0"E
138°30'0"E
N
Gulf St Vincent
Port Stanvac
35°5'0"S
3
1
4
5
8
9
10
7
2
6
0 0.5 1 2
km

(b)


138°30'0"E
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Gulf St Vincent
Glenelg
35°0'0"S
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(c)

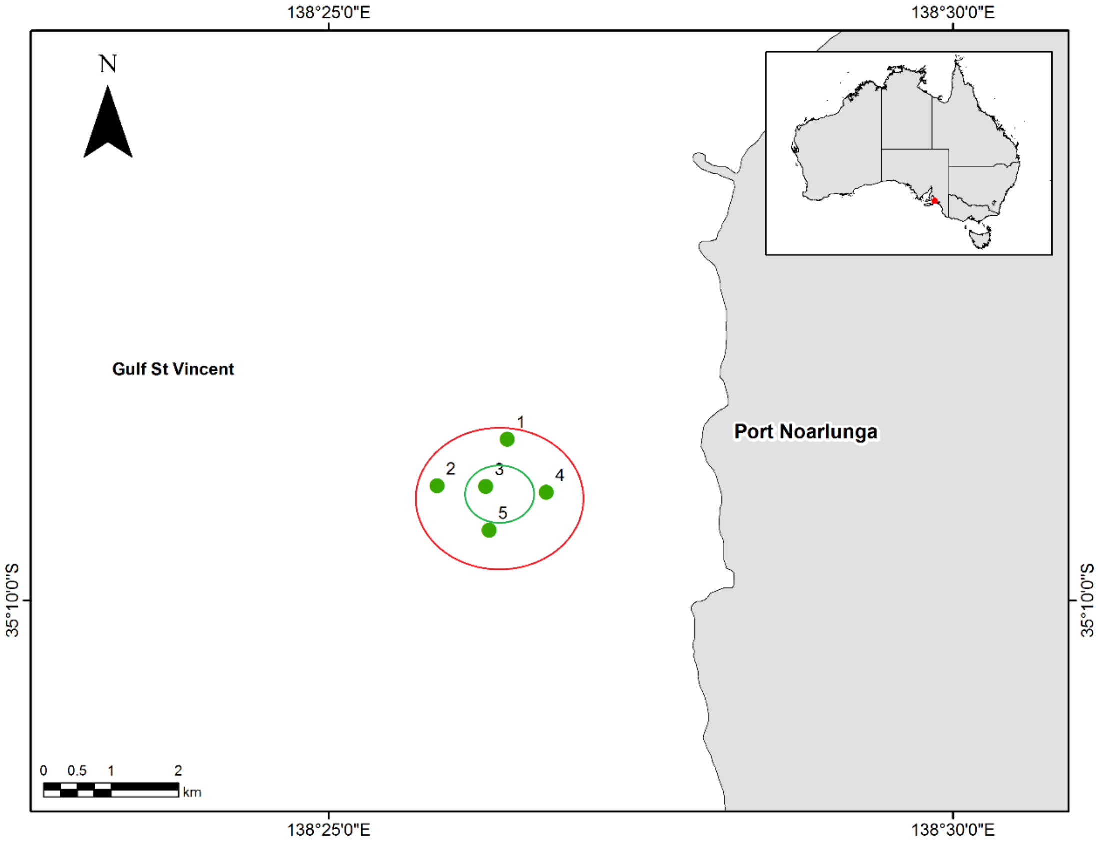


Figure 2: Maps of the (a) Port Stanvac Desalination Plant (PSDP), (b) North Control (NC), and (c) South Control (SC) sampling locations in Autumn and Winter/Spring with site positions referenced to site perimeter boundaries for previous benthic monitoring by Flinders University (red lines) and SARDI Aquatic Sciences (green lines).

monitoring program (Figure 2b). Water depths were similar in range across the three locations (14-22 m depth range across all locations) but shallowest at Port Stanvac and deepest at the North and South Control (NC and SC) locations (Table 1). All sampling of organisms occurred under a PIRSA exemption for all sites (ME9902877) and Marine Parks permit (MR00107-1) for the Port Noarlunga Southern Control location, which now falls within the Encounter Bay Marine Park.

Table 1: Locations and sites sampled during the Autumn (March) and Winter/Spring (August/September) 2017 infauna surveys. GPS locations and depth ranges are provided for each site within the three locations across the two surveys.

		Date sampled				
Location	Site	Autumn	Winter/Spring	Latitude	Longitude	Depth (m)
Port Stanvac Desalination Plant (PSDP)	1	14/3/17	28/8/17	35°05.032’	138°27.805’	15 - 19
	2	14/3/17	28/8/17	35°05.727’	138°27.625’	18 - 21
	3	14/3/17	28/8/17	35°05.296’	138°27.676’	19 - 20
	4	15/3/17	28/8/17	35°05.101’	138°28.224’	15 - 17
	5	15/3/17	30/8/17	35°05.172’	138°28.518’	14 - 16
	6	17/3/17	30/8/17 & 9/9/17	35°05.796’	138°28.142’	14 - 17
	7	17/3/17	9/9/17	35°05.623’	138°27.974’	17 - 19
	8	18/3/17	9/9/17	35°05.437’	138°27.948’	17 - 19
	9	18/3/17	9/9/17	35°05.372’	138°28.315’	15 - 17
	10	20/3/17	9/9/17	35°05.440’	138°28.395’	14 - 17
Glenelg North Control (NC)	1	23/3/17	12/9/17	35°00.377’	138°26.971’	16 - 19
	2	24/3/17	12/9/17	34°59.880’	138°26.385’	18 - 20
	3	24/3/17	30/8/17	34°59.622’	138°25.674’	18 - 21
	4	24/3/17	30/8/17	34°59.140’	138°25.079’	19 - 22
	5	23/3/17	30/8/17	34°59.533’	138°25.247’	19 - 22
Port Noarlunga South Control (SC)	1	20/3/17	26/8/17	35°08.710’	138°26.432’	18 - 21
	2	20/3/17	26/8/17	35°09.084’	138°25.871’	20 - 22
	3	21/3/17	26/8/17	35°09.088’	138°26.258’	18 - 21
	4	21/3/17	9/9/2017	35°09.134’	138°26.744’	17 - 19
	5	21/3/17	9/9/2017	35°09.440’	138°26.287’	17 - 20

2.2 Field methodology

Benthic sediment samples were taken at ten randomly pre-selected points at all sites within each location. Sediment samples were obtained using a box corer (Wildco®, model: 191-A12, internal dimensions: 0.15 x 0.15 x 0.23 m, surface area 225 cm^2), which was deployed and retrieved by electric winch from the Flinders University vessel ‘Tethys’. Penetration depths of the box corer varied depending on the bottom type but was within the range of 5 to 10 cm across all locations. Each sediment core obtained was carefully emptied into a plastic bin so that subsamples could be taken from the top horizon of the sediment for:

(a) sediment grain size characteristics (one subsample of 10 cm^3 volume), and

(b) meiofauna (three subsamples of 1.33 cm^2 sediment surface area to 1-2 cm depth pooled to one sample).

The remaining sample was sieved with seawater through 500 µm mesh and rinsed into a plastic zip-lock bag with 70 % ethanol solution for preservation of macrofauna. This sampling procedure was an efficient process for obtaining the 400 samples overall (for each of the two surveys: 100 samples from the PSDP, and 50 samples each from the NC and SC control locations) for sediment grain size, meio- and macrofauna. All sediment and meiofauna samples were kept on ice and stored in a -20°C freezer upon return to Flinders University laboratories until further processing.

2.3 Laboratory processing

2.3.1 Sediment grain size composition

Sediment grain size was assessed for each site within each location during the Autumn and Winter/Spring surveys. All of the frozen sediment samples were thawed and sorted to detect any macroinvertebrates, which were collected and added to the rest of the macroinvertebrate samples. Sediment grain sizes were then determined by laser diffraction using a particle size analyser (Malvern Mastersizer 2000). To avoid blockage in the particle size analyser, sediment grain sizes with a fraction >1 mm were manually wet sieved off each sample. The weights of the 1-2, 2-4, and >4 mm fraction, and the remaining sediment were determined and corrected so that the dataset could be normalised. Sediment data were then processed through a data analysis programme (Gradistat) to determine median grain size and the sorting coefficient, and categorized according to the parameters of 'geometric method of moments' (Blott & Pye 2001).

2.3.2 Benthic meiofauna

Frozen meiofauna samples were thawed and all meiofauna including one of the main groups of Protozoans (Foraminifera) was extracted from sediments using the Ludox™ floatation method (Somerfield and Warwick 2013). Sediment was decanted in fresh water, first through a 500 µm mesh sieve to remove larger particles and secondly with remaining supernatant poured through a finer 53 µm mesh sieve to separate the meiofauna. The meiofauna, unicellular organisms, fine sediments and detritus that remained were then processed with Ludox™ to float off and isolate the meiofauna from sediments and detritus. The Ludox floatation method was repeated three times for each sample to ensure that meiofauna was extracted from sediments. Some of the remaining sediment was cross-checked under the microscope to ensure no meiofauna was left. Extracted meiofauna samples were obtained from the supernatant volume and pipetted onto glass slides in triplicate 1 ml sub-samples with remaining moisture evaporated and meiofauna preserved with a 5% pure glycerol and 70 % ethanol mixture. Cover slides were added to microscope slides and sealed with paraffin wax for identification and enumeration of individual taxa. Around 10 % of samples on microscope slides from each survey, location and site were cross-checked between research staff for accuracy of identification and counts of meiofauna. Taxa were identified to higher taxonomic levels (e.g. Phylum, Class) as ecological knowledge of meiofauna species, especially for Australian sediments, is limited (Bouwman 1987).

2.3.3 Benthic macrofauna

In the laboratory, the preserved macrofauna samples were rinsed again, with freshwater through a 500 µm mesh sieve, to remove any further fine sediment particles and residual ethanol. Samples were sorted under dissecting microscopes and all macrofauna was extracted, identified to the lowest possible taxonomic level and all individuals from each taxa were enumerated. Macrofauna specimens were preserved in vials of 70 % ethanol for storage and future reference.

2.4 Data analyses

To test for differences in meiofauna and macrofauna the following experimental design was used; Time (random factor), Zone (fixed factor), Location nested in Zone (fixed factor), and Site nested in Location and Zone (random factor). Sediment grain sizes and species diversity indices were tested for differences with a modified experimental design that pooled replicates and used sites as replicates, thus excluding the site factor from the design in those tests. Sediment grain sizes were square root transformed and sediment fraction categories were untransformed and analysed using PERMANOVA based on Euclidean distances. Several diversity indices were used to characterise diversity per location and site: Shannon-Wiener diversity H’, Pielou’s eveness index J’, and the Simpson’s diversity index as 1-λ’. Species numbers and diversity indices data of meiofauna and macrofauna were untransformed and analysed using univariate PERMANOVA based on Euclidean distances. Total abundances and abundances of common meiofauna and macrofauna taxa were square root transformed and analysed using univariate PERMANOVA with Euclidean distances. Common indicator taxa for meiofauna (Copepoda, Nematoda) and macrofauna (Capitellidae, Echinodermata) were analysed separately.

Community structure of meiofauna and macrofauna was visualised for separation in groupings for the factors of Time and Locations with bootstrapped Metric Multidimensional Scaling (MDS) conducted on Bray Curtis Similarities. Bootstrapped MDS was used to account for the uneven design when comparing the three locations (ten sites at the PSDP and five sites each at the northern and southern control locations). PERMANOVA was also used to detect if there were any differences in community structure between Time, Zones, Locations and Sites based on Bray Curtis similarities. Significant interactions of main factors such as Zone by Location or Time x Zone were investigated further with pairwise tests. Discrimination of the species contributing to differences between Locations was investigated using SIMPER analyses with the most reliable discriminating species having a higher dissimilarity to standard deviation ratio (Clarke & Gorley 2015). To illustrate species occurring in the communities at the three locations, shade plots were prepared using the PRIMER Matrix wizard, which produces a shade plot showing abundances on a grey scale, and grouping species with similar distribution across the locations using Cluster analysis along the y-axis. For clarity, the shade plot was prepared using all 26 meiofauna taxa and the 25 most important macrofauna species. Bootstrapped MDS plots and Cluster analysis with shadeplots were also conducted on meiofauna community data with Foraminifera excluded as the previous monitoring programs had either included (Ramsdale et al. 2011b) or excluded (Loo et al. 2014) Foraminifera from meiobenthic assessments. Thus we provide assessments of meiofauna including and excluding Foraminifera to provide easy comparisons between both previous surveys and the current one. Any relationships between meiofauna and macrofauna versus sediment fractions were investigated with LINKTREE and SIMPROF tests to determine if there were any sediment conditions contributing to infauna community structure across Locations in both surveys. RELATE analyses were also conducted to determine if any infauna versus sediment relationships were significantly correlated. All analyses were conducted using PRIMER/PERMANOVA+ (Version 7).

3. Results

3.1 Sediment grain size

Across all locations, the sediments collected in both the Autumn and Winter/Spring surveys mainly consisted of coarse sands that were poorly sorted, except the moderately sorted classification at the South Control location in Autumn/Winter (Table 2, see Appendix Table A1 for Sites within Locations). Grain sizes of sediments were mainly coarse (> 500 µm) at PSDP, fine to coarse (125 – 1000 µm) at North Control, medium to coarse grain sands (250 – 1000 µm) at SC (Figure 3) across the two surveys (Figure 3) Median grain sizes were only significantly different between Locations, which was attributed to the uneven number of sites sampled between PSDP (with 10 sites and finer spatial resolution) versus the two control locations (5 sites each) (Table 3). There were significant differences in the main grain size fractions of gravel and sand between Zones (Table 3). For the mud grain size fraction there was a significant interaction of Zone x Time, which from pairwise test results, was due to a difference in the Autumn survey only ($p < 0.05$; Table 3).

Table 2*:* Descriptions of grain size distributions and sorting co-efficients using geometric methods of moments (Blott and Pye, 2001) from each location averaged across sites, during the Autumn and Winter/Spring 2017 infauna survey.

		Grain size distribution statistics and classifications							
		Median	Mean	Size		Sorting	Size Fractions (%)		
Location	Sampling date	(µm)	(µm)	Classification	Sorting	Classification	Gravel	Sand	Mud
Port Stanvac Desalination Plant (PSDP)	Autumn	940.21	912.78	Coarse sand	2.47	Poorly sorted	18.71	80.08	1.20
	Winter/Spring	894.99	887.65	Coarse sand	2.33	Poorly sorted	15.71	83.96	0.33
Glenelg North Control (NC)	Autumn	634.40	625.70	Coarse sand	2.30	Poorly sorted	9.60	90.40	0.00
	Winter/Spring	546.88	565.01	Coarse sand	2.30	Poorly sorted	8.54	91.33	0.13
Port Noarlunga South Control (SC)	Autumn	702.48	694.70	Coarse sand	2.16	Poorly sorted	13.68	86.01	0.31
	Winter/Spring	615.23	605.42	Coarse sand	1.96	Moderately sorted	7.24	92.61	0.15

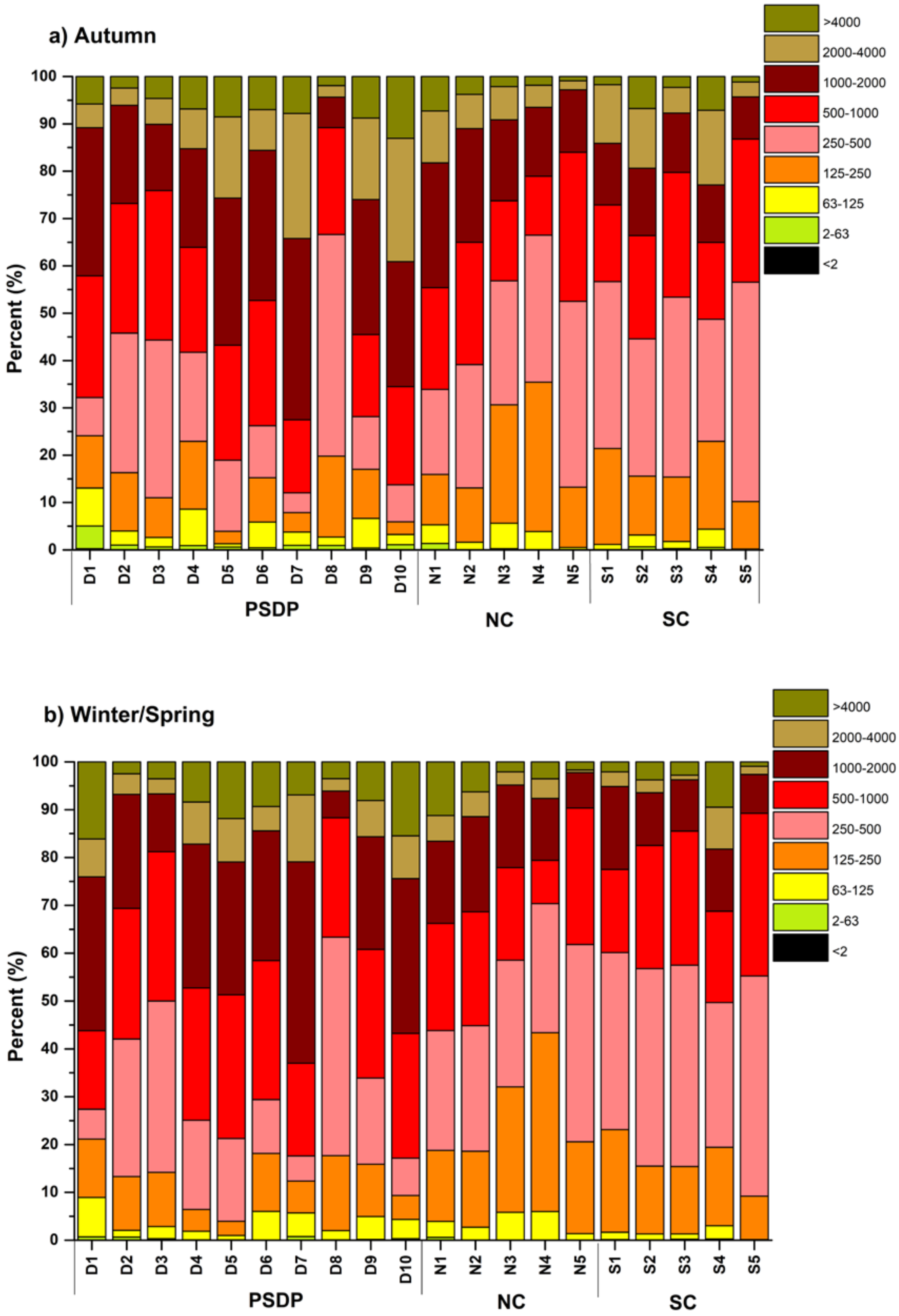


Figure3: Sediment grain size composition showing the percentages of sediments in size classes (µm) as stacked bar graphs for all Locations and Sites from a) Autumn 2017 and b) Winter/Spring 2017 infaunal surveys. PSDP = Port Stanvac Desalination Plant (ten sites), NC = North Control (five sites), and SC = South Control location (five sites).

Table 3: Univariate PERMANOVA results for median grain size and main grain size fraction categories from the Autumn and Winter/Spring 2017 surveys. Analyses were based on the experimental design with factors of: Zone, Zo; time, Ti; Location, Lo nested in Zo, factors. Significant differences are highlighted in bold. Tests were based on Euclidean distances.

Source	df	Median grain size (g)	Gravel (%)	Sand (%)	Mud (%)
Zo	1	0.09	**0.03**	**0.003**	0.38
Ti	1	0.48	0.22	0.16	**0.008**
Lo (Zo)	1	**0.002**	0.69	0.67	0.46
Zo x Ti	1	0.62	0.89	0.98	**0.02**
Ti x Lo (Zo)	1	0.99	0.48	0.45	0.64
Residual	34				

3.2 Benthic meiofauna

3.2.1 Meiofauna taxa richness and diversity

Across the three locations and two surveys, a total of 20,334 individuals from 27 meiofauna taxa were found in subtidal sediment samples. Taxa that contributed most to the species found across all locations and surveys were Foraminifera (63 %), Arthropoda (26 %) and Nematoda (6 %) (see Appendix Table A2). The total number of taxa was highest at PSDP in both surveys, with the most taxa recorded during the Autumn survey (Figure 4, see site level comparisons in Appendix Figure A1). The only significant difference in the number of meiofauna taxa was between the two survey times ($p = 0.0001$) but not specific to any particular zone or location.

Diversity indices and evenness values for meiofauna had similar patterns across Locations with more diverse and evenly distributed meiofauna in Autumn compared to Winter/Spring (Figure 5). The only significant interaction was between Zone and Time for Pielou's evenness, which was attributed to differences between the PSDP central location and control locations and between surveys for both Zones (Table 4).

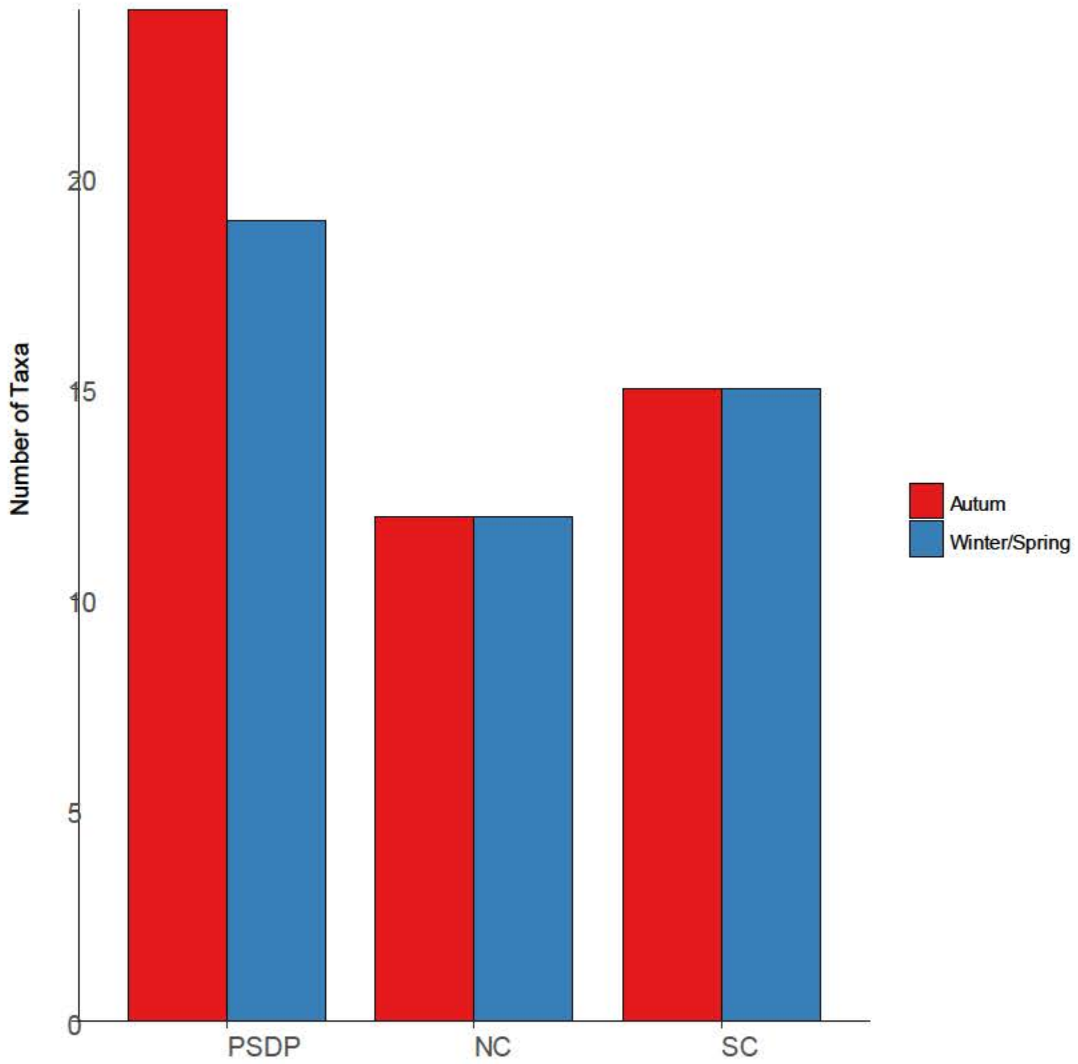


Figure 4: Total number of taxa for benthic meiofauna at each of the Locations (all sites pooled) obtained from sediments in the Autumn and Winter/Spring 2017 surveys. Port Stanvac Desalination Plant (PSDP; 10 sites), North Control (NC; 5 sites) and South Control (SC; 5 sites).

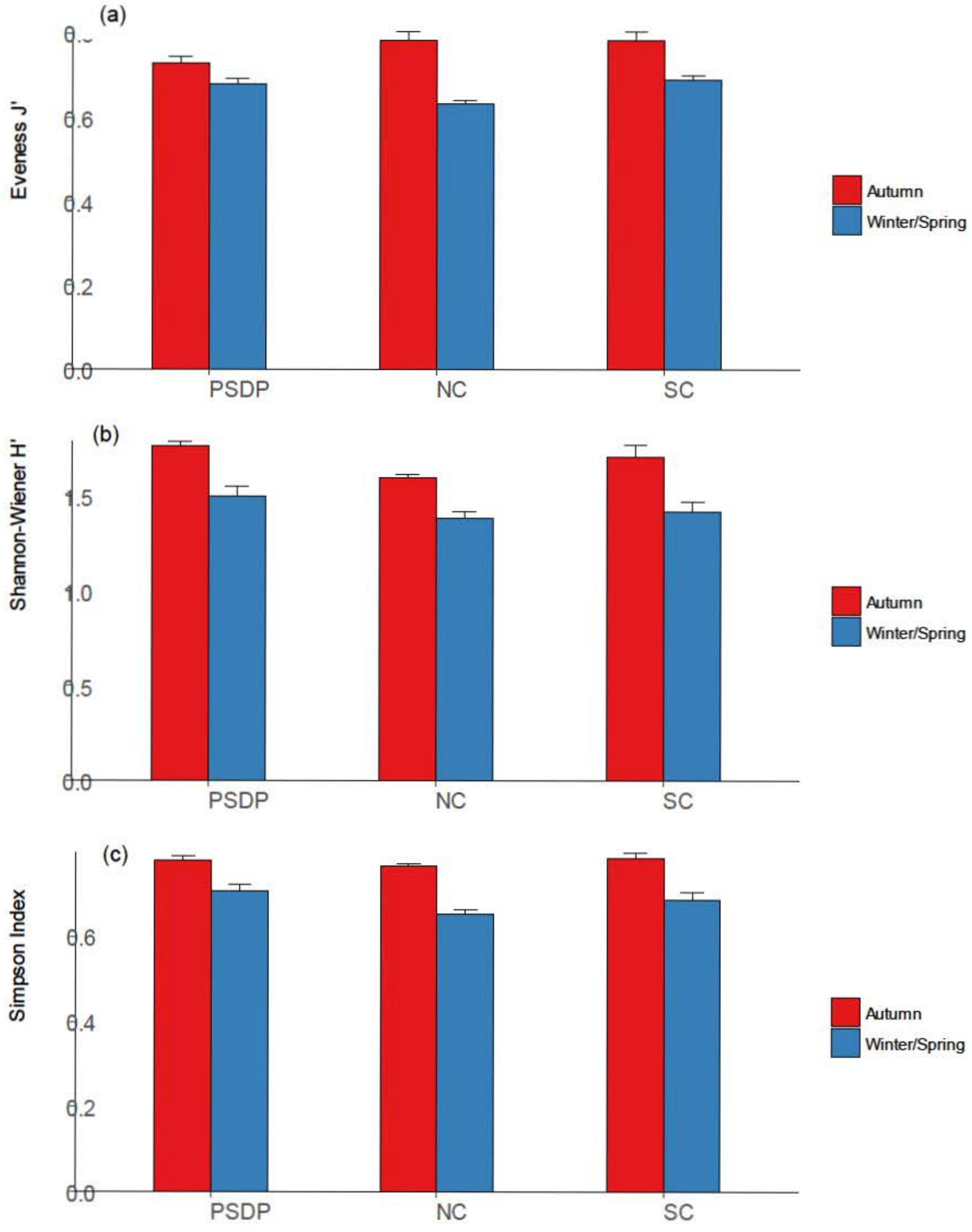


Figure 5. Diversity values for meiofauna from the infauna surveys in Autumn and Winter/Spring 2017. Values are given for three diversity indices; (a) Pielou's evenness, (b) Shannon Wiener and (c) Simpson's Index.

Table 4. Univariate PERMANOVA results for meiofauna diversity indices from the infauna surveys based on three diversity indices; Pielou's evenness, Shannon Wiener and Simpson's Index. Analyses were based on the experimental design with factors of: Zone, Zo; time, Ti; Location, Lo nested in Zo, factors. Significant differences are highlighted in bold. Tests were based on Euclidean distances.

Source	df	Pielou's J'	Shannon-Wiener Log e'	Simpson's index
Zo	1	0.69	**0.02**	**0.02**
Ti	1	**0.0001**	**0.0001**	**0.0001**
Lo (Zo)	1	0.53	0.30	0.29
Zo x Ti	1	**0.01**	0.92	0.91
Ti x Lo (Zo)	1	0.14	0.50	0.50
Residual	34			

3.2.2 Meiofauna abundances

Total abundances of meiofauna were greatest at the North Control Location in the Winter/Spring survey compared to other locations and times, which also matched the distribution of Foraminifera (Figure 6). Nematodes, copepods and bivalves were all more abundant across all locations during the Autumn survey (Figure 6). Ostracods had similar abundances in each location between the two surveys (Figure 6). Foraminifera abundances had a significant interaction for Zone by Time, which was between the PSDP Central and the Control Zone in Winter/Spring and for the Control Zone only between surveys ($p < 0.05$, Table 4). There were significant interactions between Sites and Surveys for most common meiofauna taxa (excluding bivalves) indicating large amounts of fine spatial and temporal variation (Table 4).

Table 4: Univariate PERMANOVA results for main taxa and total abundance of all benthic meiofauna from the Autumn and Winter/Spring 2017 surveys. Analyses were based on the experimental design with factors of: Zone, Zo; time, Ti; Location, Lo nested in Zo; Site, Si nested in Lo and Zo. Significant differences are highlighted in bold.

Source	df	Foraminifera	Nematoda	Copepoda	Ostracoda	Bivalvia	Total abundance
Zo	1	0.75	0.42	0.48	0.28	0.25	0.53
Ti	1	**0.005**	**0.01**	**0.0001**	0.76	**0.0004**	0.38
Lo(Zo)	1	0.48	0.50	0.30	0.81	0.12	0.76
ZoxTi	1	**0.01**	0.60	0.40	0.78	0.86	0.07
Si(Lo(Zo))	17	0.43	0.48	0.66	0.15	0.55	0.34
Lo(Zo)xTi	1	0.07	0.98	0.39	0.44	0.53	0.07
Si(Lo(Zo))xTi	5	**0.002**	**0.001**	**0.04**	**0.007**	0.05	**0.0020**
Residual	360						

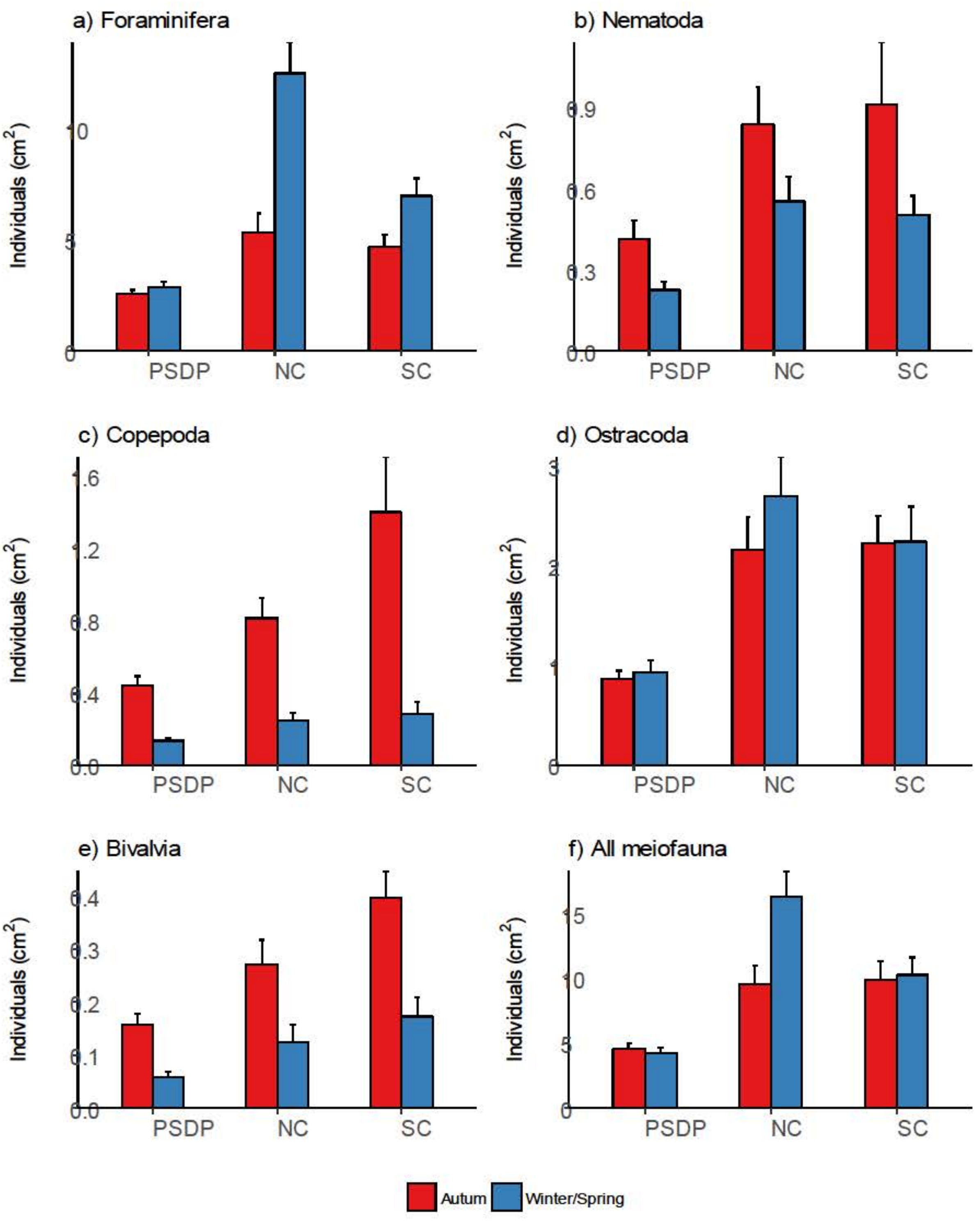


Figure 6: Abundances (mean ± SE) of common benthic meiofauna obtained from sediments in the 2017 surveys at the three Locations with sites pooled from; Desalination Plant (10 sites), North Control (five sites) and South Control (five sites). Total abundances include the main taxa found as; a) Foraminifera, b) Nematoda, c) Copepoda, d) Ostracoda, e) Bivalvia and f) All benthic meiofauna combined as total abundances. Note different ranges in Individuals (cm^2) on Y axes across taxa.

3.2.3 Meiofauna community structure

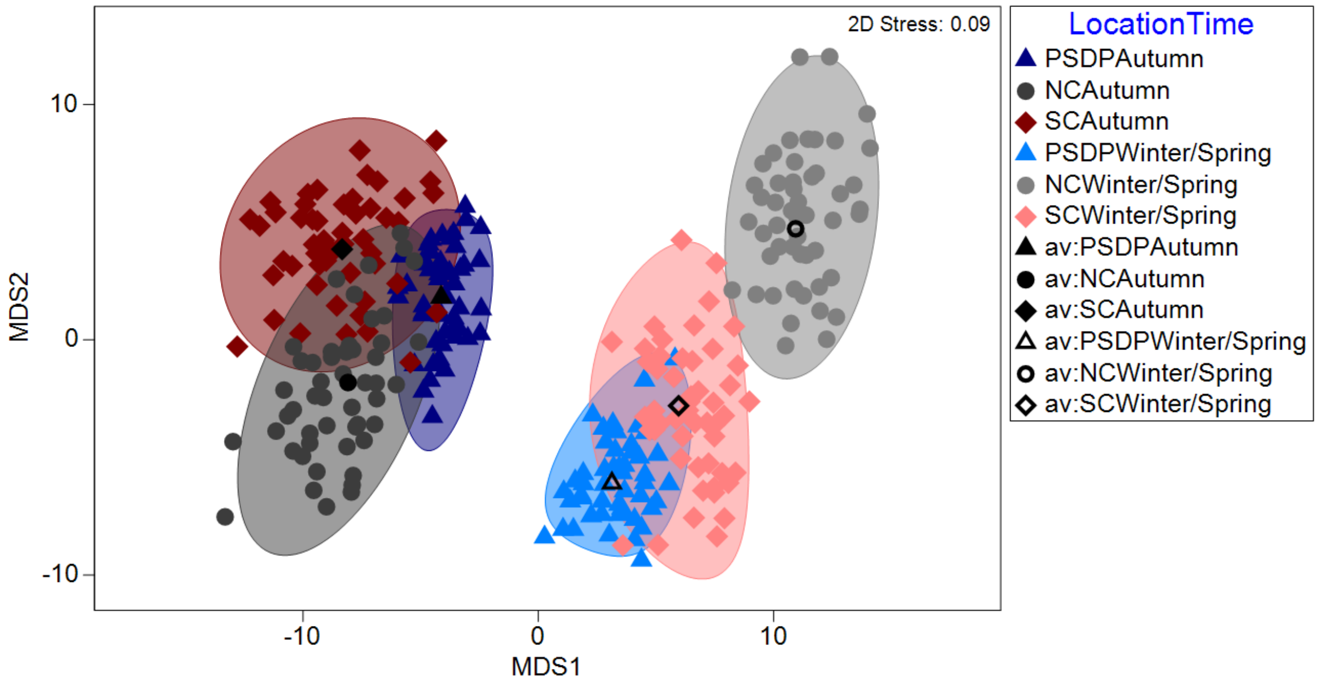
Meiofauna communities were similar in the Autumn survey across all Locations with no distinct clustering evident (Figure 7 & 8). For all Locations the Winter/Spring survey was very distinct compared to the Autumn survey and significantly different between surveys (Figure 7 & 8, Table 5). Meiofauna communities were similar between the PSDP and SC Locations, while NC clustered separately to the other two locations but it was not significantly different (Table 5). The only significant interaction was between Sites by Time, which is indicative of the fine spatial and temporal variation across all Locations (Table 5). Taxa that were contributing most to the community structure included Foraminifera, Ostracoda, Copepoda and Nematoda (Figure 8, Table 6). The dissimilarity between Locations within each survey was low indicating that there were only subtle dissimilarities in the most common taxa along the coastline from NC through to SC, with similar patterns over time (Table 6).

Exclusion of Foraminifera from the meiofauna community showed that there was distinct clustering of each survey but all Locations overlapped (Figure 7). Compared to the results of meiofauna communities that included Foraminifera, there was no distinct clustering of NC in the Winter/Spring survey (Figure 7). PERMANOVA results did not change with the exclusion of Foraminifera from the dataset (Table 5). With Foraminifera excluded from the dataset, the same taxa were contributing most to the community structure at all Locations in each survey (e.g. Ostracoda, Copepoda and Nematoda) but there was an addition of Bivalvia to that set of contributing taxa in the Autumn survey (Figure 8, Table 6). The dissimilarity values were slightly higher compared to the dataset that included Foraminifera but were still quite low due to the low variation in meiofauna community structure between Locations (Table 6).

Table 5: Multivariate PERMANOVA results for benthic meiofauna communities from the 2017 surveys. Analyses were based on the experimental design of the Zone (Zo), Location (Lo), Site (Si) and time (Ti) factors. Significant *P*-values are highlighted in bold.

Source	df	All meiofauna	Excluding Foraminifera
Zo	1	0.65	0.34
Ti	1	**0.0001**	**0.0001**
Lo(Zo)	1	0.59	0.60
ZoxTi	1	0.12	0.73
Si(Lo(Zo))	17	0.48	0.35
Lo(Zo)xTi	1	0.32	0.56
Si(Lo(Zo))xTi	17	**0.0001**	**0.0002**
Residual	360		

(a)



(b)

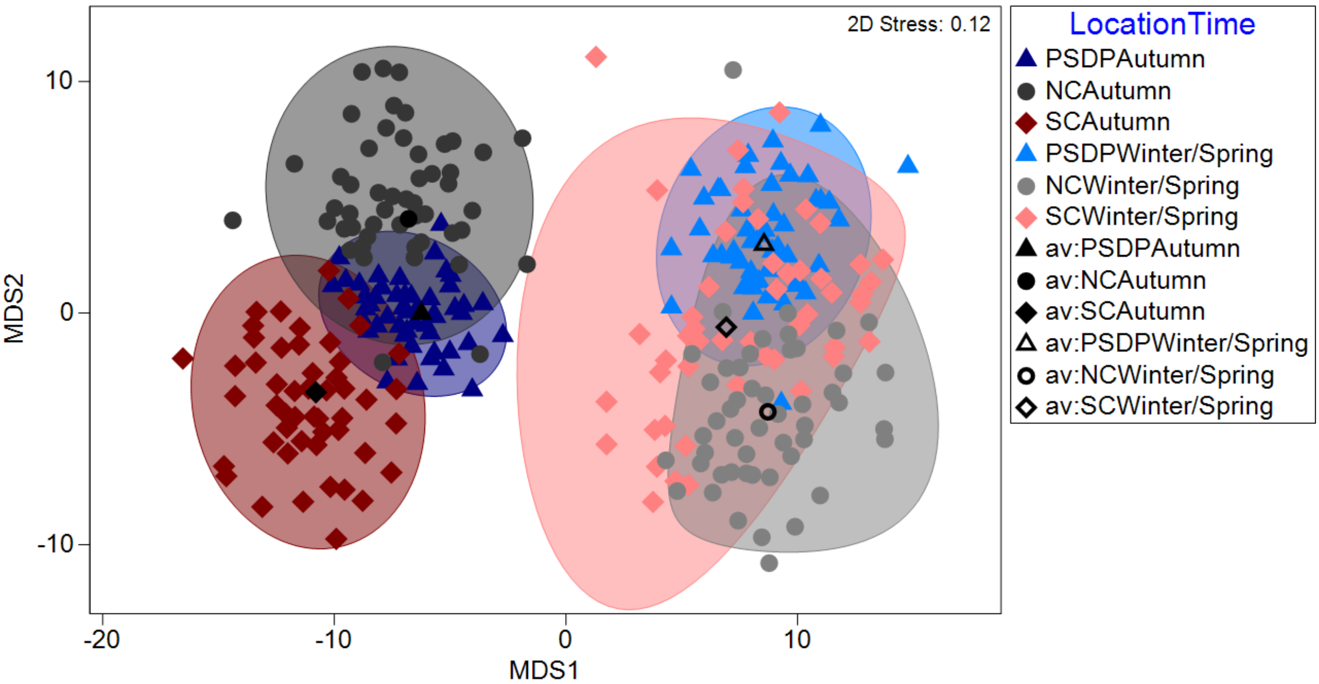
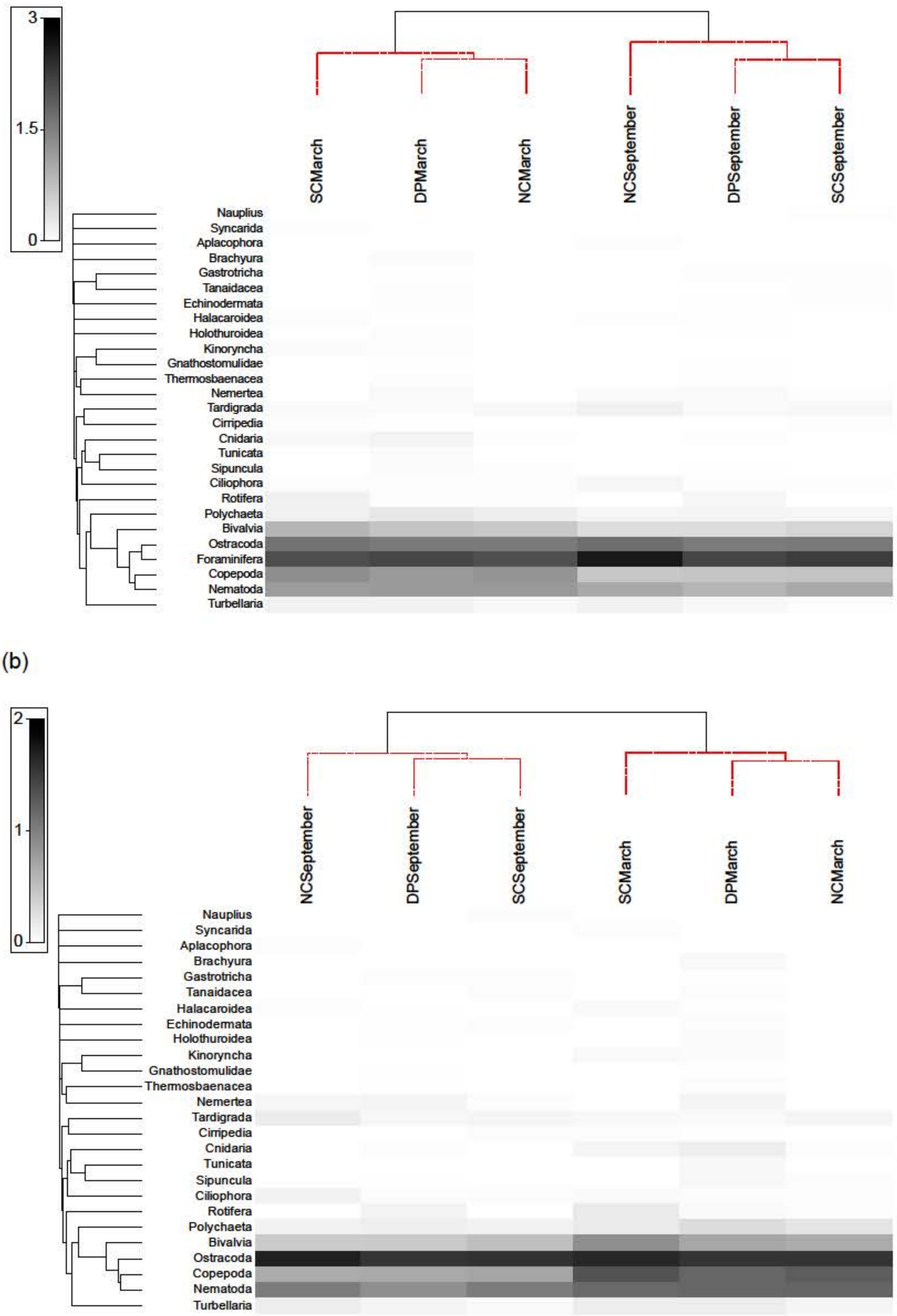


Figure 7: Community structure of (a) all benthic meiofauna and (b) meiofauna excluding Foraminifera for Locations and Surveys of the benthic infauna monitoring in 2017. Groupings and separation of Locations are based on bootstrapped Metric Multidimensional Scaling (MDS) using the Bray Curtis resemblance matrix.

(a)



(b)

Figure 8: Matrix display of meiofauna communities at the three locations of the desalination plant (DP), southern (SC) and northern (NC) control zones based on average values of all sites per location. The darker the shading, the higher the relative contribution of a taxa to the abundance. The dendrograms indicate slight groupings for the locations and taxa.

Table 6: SIMPER results of benthic meiofauna communities between all combinations of Location by Time groupings. Dissimilarities between Location group pairs within each survey. The number of contributing individuals from each phyla and the total number of individuals that are reliable discriminant taxa are shown for each Location: a) Including the Foraminifera taxa, b) Excluding Foraminifera taxa. Cutoff of cumulative contributions is 70 %.

(a)

Survey	SIMPER grouping	Average dissimilarity (%)	Foraminifera	Ostracoda	Copepoda	Nematoda
Autumn	PSDP	35.5	4.7	2.7	1.8	1.7
	SC		4.5	3	2.2	1.7
	PSDP	36	4.7	4.5	1.8	1.7
	NC		2.7	2.8	1.8	1.7
	SC	35.6	4.5	3	2.2	1.7
	NC		4.5	2.8	1.8	1.7
Winter/Spring	PSDP	36.2	4.9	2.7	1.2	0.80
	SC		5.4	2.9	1.3	0.9
	PSDP	37.7	4.9	2.7		1.2
	NC		7.3	3.2		1.4
	SC	36.7	5.4	2.9		1.3
	NC		7.3	3.2		1.4

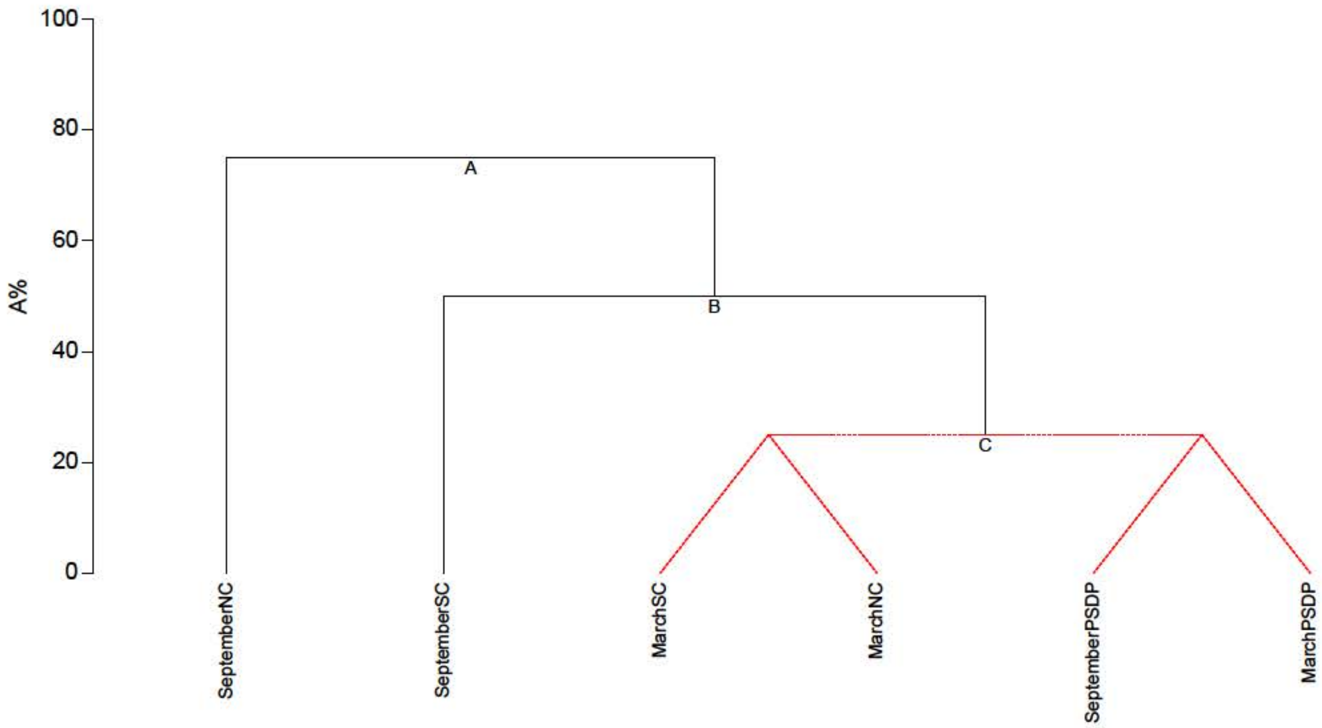
(b)

Survey	SIMPER grouping	Average dissimilarity (%)	Ostracoda	Copepoda	Nematoda	Bivalvia
Autumn	PSDP	42	2.7	1.8	1.7	0.9
	SC		3	2.2	1.7	1.1
	PSDP	41.3	2.7	1.8	1.7	0.9
	NC		2.8	1.8	1.7	0.8
	SC	40	3	2.2	1.7	1.1
	NC		2.8	1.8	1.7	0.8
Winter/Spring	PSDP	47.2	2.7		1.2	
	SC		2.9		1.3	
	PSDP	47	2.7	0.8	1.2	
	NC		3.2	0.8	1.4	
	SC	46.8	2.9	0.9		
	NC		3.2	0.8		

3.2.4 Meiofauna and sediment relationships

Meiofauna and sediment type relationships were significantly distinct (< 0.05) for the NC and SC Locations in the Winter/Spring survey, which was explained by sediment compositions of varying percentages of sand and small amounts of gravel (Figure 9). For all other Locations and surveys the meiofauna and sediment type relationships were not very strong and had more mixed sediment conditions contributing to those relationships (Figure 9). Overall, the relationship between meiofauna and sediment types was not very strong and not significant (RELATE; Rho 0.22, $p < 0.05$).

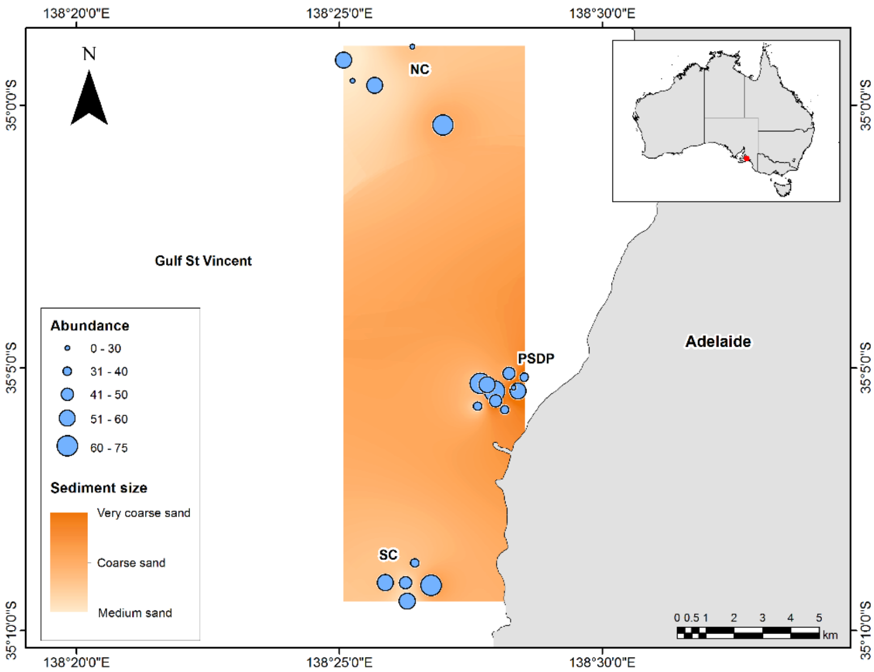
The abundance of meiofauna at PSDP was greatest at some sites with very coarse sands in Autumn, and although the PSDP site had greater percentages of coarser sand across surveys, the relationship between abundances and meiofauna was inconsistent (Figure 10). There was a shift in greater abundances at some sites with smaller grain sizes (medium sand) at NC and SC from Autumn to Winter/Spring, but that was inconsistent at the Location level (Figure 10). For some of the indicator species, there was a general pattern of greater abundances of copepods with coarser sands in the Autumn survey (Figure 11) but that was not consistent going into the Winter/Spring survey. Nematodes, which had slightly greater abundances at SC with coarser sediments switched to being more abundant in the NC with finer sediments in Winter/Spring (Figure 12).



A: (p = 0.006) R=0.72; B%=89; Gravel<7.24(>8.54) or Sand>92.6(<91.3)
B: (p = 0.002) R=0.42; B%=60; Gravel<8.54(>9.6) or Sand>91.3(<90.4)
C: (p = 0.25) R=0.25; B%=42; Gravel<13.7(>15.7) or Sand>86(<84) or Silt<0.311(>0.329)

Figure 9: Linktree cluster diagram based on meiofauna Bray-Curtis similarities and sediment Euclidean distance matrices with SIMPROF for Locations and surveys. Significant splits in Linktree are classified by black lines and non-significant splits as red-dashed lines.

(a)



(b)

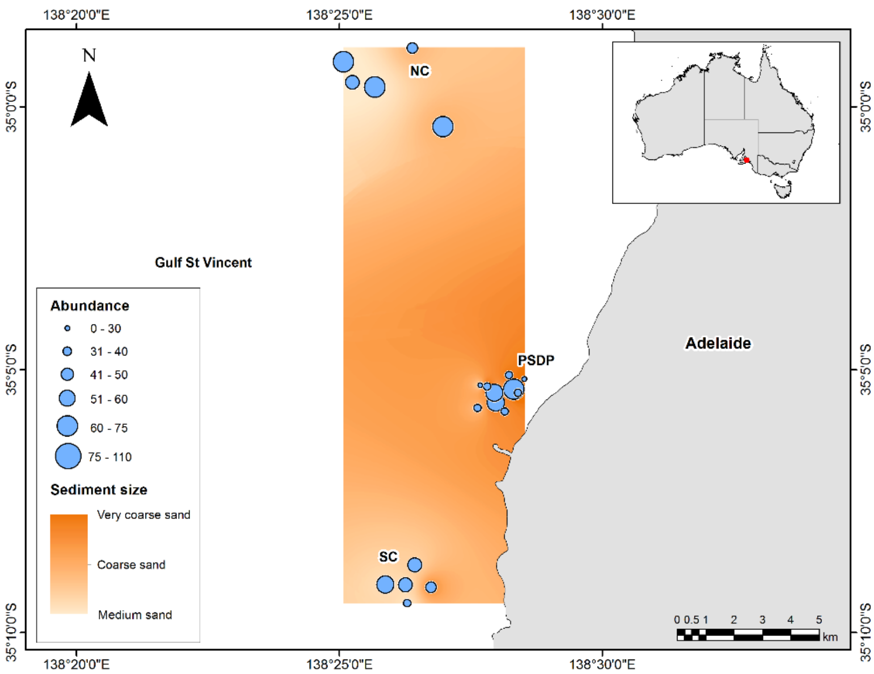
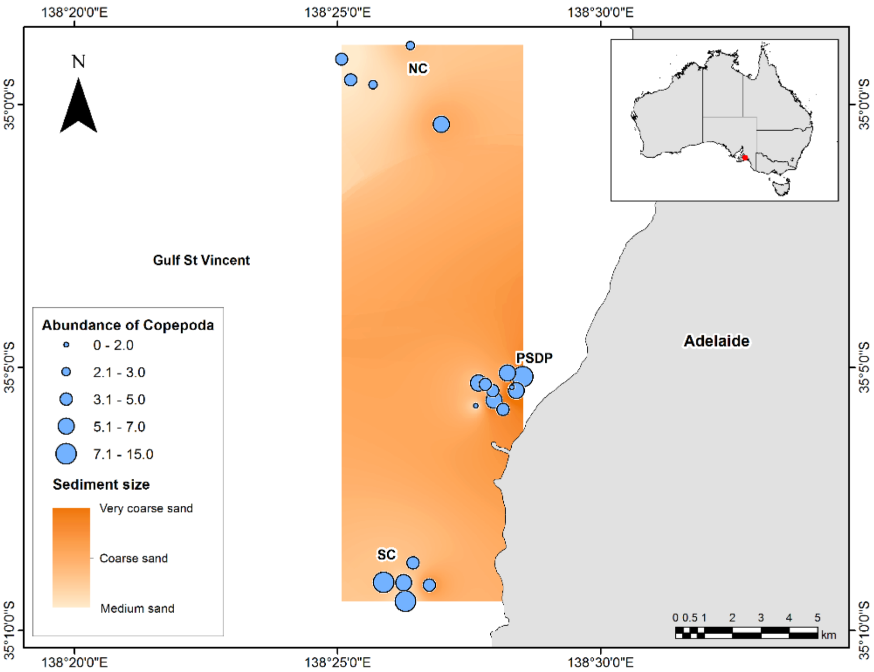


Figure 10: Map of the Port Stanvac Desalination Plant (PSDP), North Control (NC) and South Control (SC). IDW* interpolation of the sediment size classification and abundances (average) of All meiofauna taxa pooled obtained from the (a) Autumn and (b) Winter/Spring2017 survey. *Inverse Distance Weighted (IDW) interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location.

(a)



(b)

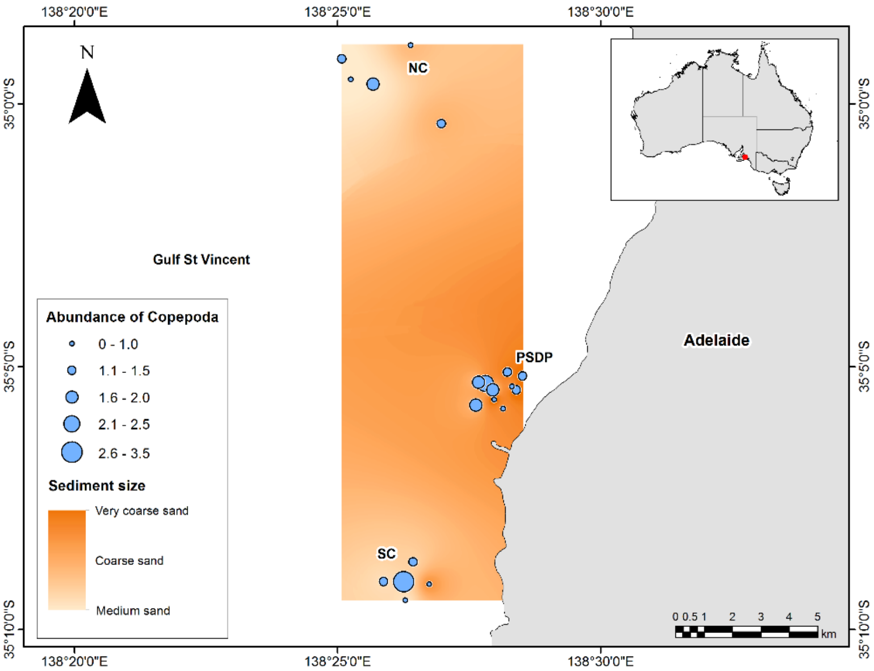
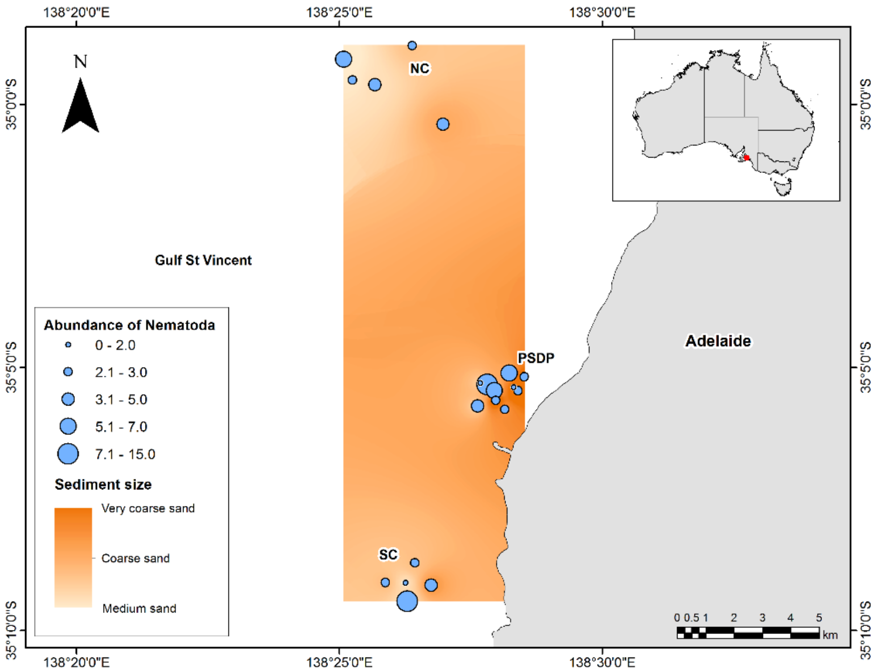


Figure 11: Map of the Port Stanvac Desalination Plant (PSDP), North Control (NC) and South Control (SC). IDW* interpolation of the sediment size classification and abundances (average) of Copepoda from the (a) Autumn and (b) Winter/Spring2017 survey. *Inverse Distance Weighted (IDW) interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location.

(a)



(b)

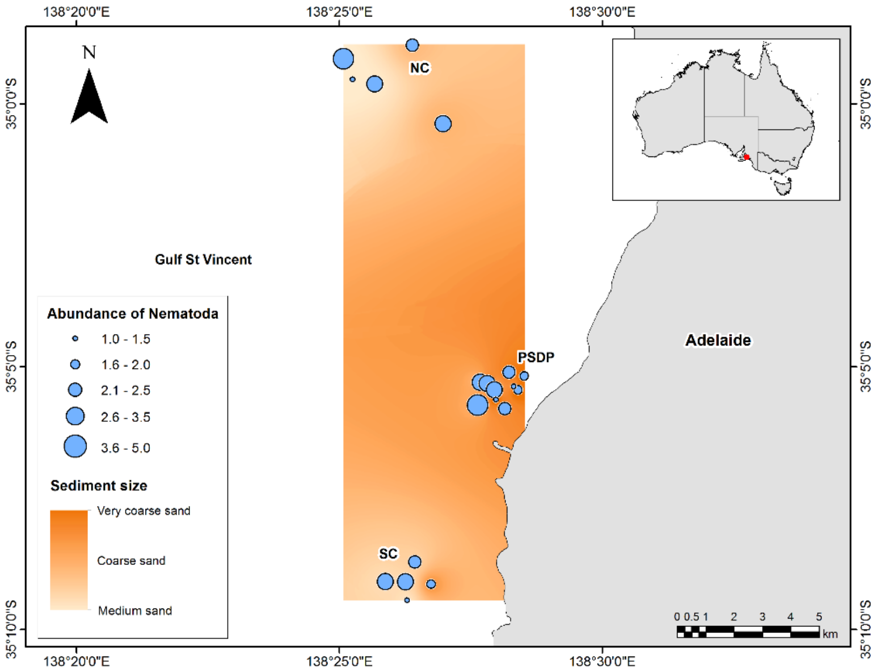


Figure 12: Map of the Port Stanvac Desalination Plant (PSDP), North Control (NC) and South Control (SC). IDW* interpolation of the sediment size classification and abundances (average) of Nematoda from the (a) Autumn and (b) Winter/Spring2017 survey. *Inverse Distance Weighted (IDW) interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location.

3.3 Benthic macrofauna

3.3.1 Macrofauna taxa richness and diversity

Across the three locations and two surveys, a total of 6,110 individuals from 150 macrofauna taxa were found in subtidal sediment samples. Taxa that contributed most to the species found across all locations and surveys were Arthropoda (36 %), Mollusca (31 %) and Annelida (22 %) (see Appendix Table A3). The total number of taxa was highest at South Control (SC), and lowest at the Port Stanvac Desalination Plant (PSDP) in both surveys, with the most macrofauna taxa for all Locations recorded during the Winter/Spring survey (Figure 13, see site level comparisons in Appendix Figure A4). There was no significant difference in the number of macrofauna taxa between Locations and surveys, nor with any interactions between these factors ($p > 0.05$).

Diversity indices and evenness values for macrofauna had very similar patterns across Location and Time, with a high diversity of taxa seen at all Locations and surveys (Figure 14). Thus, there was no significant difference in the spatial and temporal interactions for macrofauna diversity and evenness (Table 7).

Table 7. Univariate PERMANOVA results for macrofauna diversity indices from the infauna surveys based on three diversity indices; Pielou's evenness, Shannon Wiener and Simpson's Index. Analyses were based on the experimental design with factors of: Zone, Zo; time, Ti; Location, Lo nested in Zo, factors. Significant differences are highlighted in bold. Tests were based on Euclidean distances.

Source	df	Pielou's J'	Shannon-Weiner Log e'	Simpson's index
Zo	1	**0.0051**	**0.0072**	**0.0034**
Ti	1	0.5844	**0.0103**	0.4849
Lo (Zo)	1	**0.0048**	**0.0280**	**0.0050**
Zo x Ti	1	0.3356	0.1733	0.6149
Ti x Lo (Zo)	1	0.5422	0.3706	0.9366
Residual	34			

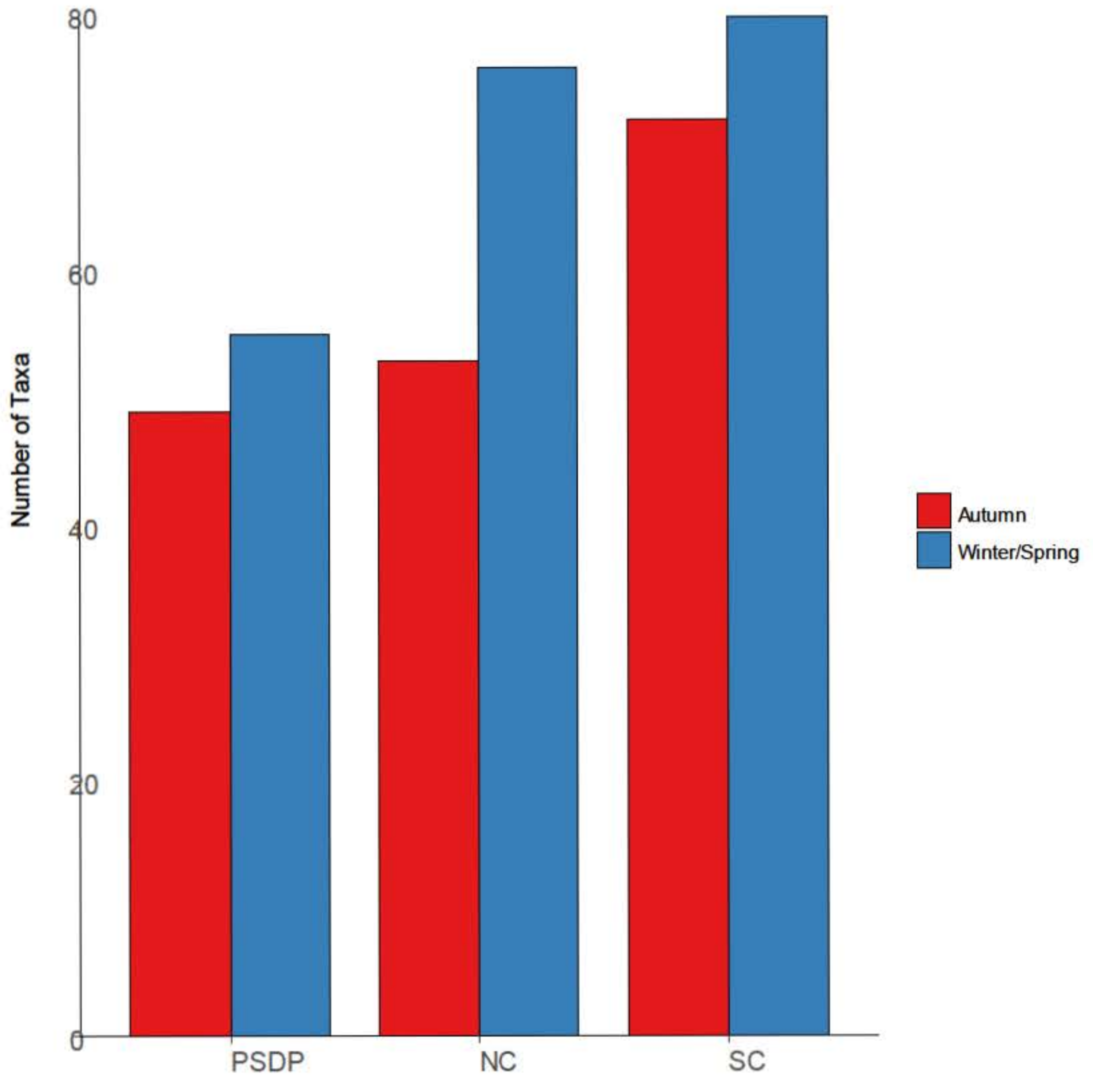


Figure 13: Total number of taxa for benthic macrofauna at each of the Locations (all sites pooled) obtained from sediments in the Autumn and Winter/Spring 2017 surveys. Port Stanvac Desalination Plant (PSDP; 10 sites), North Control (NC; 5 sites) and South Control (SC; 5 sites).

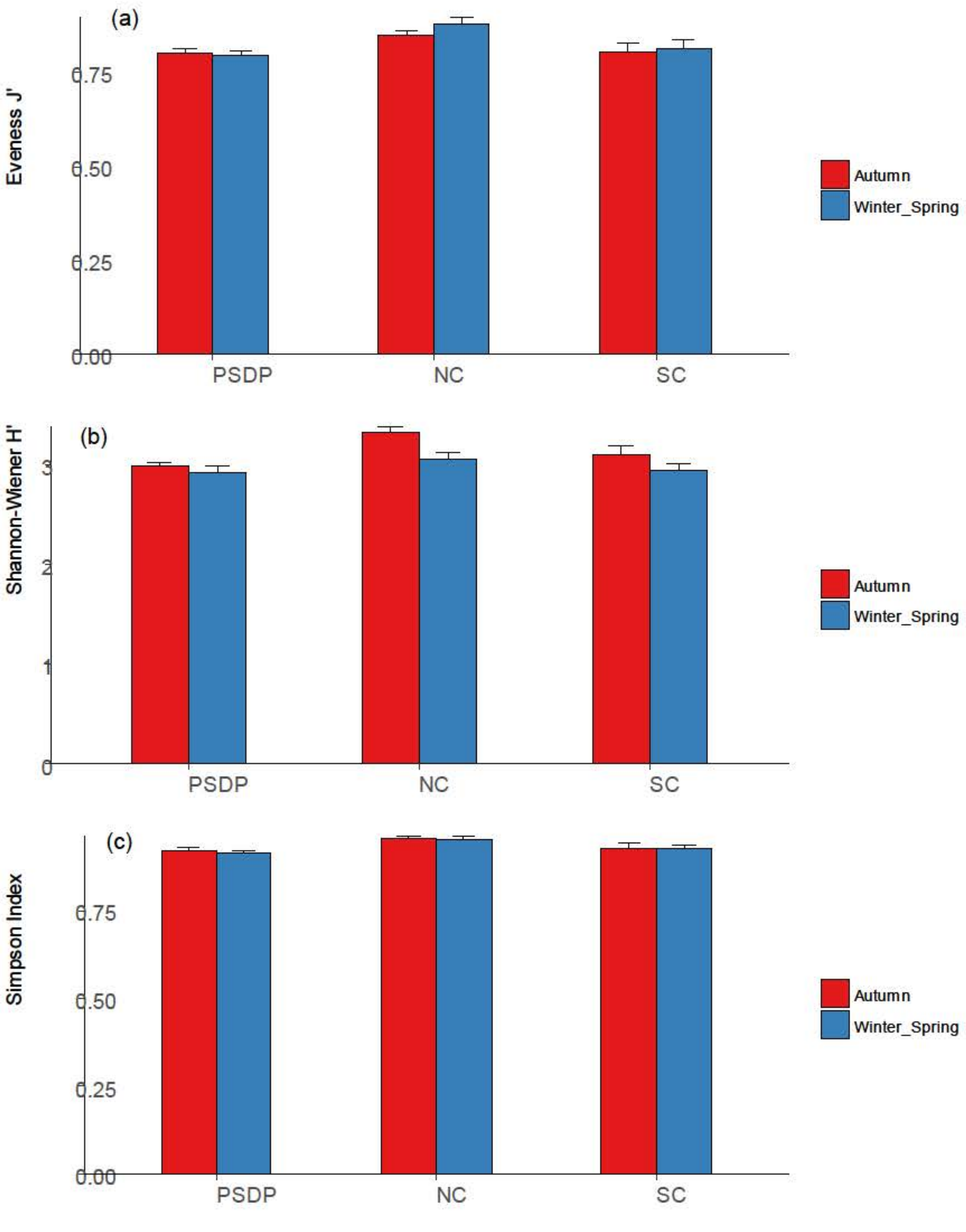


Figure 14. Diversity values for macrofauna from the infauna surveys in Autumn and Winter/Spring 2017. Values are given for three diversity indices; (a) Pielou's evenness, (b) Shannon Wiener and (c) Simpson's Index.

3.3.2 Macrofauna abundances

Total abundances of macrofauna were greatest at the PSDP Location in the Autumn survey compared to other locations and times, which also matched the distribution of Arthropoda, Annelida, Mollusca and separately for the indicator taxa Capitellidae (Figure 15). Arthropods, annelids, molluscs and Capitellidae were all more abundant across all locations during the Autumn survey (Figure 15). Echinoderms had the highest abundances in NC and SC Location in Autumn survey, while during the Winter/Spring survey the greatest abundance was at the PSDP Location (Figure 15). Echinodermata abundances had a significant interaction for Zone by Time between the PSDP Central and the Control Zone in Autumn ($p < 0.05$, Table 8). For mollusc significant interactions occurred between PSDP Central and the Control Zone in Autumn and for the Central Zone and Control Zone only between surveys ($p < 0.05$, Table 8). There were significant interactions between Sites and Surveys for most common macrofauna taxa (excluding molluscs) indicating large amounts of fine spatial and temporal variation (Table 8).

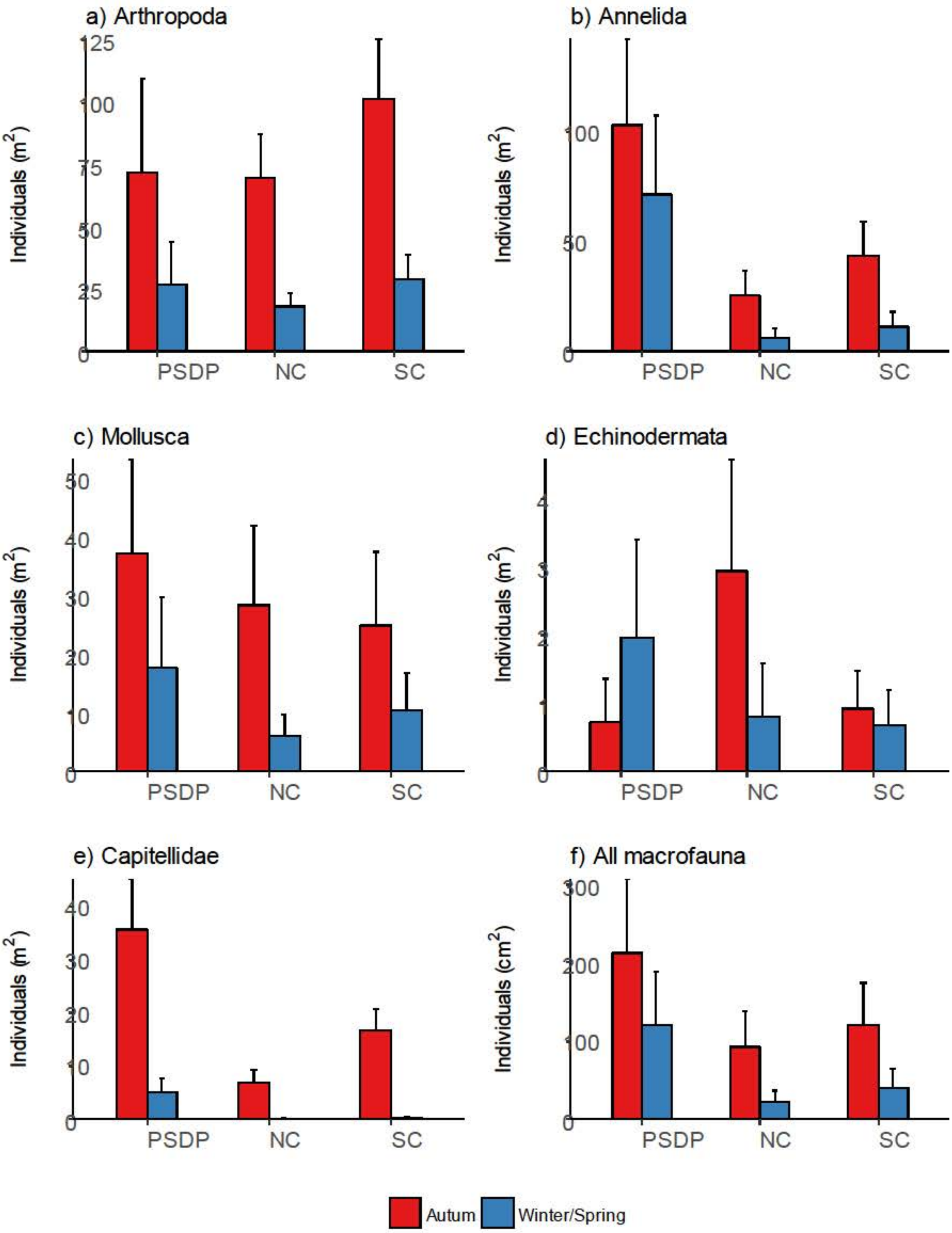


Figure 15: Abundances (mean ± SE) of common benthic macrofauna obtained from sediments in the 2017 surveys at the three Locations with sites pooled from; Desalination Plant (10 sites), North Control (five sites) and South Control (five sites). Abundances include the main taxa found as; a) Arthropoda, b) Annelida, c) Echinodermata, d) Mollusca e) the environmental indicator of Capitellidae, and f) all macrofauna combined as total abundances. Note different ranges in Individuals (m^2) on Y axes across taxa.

Table 8: Univariate PERMANOVA results for main taxa and total abundance of all benthic macrofauna from the Autumn and Winter/Spring 2017 surveys. Analyses were based on the experimental design with factors of: Zone, Zo; time, Ti; Location, Lo nested in Zo; Site, Si nested in Lo and Zo. Significant differences are highlighted in bold.

Source	df	Arthropoda	Annelida	Echinodermata	Mollusca	Capitellidae	Total abundance
Zo	1	0.7858	**0.0029**	0.7012	0.6268	0.1694	0.6090
Ti	1	**0.0001**	**0.0006**	0.4163	**0.0001**	**0.0001**	**0.0001**
Lo(Zo)	1	0.1589	0.2092	0.3532	0.9385	0.5559	0.0726
ZoxTi	1	0.1254	0.3037	**0.0232**	**0.0271**	0.3340	0.0687
Si(Lo(Zo))	17	0.1816	0.4091	0.8996	0.2415	0.0760	0.3849
Lo(Zo)xTi	1	0.2723	0.3391	0.0698	0.1415	0.0831	0.6232
Si(Lo(Zo))xTi	17	0.6820	**0.0001**	**0.0233**	0.2170	**0.0001**	**0.0254**
Residual	360						

3.3.3 Macrofauna community structure

Macrofauna communities display six different clusters across surveys and Locations (Figure 16 & 17). For all Locations the Winter/Spring survey was highly distinct compared to the Autumn survey and significantly different between surveys (Figure 16 & 17, Table 9). Macrofauna communities were also significantly dissimilar among PSDP, SC and NC Locations (Table 9). Another significant interaction was between Sites by Time, which is indicative of the fine spatial and temporal variation across all Locations (Table 9). Taxa that were contributing most to the community structure included Annelida, Arthropoda and Mollusca (Figure 17, Table 10). In Winter/Spring the communities at PSDP/NC and SC/NC showed high dissimilarity and did not share many taxa, which represent that the community structure at each location was unique (Table 10). The dissimilarity between Locations within each survey was high indicating that there were a great variation in the macrofauna community structure (Table 10).

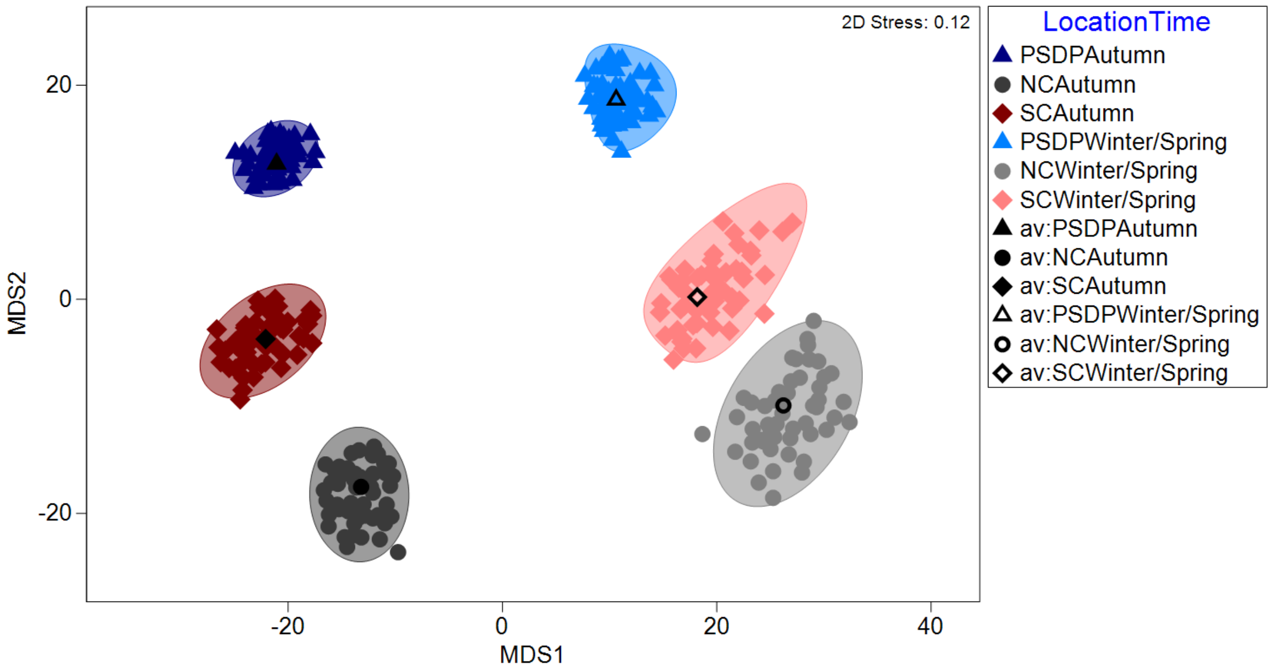


Figure 16: Community structure of all benthic macrofauna for Locations and Surveys of the benthic infauna monitoring in 2017. Groupings and separation of Locations are based on bootstrapped Metric Multidimensional Scaling (MDS) using the Bray Curtis resemblance matrix.

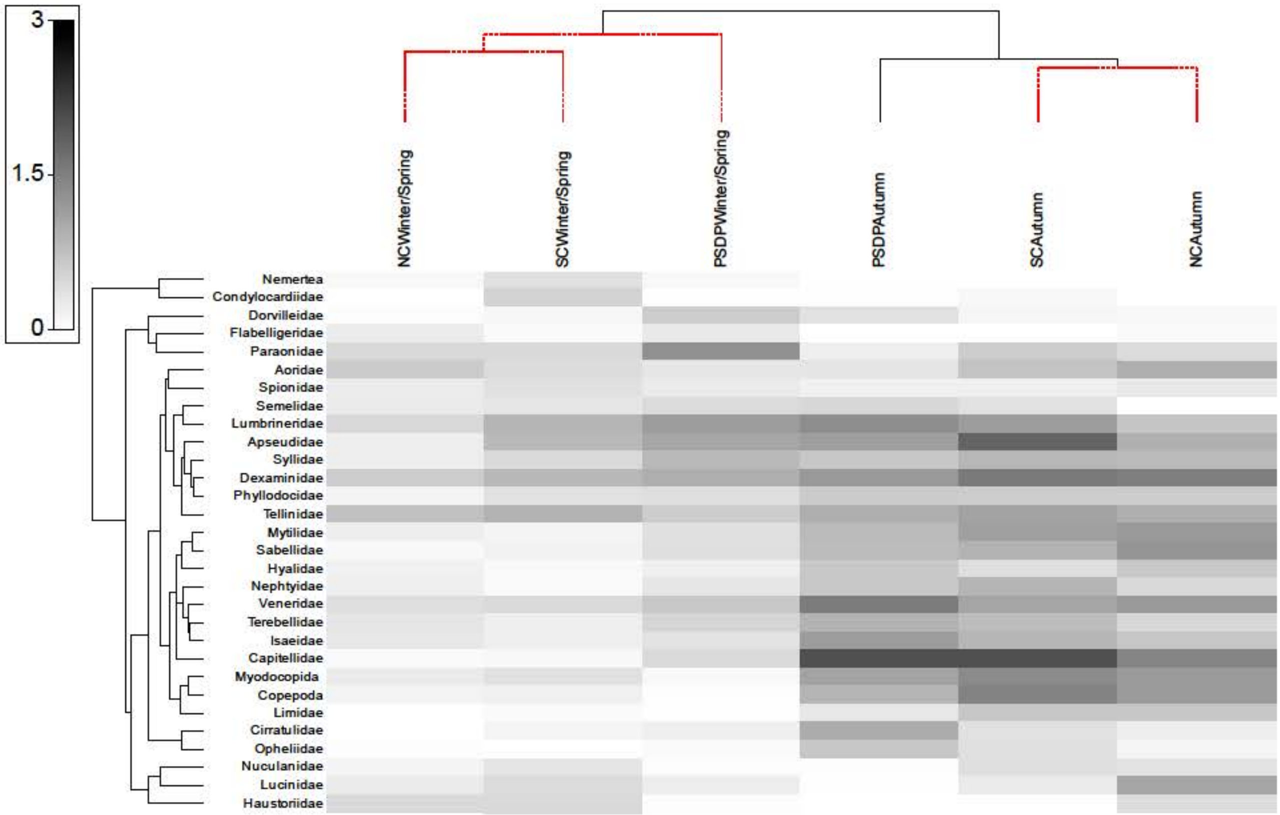


Figure 17: Matrix display of macrofauna communities at the three locations of the desalination plant (DP), southern (SC) and northern (NC) control zones based on average values of all sites per location. The darker the shading, the higher the relative contribution of a taxa to the abundance. The dendrograms indicate slight groupings for the locations and taxa.

Table 9: Multivariate PERMANOVA results for benthic macrofauna communities from the 2017 surveys. Analyses were based on the experimental design of the Zone (Zo), Location (Lo), Site (Si) and time (Ti) factors. Significant *P*-values are highlighted in bold.

Source	df	All macrofauna
Zo	1	0.24
Ti	1	**0.0001**
Lo(Zo)	1	0.30
ZoxTi	1	**0.0004**
Si(Lo(Zo))	17	**0.005**
Lo(Zo)xTi	1	0.06
Si(Lo(Zo))xTi	17	**0.0001**
Residual	360	

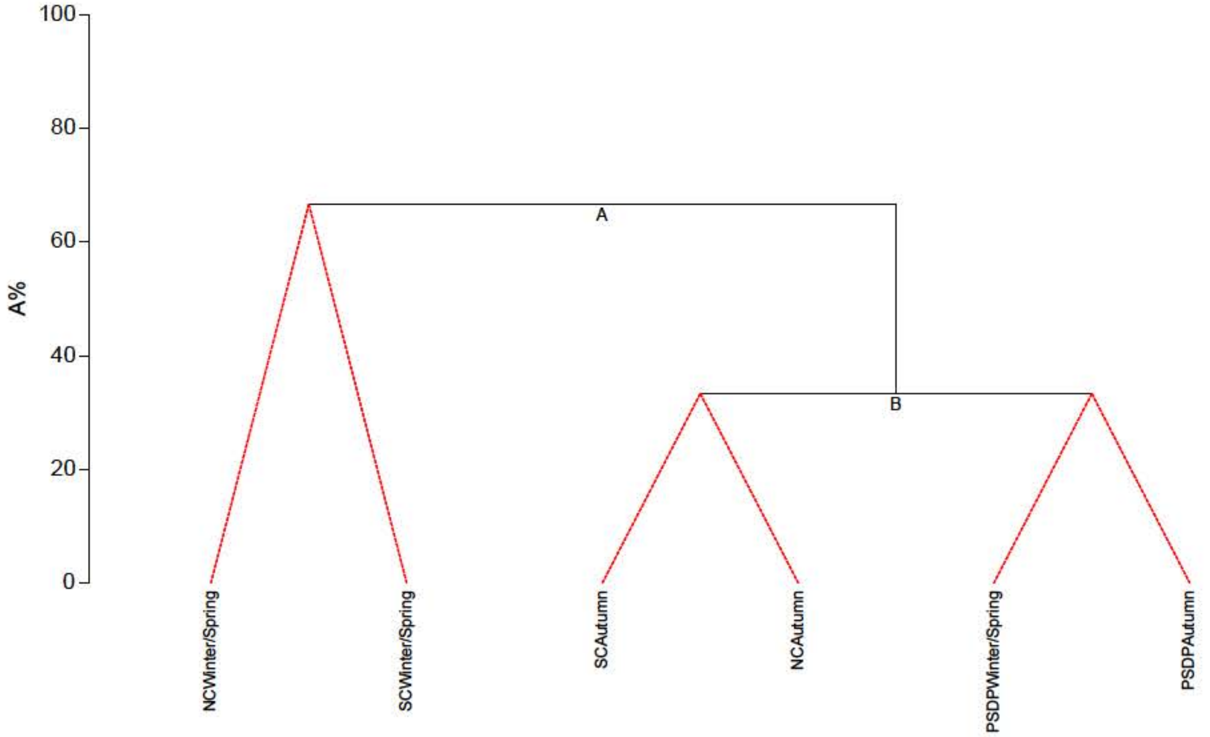
Table 10: SIMPER results of benthic macrofauna communities between all combinations of Location by Time groupings. Dissimilarities between Location group pairs within each survey. The number of families within each major phyla and the total number of families overall that are reliable discriminant taxa are shown for each Location and survey. Cut off of cumulative contributions is 70 %.

			Reliable discriminant taxa (Family level)			
Survey	SIMPER grouping	Average dissimilarity (%)	Annelida	Arthropoda	Mollusca	Total number of Families
Autumn	PSDP SC	63.8	4	5	3	12
	PSDP NC	68	4	6	4	14
	SC NC	64	4	6	4	14
Winter/Spring	PSDP SC	81.1	2	1		3
	PSDP NC	84.8	1			1
	SC NC	84				0

3.3.4 Macrofauna and sediment relationships

Macrofauna and sediment type relationships were significantly distinct ($p < 0.05$) for the NC and SC Locations in the Autumn survey compared to the Winter/Spring survey, which was influenced by less-mixed and finer sediments in the former survey (Figure 18). The PSDP macrofauna and sediment relationship was similar in both surveys but significantly different ($p < 0.05$) to the NC and SC locations in Winter/Spring (Figure 18). Overall, the relationship between macrofauna and sediment types was not very strong and not significant (RELATE; Rho 0.13 $p < 0.05$).

The abundance of macrofauna at PSDP was greatest at some sites with very coarse sands in both Autumn and Winter/Spring. Both surveys showed a greater abundance of macrofauna at coarser sediment Locations, PSDP and SC, however varied slightly within Locations (Figure 19). When looking specifically at the macrofaunal indicator species, there was a weak pattern of greater abundances of Capitellidae with coarser sands for both surveys (Figure 20). However, the relationship between sediment size and echinoderm abundance was not consistent, as they occurred in greater numbers at SC (finer sediment) during the Autumn survey , then switched to being more abundant at PSDP (coarser sediment) during Winter/Spring survey, regardless of the sediment size (Figure 21).

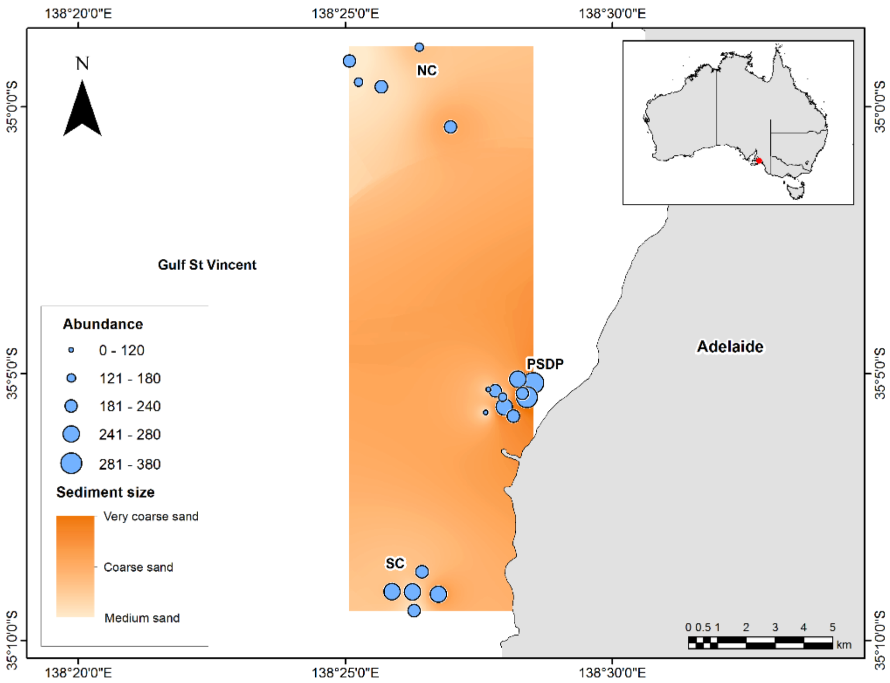


A: ($p = 0.001$) R=0.86; B%=96; Gravel<8.54(>9.6) or Sand>91.3(<90.4)
B: ($p = 0.001$) R=0.50; B%=48; Gravel<13.7(>15.7) or Sand>86(<84) or Silt<0.311(>0.329)

RELATESample statistic (Rho): 0.128
Significance level of sample statistic: 21.4 %

Figure 18: Linktree cluster diagram based on macrofauna Bray-Curtis similarities and sediment Euclidean distance matrices with SIMPROF for Locations and surveys. Significant splits in Linktree are classified by black lines and non-significant splits as red-dashed lines.

(a)



(b)

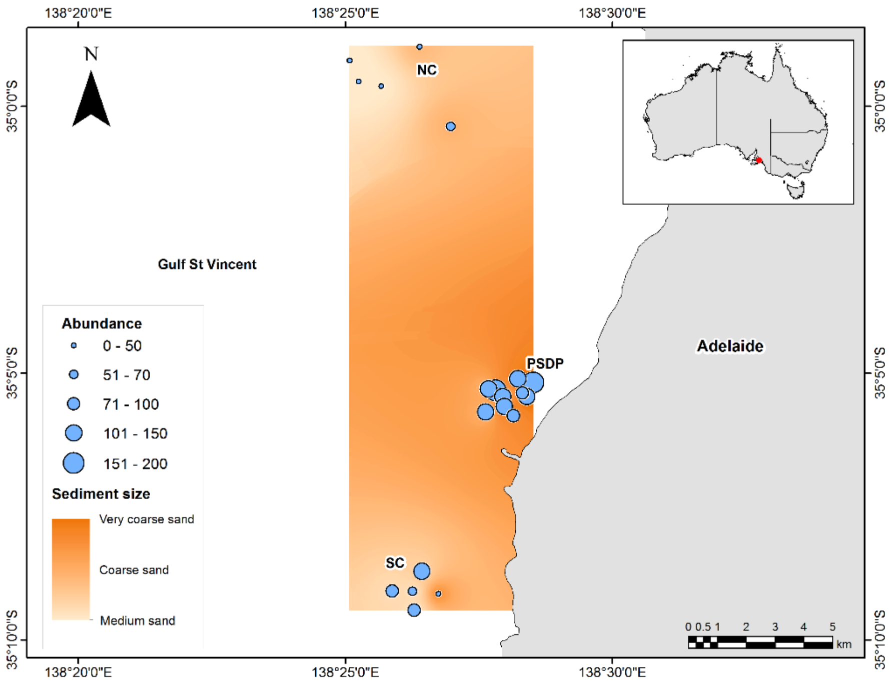
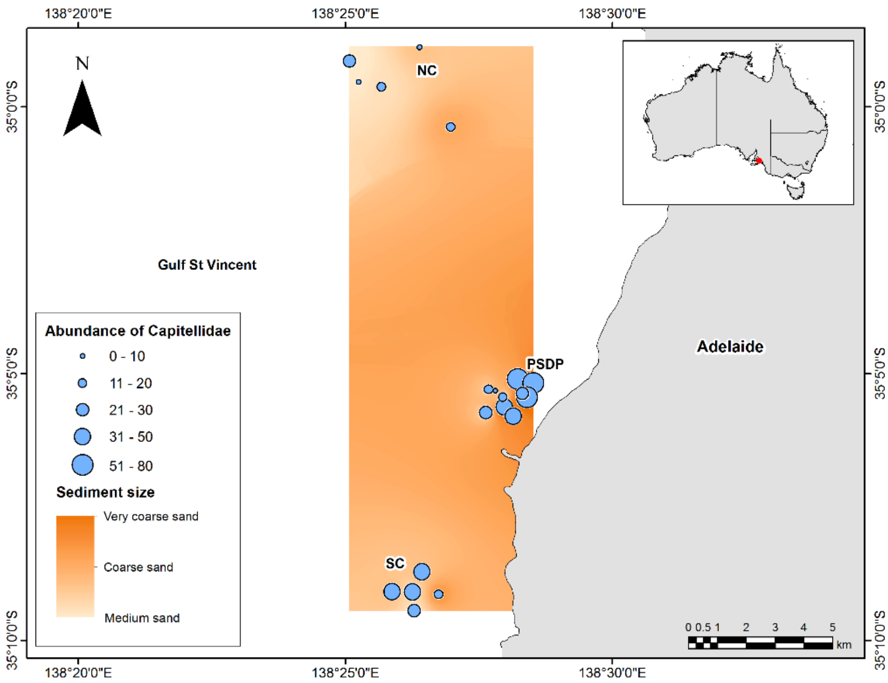


Figure 19: Map of the Port Stanvac Desalination Plant (PSDP), North Control (NC) and South Control (SC). IDW* interpolation of the sediment size classification and abundances (average) of all macrofauna taxa pooled obtained from the (a) Autumn and (b) Winter/Spring2017 survey. *Inverse Distance Weighted (IDW) interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location.

(a)



(b)

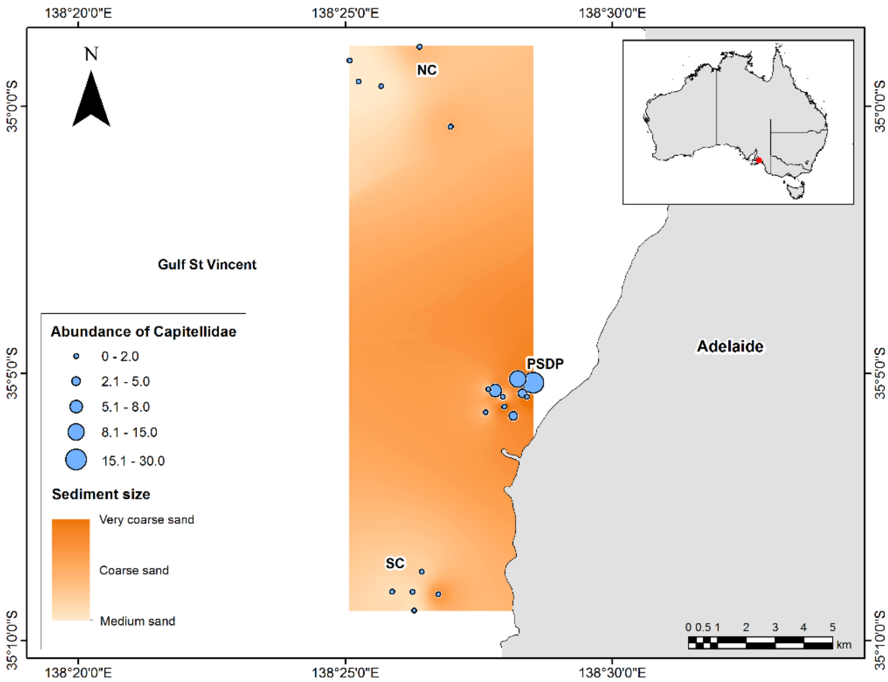
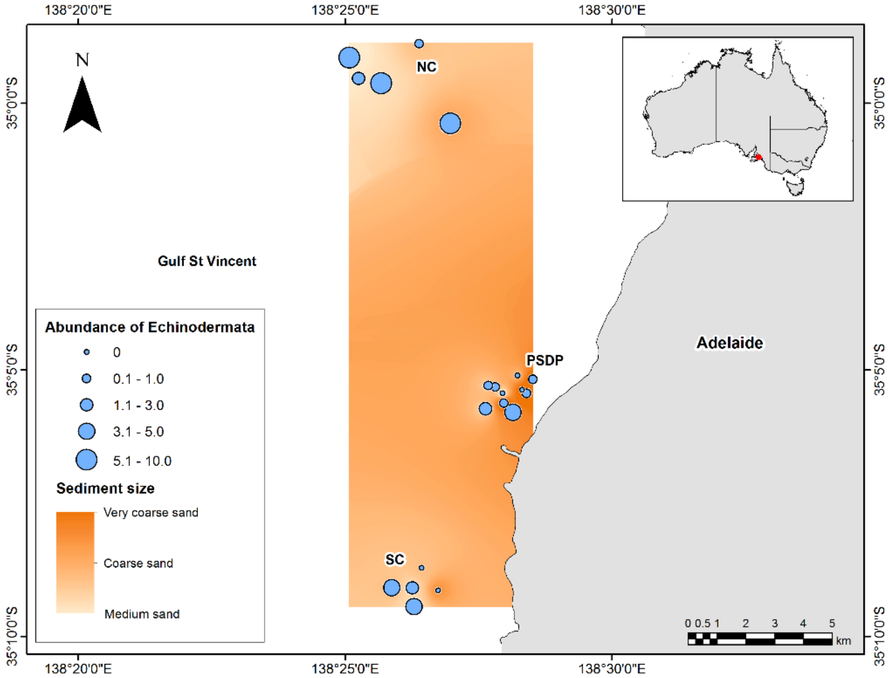


Figure 20: Map of the Port Stanvac Desalination Plant (PSDP), North Control (NC) and South Control (SC). IDW* interpolation of the sediment size classification and abundances (average) of Capitellidae obtained from the (a) Autumn and (b) Winter/Spring2017 survey. *Inverse Distance Weighted (IDW) interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location.

(a)



(b)

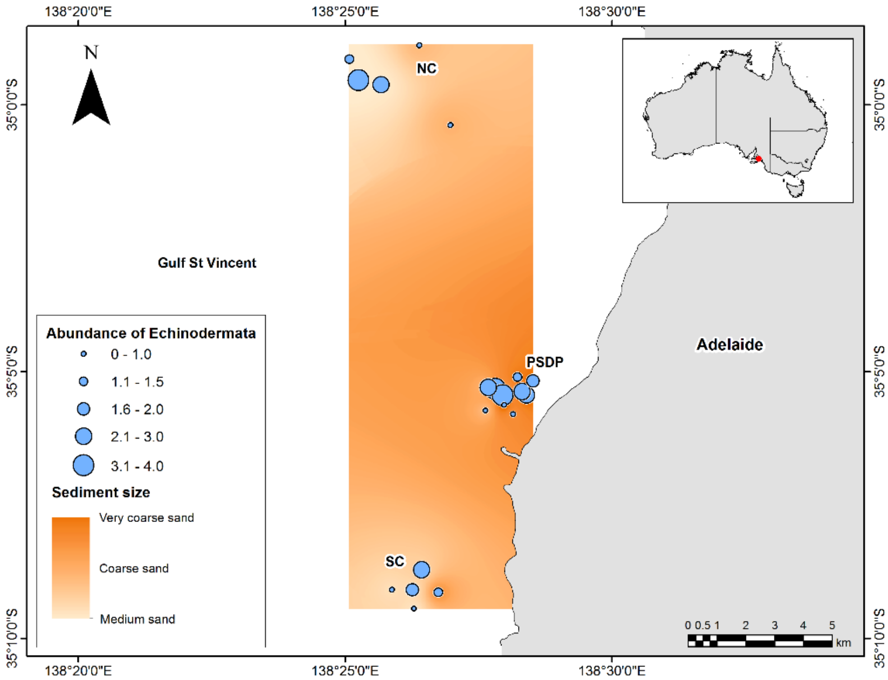


Figure 21: Map of the Port Stanvac Desalination Plant (PSDP), North Control (NC) and South Control (SC). IDW* interpolation of the sediment size classification and abundances (average) of Echinodermata obtained from the (a) Autumn and (b) Winter/Spring2017 survey. *Inverse Distance Weighted (IDW) interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location.

4. Discussion

Overall, there were no significant differences in the benthic infauna communities between the desalination plant and control zones, nor between the locations of the Central Port Stanvac Desalinisation Plant (PSDP), and the Northern (NC) and Southern Controls (SC) during either of the two survey periods. Surveys conducted at the three locations in Autumn and Winter/Spring identified idiosyncratic site specific spatial and temporal variation in the benthic infauna and sediment composition, which is typical of shallow subtidal soft sediments in Gulf St. Vincent and other coastal environments (Ramsdale et al. 2011b; Riera et al. 2013). Infauna analyses revealed more temporal variation between the autumn and winter/spring survey in 2017 than differences subject to the location near the desalination plant or control zone.

Sediment grain sizes and fractions were mainly coarse sands, particularly at PSDP where gravel and larger sand grain sizes were consistently found, compared to the finer sediment fractions at NC and SC. The grain size composition found in both surveys from 2017 aligned well with the sediment characteristics described from previous monitoring (Ramsdale et al. 2011a, b), while Loo et al. (2014) also recorded a higher variability in grain size compositions between sites, and some finer sediment near the desalination plant.

The most common meiofauna taxa found in the 2017 surveys included Foraminifera, Ostracoda, Arthropoda and Nematoda. A higher number of meiofauna taxa were found in sediments near the desalination plant, yet meiofauna diversity was comparable across the three locations and only varied between the autumn and winter/spring surveys. Previous surveys have also found relatively even taxonomic richness of meiofauna across the locations (Ramsdale et al. 2011b) with seasonal variation and site specific variability (Loo et al. 2014).

Total abundances and some of the major meiofauna taxa varied between sites within locations and across all surveys but mostly there were no changes between Zones or Locations. Foraminifera abundances were greater in the Control versus the Central PSDP zone in August/September, which may be a seasonal shift in distribution. In general, Foraminifera abundances usually do not appear to be affected by brine discharge, though any effects on their diversity is unknown (Small 2015). The abundance of nematodes, a known bio-indicator to benthic disturbance (Bongers & Ferris 1999; Morenoa et al. 2011), was found to be around twice as high within the Control sites compared to the Central PSDP during the two surveys. Nematodes typically prefer fine-grained sediments (Coull 1985; as seen in Riera et al. 2011), therefore, with the finer sediments found at the Control sites, compared to the coarser, shelly sediments at PSDP, sediment size could be the contributing factor for nematode abundance.

The methods for meiofauna sampling have changed across previous surveys (Cheshire 2014a) and abundances cannot be directly compared. However, the pattern of differences or variability across locations can be compared. Previous surveys found higher meiofauna abundance at the Port Stanvac desalination site compared to the northern and southern control zone (Ramsdale et al. 2011b, Loo et al. 2014), whereas the current surveys from 2017 showed lower abundances near the desalination plant compared to the northern control zone. All surveys found high site specific temporal variability in abundances.

Meiofauna communities varied more over time than between locations or zones in the surveys from 2017, with Foraminifera either included or excluded. Seasonal variations in meiofauna communities has been found in previous surveys (Ramsdale et al. 2011b, Loo et al. 2014). Sediment composition can explain some of the variation in meiofaunal communities over time, as was found in the present surveys, but there were no clear patterns for meiofauna communities or the most prominent meiofauna indicator taxa (nematodes and copepods) across the locations and surveys.

Across all locations and surveys, macrofaunal taxa were diverse, with the most common taxa being from Arthropoda, Mollusca, and Annelida (predominantly polychaetes). The number of macrofauna taxa varied between the two surveys and across sites and locations but little spatial or temporal variation occurred in diversity indices. The number of taxa found in the current surveys, as well as the prominence of arthropods and molluscs in species numbers, was comparable to previous surveys from 2009-2011 (Ramsdale 2011b), and higher than reported by Loo et al. (2014).

Macrofauna was more abundant at the PSDP Zone compared to the Control Zone, especially during the winter/spring survey, although spatial and temporal difference in abundance where high for specific taxa. Previous surveys have also found high spatial and temporal variability across locations and zones (Ramsdale et al. 2011b, Loo et al. 2014).

The opportunistic behaviour of some polychaete species make them a useful bio-indicator to test for impacts in disturbed marine habitats (Del-Pilar-Ruso et al. 2008). The known opportunistic Capitellidae (Polychaeta) (Dauvin & Ruellet 2007; de-la-Ossa-Carretero et al. 2016) were more common near the desalination plant than in the control locations. The higher abundances in Capitellidae at the PSDP, which was characterised by coarser sands, contradicts the common predominance of Capitellidae in muddier, organic rich sediments (Ramskov & Forbes 2008). The difference in Capitellidae abundances between the Central and Control Zones could be linked to the closer proximity of the PSDP to the shore, thus being potentially more exposed to land-based impacts, including previous industrial practices at the site. Other non-opportunistic polychaetes and crustaceans had similar average abundances across locations.

Although echinoderms did not constitute a large amount of macrofauna found, their presence, or lack thereof, were also assessed as a useful indicator to the health of the benthos due to their narrow tolerable salinity ranges (de-la-Ossa-Carretero et al. 2016) and their inability to move far from a pollution source (Fernandez-Torquemada et al. 2012). There was no overall difference in echinoderm abundance between Central PSDP and Control Zones, and any differences seen were likely to be seasonal and small-scale spatial variation.

Seasonal differences appeared also for the community structure of macrofauna, which were distinct between all locations at the two surveys. A great variability across locations and surveys for macrofaunal communities had also emerged in previous monitoring (Ramsdale et al. 2011b, Loo et al.

2014). Sediment conditions (coarser or finer grain size) contributed to some of the temporal and spatial differences in benthic communities, but in no consistent pattern across the zones.

For more quantitative comparisons over time, data from all previous monitoring since 2009 have to be evaluated and aligned for taxonomic levels (different taxonomic resolutions used) as well as sampling units and factor coding. For meiofauna, quantitative comparison per unit area can be done for all surveys, but for macrofauna, quantitative analyses cannot be done in all cases (e.g. where volume and area were used in the past). In such cases the variability as such between sites/locations and over time can be analysed to detect differences or similarities. Given the seasonal variability seen in all monitoring years, comparisons over time should be carried out separately for particular seasons. Standardised time series analysis (Babcock et al. 2010) can also be explored to detect relative changes. The creation of combined data sets from all past and current monitoring is recommended and will be useful for ongoing monitoring in the future.

5. Acknowledgements

We like to thank Matt Lloyd for carefully skippering the *Tethys* and his hands-on help for facilitating the boat work. Patrick Fitzgerald was part of the project team for field sampling and processing of samples in the laboratory. Rob Klima, Holly Barnett and further student volunteers helped with some of the sorting of samples under supervision.

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7. Appendix

Table A1*:* Descriptions of grain size distributions and sorting co-efficients using geometric methods of moments (Blott and Pye, 2001) from all Sites and Locations, during the (a) Autumn and (b) Winter/Spring 2017 infauna surveys.

(a)

		Grain size distribution statistics and classifications					Size Fractions (%)		
Location	**Site**	**Median (µm)**	**Mean (µm)**	**Size Classification**	**Sorting**	**Sorting Classification**	**Gravel**	**Sand**	**Silt**
Port Stanvac Desalination Plant (PSDP)	1	776.56	799.47	Coarse sand	2.92	Poorly sorted	10.79	84.18	5.03
	2	595.39	598.75	Coarse sand	2.33	Poorly sorted	6.07	92.92	1.01
	3	574.65	626.18	Coarse sand	2.37	Poorly sorted	10.10	89.26	0.64
	4	731.74	737.48	Very coarse sand	2.58	Poorly sorted	15.23	83.87	0.89
	5	1180.39	1151.38	Very coarse sand	2.35	Poorly sorted	25.68	73.72	0.60
	6	890.97	900.31	Coarse sand	2.49	Poorly sorted	15.57	83.98	0.45
	7	1518.91	1396.81	Very coarse sand	2.36	Poorly sorted	34.23	64.81	0.96
	8	400.31	430.08	Medium sand	2.15	Poorly sorted	4.36	94.70	0.94
	9	1149.16	1064.22	Very coarse sand	2.62	Poorly sorted	25.99	73.60	0.41
	10	1584.07	1423.10	Very coarse sand	2.51	Poorly sorted	39.10	59.80	1.10
Glenelg North Control (NC)	1	898.35	818.33	Coarse sand	2.83	Poorly sorted	18.49	81.50	0.01
	2	711.65	705.16	Coarse sand	2.36	Poorly sorted	11.02	88.98	0.00
	3	574.22	582.29	Coarse sand	2.27	Poorly sorted	9.17	90.83	0.00
	4	464.05	482.32	Medium sand	2.18	Poorly sorted	6.52	93.48	0.00
	5	523.74	540.40	Coarse sand	1.85	Moderately sorted	2.80	97.20	0.00
Port Noarlunga South Control (SC)	1	763.69	715.22	Coarse sand	1.92	Moderately sorted	14.10	85.82	0.09
	2	684.36	724.01	Coarse sand	2.70	Poorly sorted	19.36	80.00	0.65
	3	553.01	573.59	Coarse sand	2.11	Poorly sorted	7.73	91.98	0.30
	4	1010.89	925.32	Coarse sand	2.29	Poorly sorted	22.90	76.57	0.53
	5	500.46	535.35	Coarse sand	1.79	Moderately sorted	4.31	95.69	0.00

(b)

Location	Site	Median (µm)	Mean (µm)	Size Classification	Sorting	Sorting Classification	Gravel	Sand	Silt
		Grain size distribution statistics and classifications					**Size Fractions (%)**		
Port Stanvac Desalination Plant (PSDP)	1	1155.28	1171.43	Very coarse sand	2.45	Poorly sorted	24.03	75.25	0.72
	2	684.21	674.07	Coarse sand	2.15	Poorly sorted	6.79	92.56	0.65
	3	520.02	555.77	Coarse sand	2.22	Poorly sorted	6.69	92.97	0.34
	4	933.20	975.36	Coarse sand	2.28	Poorly sorted	17.21	82.71	0.09
	5	1046.13	1064.18	Very coarse sand	2.30	Poorly sorted	20.92	79.00	0.08
	6	860.25	868.96	Coarse sand	2.35	Poorly sorted	14.43	85.52	0.05
	7	1200.35	1110.71	Very coarse sand	2.43	Poorly sorted	20.89	78.35	0.76
	8	436.86	476.50	Medium sand	2.08	Poorly sorted	6.11	93.80	0.09
	9	807.86	801.54	Coarse sand	2.57	Poorly sorted	15.65	84.17	0.18
	10	1305.78	1177.98	Very coarse sand	2.46	Poorly sorted	24.40	75.27	0.33
Glenelg North Control (NC)	1	719.51	717.76	Coarse sand	2.80	Poorly sorted	16.57	82.84	0.60
	2	641.75	686.77	Coarse sand	2.37	Poorly sorted	11.45	88.53	0.01
	3	477.40	492.92	Medium sand	2.27	Poorly sorted	4.82	95.17	0.00
	4	458.70	473.51	Medium sand	2.18	Poorly sorted	7.63	92.37	0.00
	5	437.05	454.09	Medium sand	1.88	Moderately sorted	2.24	97.74	0.02
Port Noarlunga South Control (SC)	1	588.64	589.72	Coarse sand	1.85	Moderately sorted	5.15	94.70	0.15
	2	493.36	536.66	Medium - coarse sand	2.12	Poorly sorted	6.45	93.47	0.07
	3	513.22	528.01	Coarse sand	1.90	Moderately sorted	3.72	96.05	0.23
	4	993.82	861.24	Coarse sand	2.18	Poorly sorted	18.24	81.48	0.28
	5	487.10	511.48	Medium - coarse sand	1.77	Moderately sorted	2.64	97.36	0.00

Table A2: List and total abundances of meiofauna taxonomic groups from all sites and Locations during the 2017 infauna survey.

Phylum	Subphylum	Class	Subclass	Infraclass / Superorder	Order	Family	PSDP	SC	NC
Annelida		Polychaeta					57	17	19
Arthropoda	Crustacea	Hexanauplia	Thecostraca	Cirripedia			1	4	-
Arthropoda	Crustacea	Hexanauplia	Copepoda				577	421	266
Arthropoda	Crustacea	Ostracoda					1813	1117	1219
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Eucarida	Decapoda		5	-	-
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Peracarida	Thermosbaenacea		3	-	-
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Peracarida	Tanaidacea		2	1	-
Arthropoda	Crustacea	Malacostraca	Eumalacostraca	Syncarida			-	1	-
Arthropoda	Crustacea						-	1	-
Arthropoda	Chelicerata	Arachnida	Acari	Acariformes	Trombidiformes	Halacaridae	2	2	1
Chordata	Tunicata						6	-	-
Ciliophora							5	3	6
Cnidaria							20	4	1
Echinodermata							3	1	-
Echinodermata	Echinozoa	Holothuroidea					4	-	-
Foraminifera							5396	2925	4470
Gastrotricha							3	1	-
Gnathostomulida							2	-	-
Kinorhyncha							3	3	-
Mollusca	Aculifera	Aplacophora					-	-	1
Mollusca	Bivalvia						215	142	99
Nematoda							644	354	349
Nemertea							20	1	3
Plathyelminthes		Turbellaria					31	12	14
Rotifera							14	11	1
Sipuncula							7	-	1
Tardigrada							11	7	12

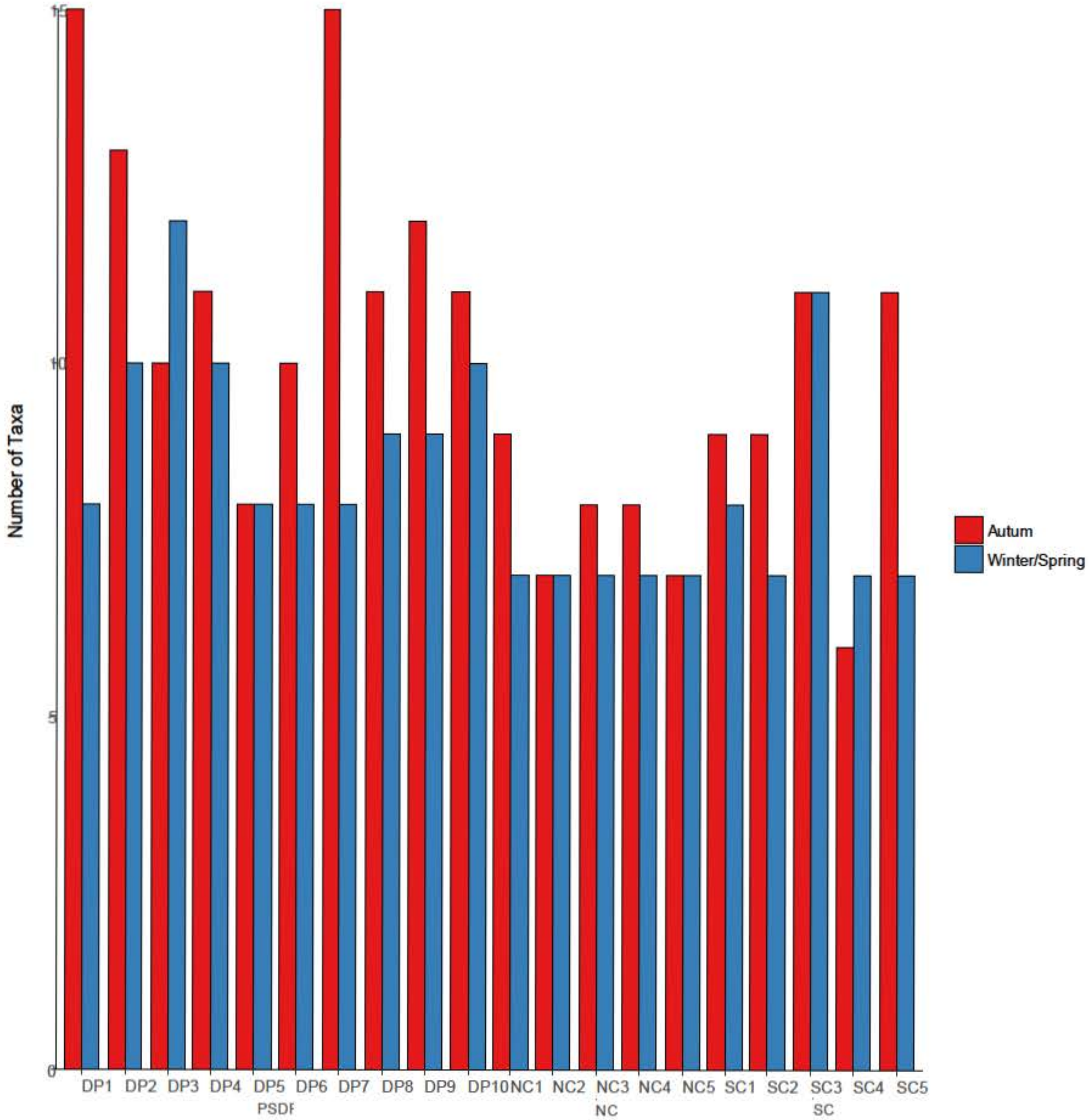

Figure A1: Total number of meiofauna taxa from benthic sediment sampling for locations and sites obtained from sediments in the two 2017 surveys. Desalination Plant (10 sites), North Control (five sites) and South Control (five sites).

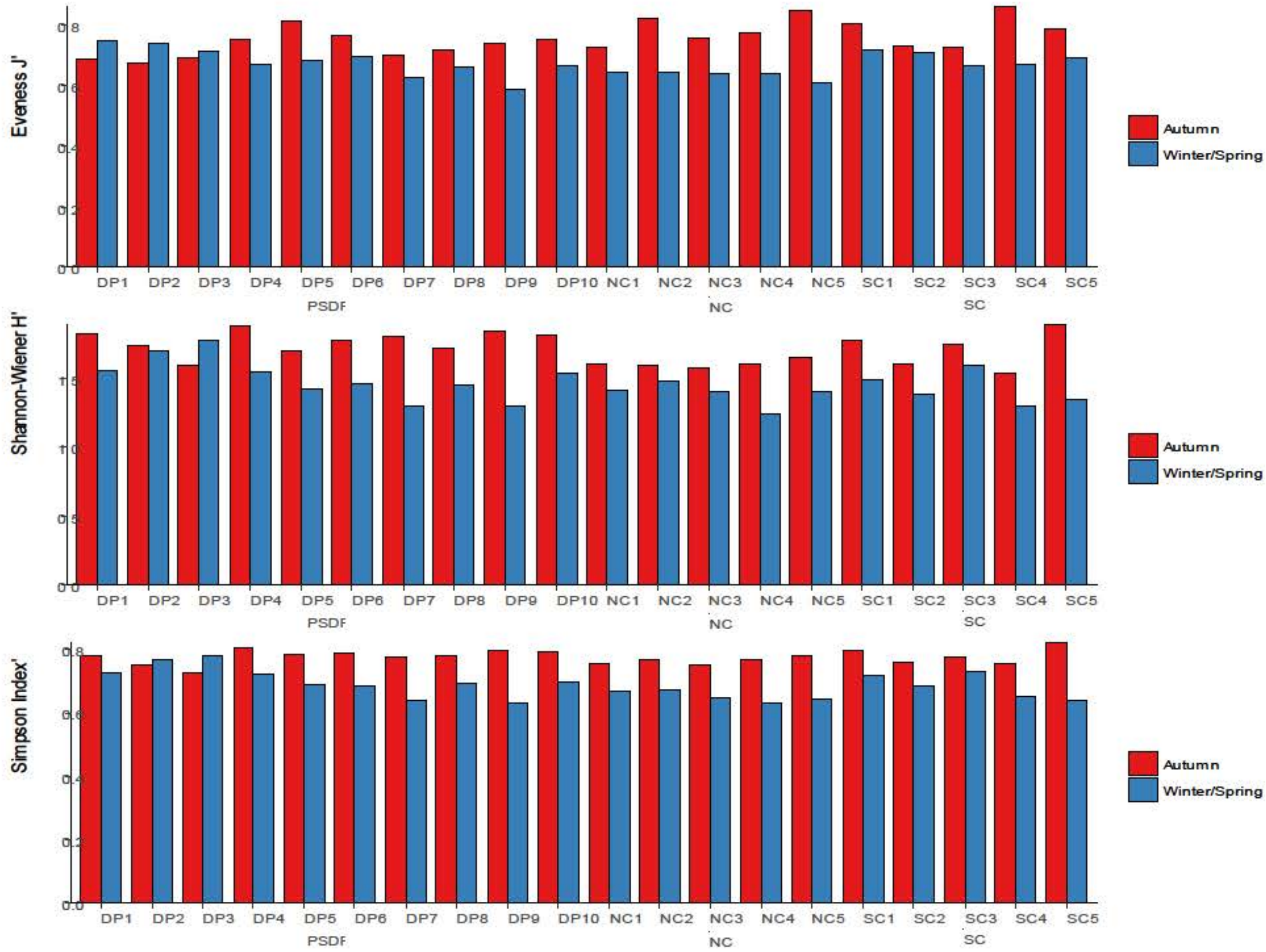

Figure A2: Diversity values for benthic meiofauna from the infauna surveys at all locations and sites in 2017. Values given per Site include three indices; evenness (Pielou's J) and diversity (Shannon-Wiener H' and Simpsons 1-λ'). Desalination Plant (PSDP 10 sites), North Control (NC five sites) and South Control (SC five sites). Note different ranges Y axes across index.

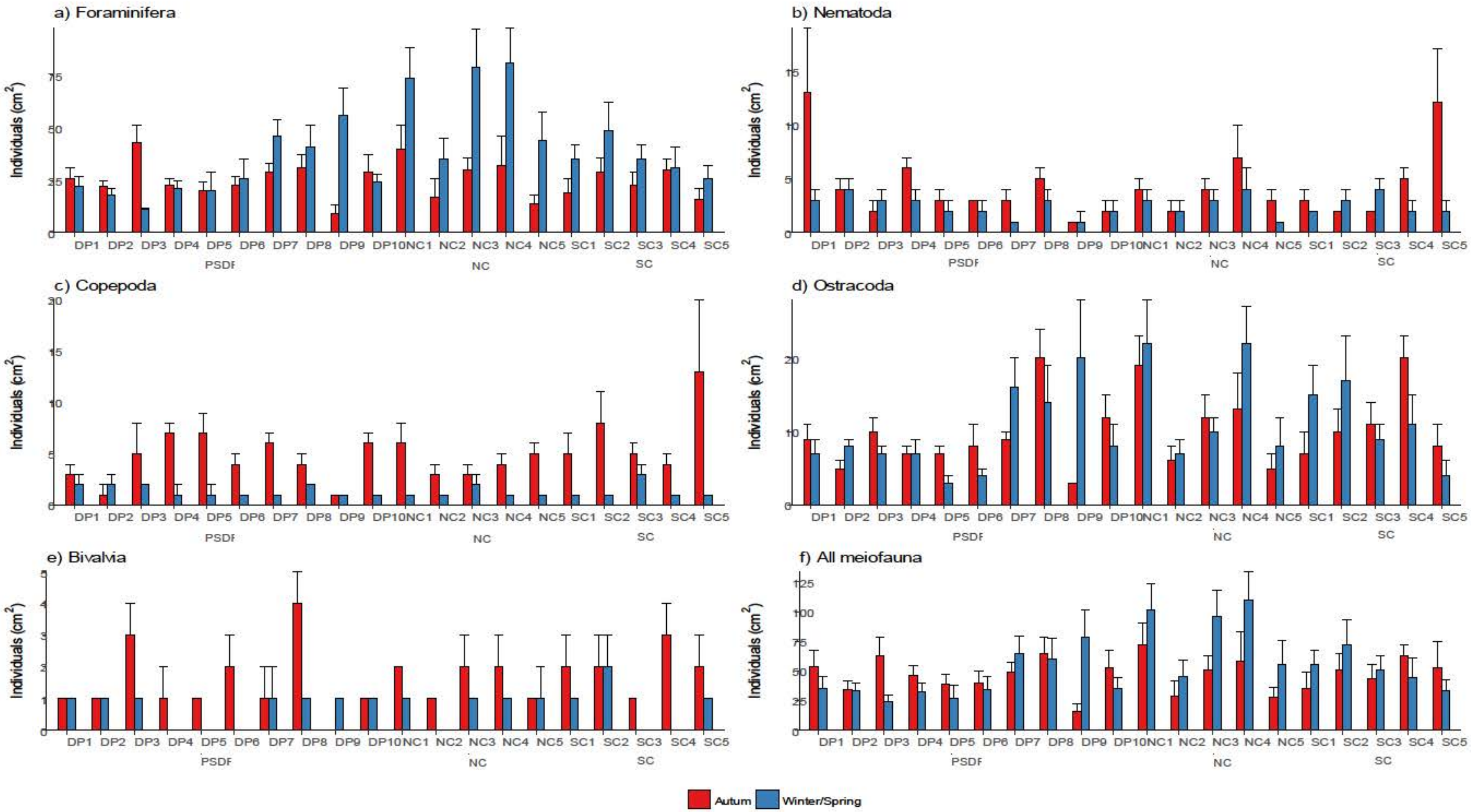

Figure A3: Abundances (mean ± SE) of benthic meiofauna as catch per unit effort for Sites and Locations obtained from sediments in the 2017 survey. Desalination Plant (10 sites), North Control (five sites) and South Control (five sites). Abundances include the main separate taxa found as a) Foraminifera, b) Nematoda, c) Copepoda, d) Ostracoda, e) Bivalvia and f) All benthic meiofauna combined as total abundances. Note different ranges in Individuals (m²) on Y axes across taxa.

Table A3: List and total abundances of macrofauna taxonomic groups from all sites and Locations during the 2017 infauna survey.

Phylum	Class	Subclass	Order	Family	PSDP	SC	NC
Annelida	Polychaeta	Errantia	Amphinomida	Amphinomidae	17	13	18
Annelida	Polychaeta	Errantia	Amphinomida	Euphrosinidae	12	-	-
Annelida	Polychaeta	Errantia	Eunicida	Dorvilleidae	696	56	25
Annelida	Polychaeta	Errantia	Eunicida	Eunicidae	223	152	65
Annelida	Polychaeta	Errantia	Eunicida	Lumbrineridae	3393	913	343
Annelida	Polychaeta	Errantia	Eunicida	Oenonidae	9	-	4
Annelida	Polychaeta	Errantia	Phyllodocida	Aphroditidae	-	-	25
Annelida	Polychaeta	Errantia	Phyllodocida	Glyceridae	49	29	4
Annelida	Polychaeta	Errantia	Phyllodocida	Nephtyidae	577	303	152
Annelida	Polychaeta	Errantia	Phyllodocida	Nereididae	13	-	12
Annelida	Polychaeta	Errantia	Phyllodocida	Phyllodocidae	761	306	169
Annelida	Polychaeta	Errantia	Phyllodocida	Polynoidae	330	-	-
Annelida	Polychaeta	Errantia	Phyllodocida	Sigalionidae	4	13	21
Annelida	Polychaeta	Errantia	Phyllodocida	Syllidae	1242	491	305
Annelida	Polychaeta	Sedentaria	Sabellida	Oweniidae	38	-	-
Annelida	Polychaeta	Sedentaria	Sabellida	Sabellidae	762	317	431
Annelida	Polychaeta	Sedentaria	Sabellida	Serpulidae	-	4	-
Annelida	Polychaeta	Sedentaria	Spionida	Magelonidae	42	-	-
Annelida	Polychaeta	Sedentaria	Spionida	Spionidae	266	163	97
Annelida	Polychaeta	Sedentaria	Terebellida	Ampharetidae	176	33	4
Annelida	Polychaeta	Sedentaria	Terebellida	Cirratulidae	764	108	38
Annelida	Polychaeta	Sedentaria	Terebellida	Flabelligeridae	123	8	45
Annelida	Polychaeta	Sedentaria	Terebellida	Pectinariidae	50	12	-
Annelida	Polychaeta	Sedentaria	Terebellida	Terebellidae	938	360	178
Annelida	Polychaeta	Sedentaria		Capitellidae	4090	1690	703
Annelida	Polychaeta	Sedentaria		Maldanidae	43	24	12
Annelida	Polychaeta	Sedentaria		Opheliidae	347	72	20
Annelida	Polychaeta	Sedentaria		Orbiniidae	106	4	130
Annelida	Polychaeta	Sedentaria		Paraonidae	2398	378	253
Annelida	Polychaeta	Sedentaria		Sabellariidae	13	9	26
Annelida	Polychaeta	Sedentaria		Scalibregmatidae	22	9	4

Phylum	Class	Subclass	Order	Family	PSDP	SC	NC
Annelida	Polychaeta				4	-	62
Arthropoda	Arachnida	Acari	Trombidiformes	Halacaridae	4	-	17
Arthropoda	Hexanauplia	Copepoda			478	683	416
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Amaryllididae	105	16	64
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Ampeliscidae	72	39	71
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Ampithoidae	4	8	4
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Aoridae	314	234	520
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Aristiidae	-	-	17
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Caprellidae	57	20	29
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Corophiidae	4	-	-
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Cyproideidae	-	48	22
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Dexaminidae	2012	1253	770
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Eusiridae	308	83	103
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Haustoriidae	67	111	361
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Hyalidae	1108	179	357
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Isaeidae	1957	482	241
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Lysianassidae	48	9	-
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Pardaliscidae	35	17	13
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Perthiidae	8	-	-
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda	Phoxocephalidae	21	-	4
Arthropoda	Malacostraca	Eumalacostraca	Amphipoda		4	-	-
Arthropoda	Malacostraca	Eumalacostraca	Cumacea	Bodotriidae	28	8	-
Arthropoda	Malacostraca	Eumalacostraca	Cumacea	Ceratocumatidae	-	8	-
Arthropoda	Malacostraca	Eumalacostraca	Cumacea	Diastylidae	28	102	70
Arthropoda	Malacostraca	Eumalacostraca	Cumacea	Gynodiastylidae	-	4	-
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Callianassidae	13	4	-
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Corystidae	-	-	4
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Dromiidae	4	-	-
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Galatheidae	4	4	17
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Hymenosomatidae	250	101	64
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Leucosiidae	163	79	8
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Litocheiridae	-	8	4
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Paguridae	4	-	8

Phylum	Class	Subclass	Order	Family	PSDP	SC	NC
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Penaeidae	4	4	-
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Planopilumnidae	-	-	4
Arthropoda	Malacostraca	Eumalacostraca	Decapoda	Caridea	8	-	-
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Antarcturidae	-	-	4
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Antheluridae	29	53	46
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Arcturidae	4	12	4
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Cirolanidae	12	33	12
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Gnathiidae	9	-	-
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Idoteidae	-	-	4
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Janiridae	34	-	109
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Phoratopodidae	4	4	-
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Plakarthriidae	-	-	4
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Serolidae	4	-	-
Arthropoda	Malacostraca	Eumalacostraca	Isopoda	Sphaeromatidae	4	20	51
Arthropoda	Malacostraca	Eumalacostraca	Mysida	Mysidae	62	17	12
Arthropoda	Malacostraca	Eumalacostraca	Tanaidacea	Apseudidae	1573	2193	471
Arthropoda	Malacostraca	Eumalacostraca	Tanaidacea	Leptocheliidae	39	97	17
Arthropoda	Malacostraca	Eumalacostraca	Tanaidacea	Parapseudidae	13	-	-
Arthropoda	Malacostraca	Eumalacostraca	Tanaidacea	Paratanaidae	80	-	-
Arthropoda	Malacostraca	Phyllocarida	Leptostraca	Paranabaliidae	118	95	143
Arthropoda	Ostracoda				13	93	43
Arthropoda	Ostracoda	Myodocopa	Myodocopida		707	535	434
Brachiopoda	Rhynchonellata		Terebratulida	Terebratellidae	12	4	25
Chordata	Ascidiacea		Aplousobranchia	Holozoidae	8	8	-
Chordata	Ascidiacea		Aplousobranchia	Polyclinidae	8	-	8
Chordata	Ascidiacea		Phlebobranchia	Ascidiidae	68	16	20
Cnidaria				Cnidaria	4	-	4
Echinodermata	Asteroidea		Forcipulatida	Asteriidae	9	-	9
Echinodermata	Echinoidea	Euchinoidea	Camarodonta	Temnopleuridae	134	132	209
Echinodermata	Holothuroidea		Aspidochirotida	Holothuriidae	-	-	4
Echinodermata	Holothuroidea		Synallactida	Stichopodidae	4	-	-
Echinodermata	Ophiuroidea		Ophiurida	Amphiuridae	85	16	45
Echinodermata	Ophiuroidea		Ophiurida	Ophiactidae	-	-	52

Phylum	Class	Subclass	Order	Family	PSDP	SC	NC
Echinodermata	Ophiuroidea		Ophiurida	Ophiomyxidae	33	-	35
Echinodermata	Ophiuroidea		Ophiurida	Ophiotrichidae	4	12	21
Mollusca	Bivalvia	Autobranchia	Pectinida	Pectinidae	20	-	12
Mollusca	Bivalvia	Heterodonta	Adapedonta	Hiatellidae	102	31	18
Mollusca	Bivalvia	Heterodonta	Cardiida	Cardiidae	93	56	12
Mollusca	Bivalvia	Heterodonta	Cardiida	Psammobiidae	16	8	4
Mollusca	Bivalvia	Heterodonta	Cardiida	Tellinidae	874	684	547
Mollusca	Bivalvia	Heterodonta	Cardiida	Semelidae	510	297	79
Mollusca	Bivalvia	Heterodonta	Carditida	Carditidae	22	-	4
Mollusca	Bivalvia	Heterodonta	Carditida	Condylocardiidae	8	178	-
Mollusca	Bivalvia	Heterodonta	Lucinida	Lucinidae	122	270	413
Mollusca	Bivalvia	Heterodonta	Myida	Teredinidae	-	-	4
Mollusca	Bivalvia	Heterodonta	Venerida	Veneridae	1778	477	402
Mollusca	Bivalvia	Heterodonta		Chamidae	-	-	4
Mollusca	Bivalvia	Heterodonta		Laternulidae	63	30	279
Mollusca	Bivalvia	Heterodonta		Mactridae	55	60	25
Mollusca	Bivalvia	Heterodonta		Myochamidae	4	8	4
Mollusca	Bivalvia	Heterodonta	Venerida	Trapezidae	9	4	-
Mollusca	Bivalvia	Palaeoheterodonta	Trigoniida	Trigoniidae	-	4	-
Mollusca	Bivalvia	Protobranchia	Nuculanida	Nuculanidae	26	221	131
Mollusca	Bivalvia	Pteriomorphia	Arcida	Glycymerididae	12	-	42
Mollusca	Bivalvia	Pteriomorphia	Limida	Limidae	169	363	376
Mollusca	Bivalvia	Pteriomorphia	Mytilida	Mytilidae	1139	613	916
Mollusca	Bivalvia	Pteriomorphia	Ostreida	Pinnidae	8	-	25
Mollusca	Bivalvia	Pteriomorphia	Pterioida	Pteriidae	17	29	12
Mollusca	Gastropoda	Patellogastropoda		Lottiidae	108	44	29
Mollusca	Gastropoda	Caenogastropoda	Littotinimorpha	Naticidae	4	-	8
Mollusca	Gastropoda	Caenogastropoda	Littotinimorpha	Rissoinidae	24	-	4
Mollusca	Gastropoda	Caenogastropoda	Neograstropoda	Columbellidae	21	-	-
Mollusca	Gastropoda	Caenogastropoda	Neograstropoda	Nassariidae	8	-	-
Mollusca	Gastropoda	Caenogastropoda		Bittiidae	4	-	4
Mollusca	Gastropoda	Caenogastropoda		Epitoniidae	4	-	-
Mollusca	Gastropoda	Caenogastropoda		Turritellidae	4	4	-

Phylum	**Class**	**Subclass**	**Order**	**Family**	**PSDP**	**SC**	**NC**
Mollusca	Gastropoda	Heterobranchia	Cephalaspidea	Haminoeidae	30	57	16
Mollusca	Gastropoda	Heterobranchia	Cephalaspidea	Philinidae	-	4	-
Mollusca	Gastropoda	Heterobranchia	Nudibranchia		4	-	-
Mollusca	Gastropoda	Vetigastropoda		Scissurellidae	-	-	4
Mollusca	Gastropoda	Orthogastropoda	Sorbeoconcha	Muricidae	4	-	-
Mollusca	Gastropoda	Patellogastropoda		Nacellidae	21	-	16
Mollusca	Gastropoda	Vetigastropoda		Chilodontidae	4	-	-
Mollusca	Gastropoda	Vetigastropoda		Trochidae	57	4	-
Mollusca	Polyplacophora	Neoloricata	Chitonida	Acanthochitonidae	12	16	8
Mollusca	Polyplacophora	Neoloricata	Chitonida	Ischnochitonidae	141	42	55
Mollusca	Polyplacophora	Neoloricata	Chitonida	Mopaliidae	4	-	-
Mollusca	Polyplacophora	Neoloricata	Chitonida	Chitonidae	4	-	4
Mollusca	Polyplacophora				-	-	4
Mollusca	Scaphopoda		Gadilida	Gadilidae	-	52	4
Mollusca	Scaphopoda		Dentaliida	Dentaliidae	-	4	4
Nematoda					-	4	43
Nemertea					107	254	31
Porifera	Calcarea	Calcaronea	Leucosolenida	Leucosoleniidae	13	-	4
Sipuncula	Phascolosomatidea		Phascolosmatida	Phascolosomatidae	17	-	4
Sipuncula	Sipunculidea				4	72	52

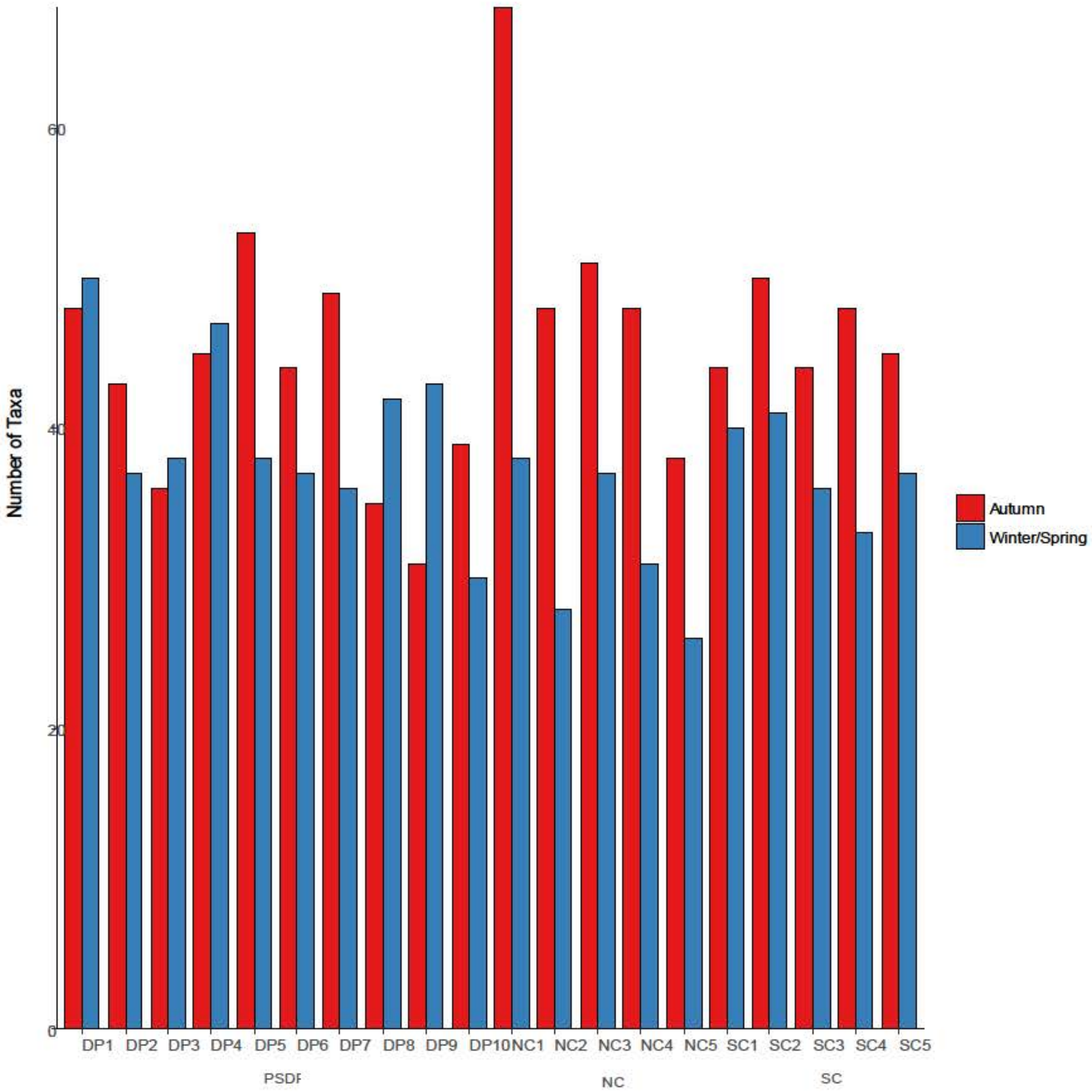

Figure A4: Total number of macrofauna taxa from benthic sediment sampling for locations and sites obtained from sediments in the two 2017 surveys. Desalination Plant (10 sites), North Control (five sites) and South Control (five sites).

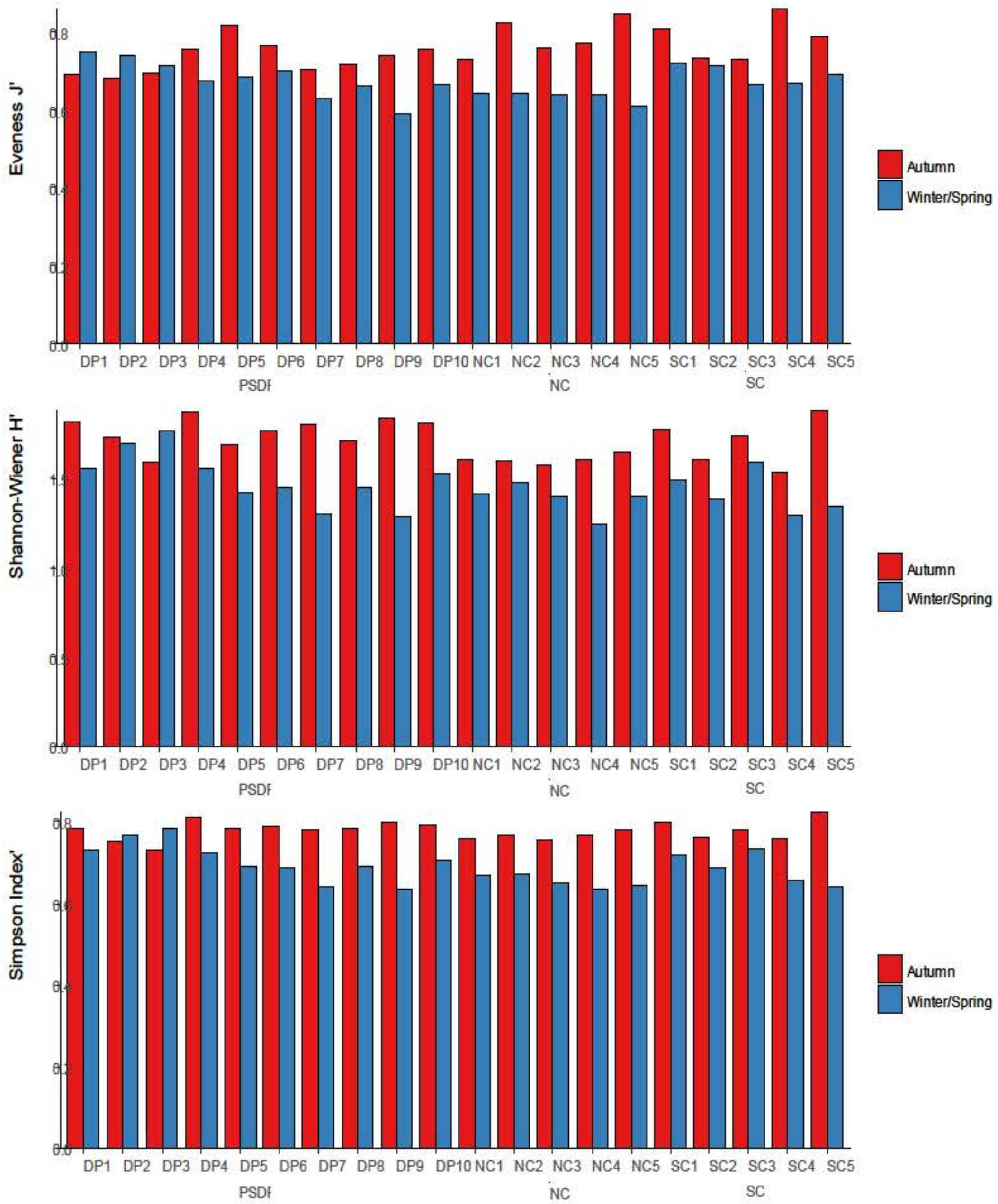

Figure A5: Diversity values for benthic macrofauna from the infauna surveys at all locations and sites in 2017. Values given per Site include three indices; evenness (Pielou's J) and diversity (Shannon-Wiener H' and Simpsons 1-λ'). Desalination Plant (PSDP 10 sites), North Control (NC five sites) and South Control (SC five sites). Note different ranges Y axes across index.

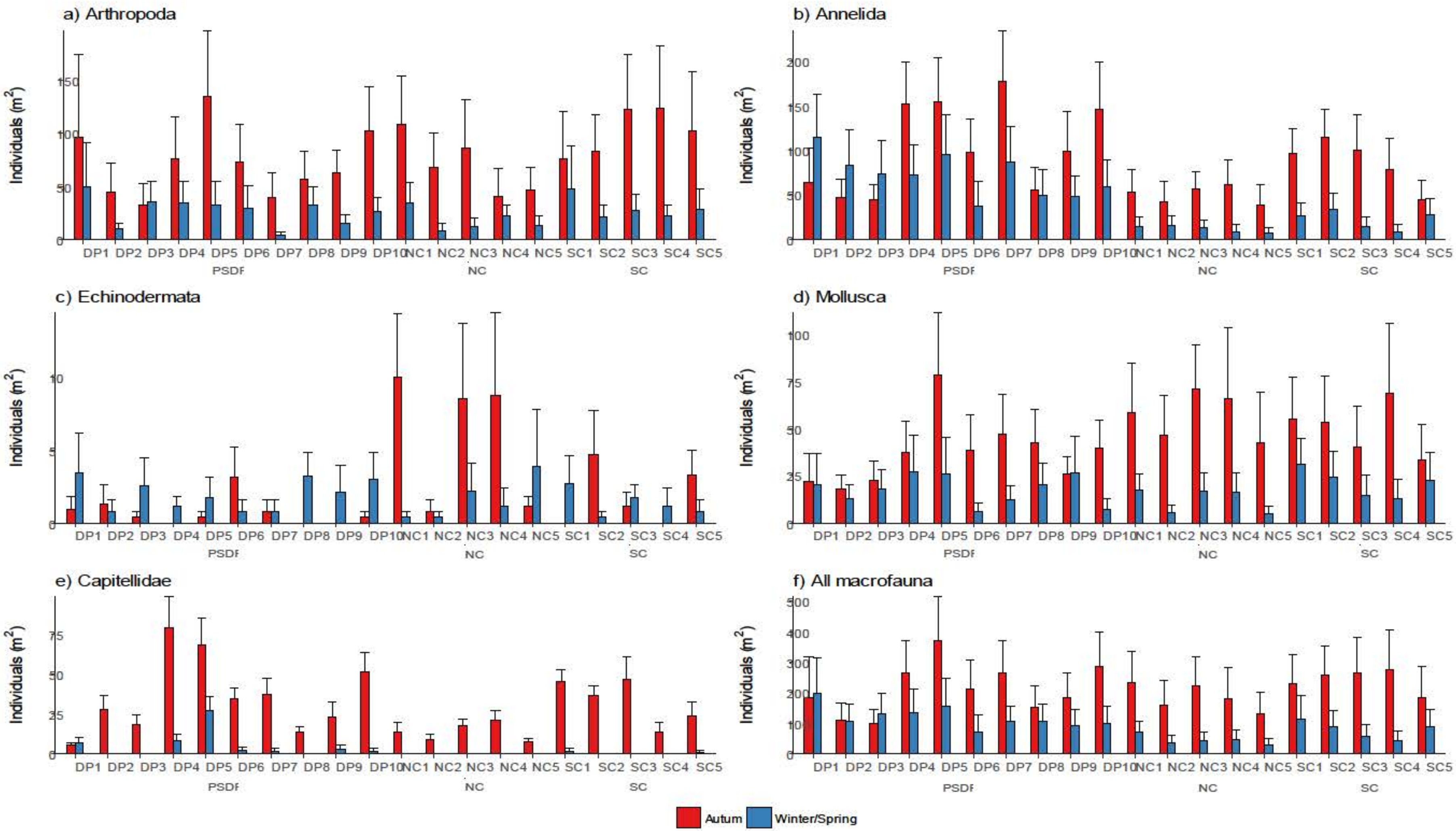

Figure A6: Abundances (mean ± SE) of benthic macrofauna for Sites and Locations obtained from sediments in the 2017 survey. Desalination Plant (10 sites), North Control (five sites) and South Control (five sites). Abundances include the main separate taxa found as a) Arthropoda, b) Annelida, c) Echinodermata, d) Mollusca e) the environmental indicator of Capitellidae, and f) all macrofauna combined as total abundances. Note different ranges in Individuals (m^2) on Y axes across taxa