Biodiversity and habitat characteristics of intertidal and estuarine mudflats of the Fleurieu Peninsula and Gulf St. Vincent

Report for the DEH and AMLNRM

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1. Executive summary

- The objectives of this investigation were to assess the biodiversity of benthic macrofauna in intertidal soft sediments of estuaries and mudflats of the Fleurieu Peninsula and Gulf St. Vincent in conjunction with characterising the habitats at the respective sampling sites. Four estuaries and five tidal flats were selected for this study. This was the first comprehensive survey of intertidal soft-sediment biodiversity in this region and will provide a baseline for future studies and monitoring.
- Sampling was carried out in the summer of 2006/07, with additional sampling in the estuaries of the Fleurieu Peninsula and on Section Bank in spring 2007. This was necessary as, apart from the Onkaparinga, estuaries were closed during the dry summer; however the winter rainfall had not been sufficient for the rivers to breach the barriers to the adjacent sea. A stratified random sampling design was chosen to investigate the benthic assemblages associated to specific sediment types or biogenic structures. In total, 160 benthic samples were taken. Several parameters for water quality and sediment characteristics were measured and analysed to characterise the habitats.
- Salinities ranged from brackish in some of the estuaries to values above marine salinities in some of the mudflats. Oxygen concentrations and saturation were lower in the estuaries than the exposed mudflats. Ammonium and phosphate concentrations in the water exceeded the ANZECC values for stressors in almost all cases. Sediments were mainly fine to medium sands, with variable contents of organic matter and low microphytobenthic biomass.
- In total, 93 morphospecies were differentiated at the studied sites, but diversity was significantly higher in the tidal flats of the Gulf St. Vincent than in the estuaries of the Fleurieu Peninsula. Polychaetes and molluscs were richest in species, and several insect larvae were found in the estuaries. The highest species diversity index was recorded for Section Bank, which also had the highest species richness together with Coobowie.
- Abundances varied greatly between sites, from almost no macrofauna found in the Inman River estuary in September 2007 to 17618 individuals m^{-2} recorded at Coobowie. The estuary of the Hindmarsh River as well as the mudflats at Port Gawler and Coobowie had the highest abundances, partly due to the occurrence of mussel beds at the latter two sites. Capitellid polychaetes, chironomid insect larvae, amphipods and the micromollusc *Arthritica helmsi* accounted for differences in abundances of the estuaries. Larger polychaete specimens of the family Nereididae and the large bivalve *Soletellina alba* were found at the Hindmarsh estuary. The mudflats around the Gulf St.Vincent were much more particular in their species composition, especially for the polychaetes, and a greater range of taxa was recorded (Nemertinea, Sipunculida, endobenthic anthozoa and holothurids). There were inconsistent patterns of species diversity and individual densities found at the sites, as some sites characterised by higher diversity were poor in abundances.

- Multivariate community analyses showed no significantly different assemblages at the estuaries around the Fleurieu Peninsula, whereas the mudflats around the Gulf St. Vincent were quite distinct. The occurrence of mussel beds caused a higher similarity of benthic communities between Port Gawler and Coobowie, and Section Bank was also very distinct to the other sites. Characteristic species for the five mudflat sites are detailed in this report. Analysed across all 11 sites, significant differences emerged in benthic communities of the estuaries and open mudflats of the Gulf St Vincent. Insect larvae, several polychaete families, and the snail *Salinator fragilis* contributed to these differences.
- Benthic biomass was determined only for the sites sampled in spring 2007. The biomass at Section Bank was 16 x higher than at the estuaries, which had partly negligible amounts of biomass.
- This study revealed idiosyncrasies of tidal flat communities on a regional scale, which has implications for the design of a comprehensive and representative network of reserves. Within site heterogeneity also implies the need to protect extensive areas of tidal flats.

2. Introduction

Marine sediments constitute the largest habitat on Earth with an as yet unknown diversity of organisms (Snelgrove 1998). Nearshore soft sediments have been more intensively studied than the deep sea and revealed important links between benthic biodiversity and ecosystem functions (Snelgrove et al. 1997; Hall et al. 2000; Raffaelli et al. 2003). In estuaries and tidal flats in particular, benthos contributes to biogeochemical exchange processes in such critical transition zones (Levin et al. 2001). An understanding of species and functional diversity in coastal sedimentary environments is therefore crucial to evaluate linkages between catchments and coastal seas. Furthermore, assessing benthic communities is an important step for the protection of coastal wetlands and planning of Marine Parks (Banks & Skilleter 2002, Roff et al. 2003, Stevens & Connolly 2004). This is specifically relevant in an area like the Gulf St. Vincent where wetlands are subject to a range of environmental pressures (Edyvane 1999).

Intertidal habitats around the Gulf St. Vincent comprise rocky shores, beaches and tidal flats, which have a unique flora and fauna each (Benkendorff et al. 2008). The estuaries around the Fleurieu Peninsula and Gulf St. Vincent are river-, wave- or tide-dominated and vary considerably in size (Gillanders et al. 2008). Almost all have an urbanised or agriculturally used hinterland, and such catchment activities are known to affect the estuarine water quality and habitats (Valiela 2006).

The mapping of benthic habitats and establishment of links between diversity and habitat types can be a useful tool for monitoring and detecting changes in a system (Hewitt et al. 2004). Criteria for classifying intertidal benthic habitats include sediment characteristics (grain size, organic matter, Chlorophyll-a), geomorphology or exposure (Dyer 1998). Biotic parameters include species richness and density. As taxonomic problems are often encountered with benthic invertebrates, approaches have been explored to use higher taxonomic levels or habitat characteristics as surrogates for diversity (Olsgard & Somerfield 2000, Terlizzi et al. 2003, Stevens & Connolly 2004). However, these turned out to be not reliable enough to indicate certain habitat conditions and differentiate benthic communities, and abiotic surrogates such as sediment properties do not fully explain the distribution of species (Olsgard & Somerfield 2000, Freeman & Rogers 2003, Stevens & Connolly 2004). Taxonomically, organisms should be identified at least to family level and quantitative studies are needed to evaluate associations with habitats and possible changes (Terlizzi et al. 2003, Thrush et al. 2003).

The objectives of this study were to survey the macrobenthic biodiversity and benthic communities of intertidal sand- and mudflats around the Fleurieu Peninsula and Gulf St. Vincent and to assess the prevailing habitat characteristics at each site. Findings from this study will form a base for the inclusion of intertidal soft sediment habitats in marine planning.

3. Material and Methods

3.1 Study sites and sampling design

The investigation covered a total of nine sites, located around the Gulf St. Vincent (five sites) and Fleurieu Peninsula (four estuaries) (Figure 1, Plate 1). The sampling sites ranged from narrow mudbanks in some estuaries to extensive tidal flats at the northern end of the Gulf (Table 1). They were confined to muddy and sandy intertidal areas (up to knee-deep water) and did not include seagrass beds. Detailed habitat characteristics of individual study sites are given separate site pamphlets.

Sampling was carried out over the summer of 2006/2007. However, as the estuaries around the Fleurieu Peninsula were closed at the time of sampling following a severe drought, these estuaries as well as Section Bank were sampled again in spring 2007 (Table 1). Yet, the winter rain was not enough to breach the barriers and open the estuaries, but seawater might have flushed in at high tides.

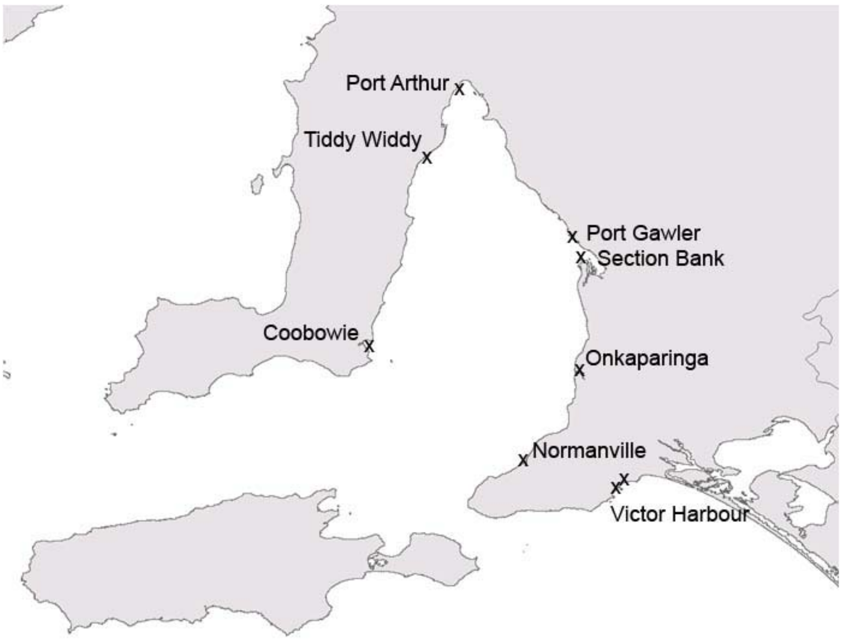

Figure 1: Map of Gulf St. Vincent with the Fleurieu and Yorke Peninsula, showing the location of the sites sampled in the survey over summer 2006/07 and spring 2007. Two sites were sampled in Victor Harbour, the Hindmarsh and Inman River estuaries. In Normanville, the estuary of the Bungala River was sampled. The Onkaparinga estuary is located in Port Noarlunga.

Plate 1: Photos of the study sites at the Fleurieu Peninsula and Gulf Saint Vincent.

Table 1: Sampling dates and GPS positions of the estuaries and tidal flats surveyed over summer 2006/07 and spring 2007.

site	sampling dates	GPS position S	GPS position E
Fleurieu Peninsula			
Hindmarsh River (Victor Harbour)	27.2.07 / 19.9.07	35º32'636"	138º37'846"
Inman River (Victor Harbour)	27.2.07 / 19.9.07	35º33'699"	138º36'683"
Bungala River (Normanville)	27.2.07 / 19.9.07	35º26'865"	138º18'418"
Onkaparinga	21.2. 07 / 17.9.07	35º09'671"	138º28'281"
Gulf St. Vincent			
Section Bank	8.3.07 / 27.11.07	34º45'230"	138º30'296"
Port Gawler	12. & 19.12.06	34º39'139"	138º26'310"
Port Arthur	3.1.07	34º08'982"	138º03'871"
Tiddy Widdy (Ardrossan)	4. & 5.1.07	34º24'499"	137º56'315"
Coobowie Bay	5.1.07	35º03'817"	137º44'165"

The sites differed in size and in the presence of habitats (Table 2). A stratified random sampling approach was taken to cover possible spatial variation in benthic communities with changes in elevation, sediment properties, or presence of biogenic structures (such as mussel beds). For this design, the selection of environmental strata or different microhabitats followed from an initial visual inspection of habitat patterns present. The number of replicate samples per strata was adjusted to the spatial extent of the respective habitat. This and the overall size of the intertidal area available for sampling caused variation in the total number of samples taken per site (Table 3). As a requirement had been to exclude seagrass beds, site selection on the Gulf St. Vincent coast was not easy, as many intertidal and shallow subtidal areas are covered in dense seagrass beds.

Table 2: Habitats present (denoted by X) in the sampling areas of the estuaries and tidal flats surveyed over summer 2006/07 and spring 2007. Samples were only taken in the exposed unvegetated soft sediments and in mussel beds.

site	Habitats present					
	Sand-& mudflat	Mussel beds	Seagrass	Algal mats	Mangrove	Creeks
Fleurieu Peninsula						
Hindmarsh River	X					X
Inman River	X			X		X
Bungala River	X			X		X
Onkaparinga	X		X			X
Gulf St. Vincent						
Section Bank	X		X	X	X	X
Port Gawler	X	X	X	X	X	X
Port Arthur	X		X		X	X
Tiddy Widdy	X					
Coobowie Bay	X	X	X			

3.2 Sampling methods and sample analysis

To characterize the habitat and benthic communities at the sites, both environmental and biotic data were recorded. Water temperature, salinity, oxygen and nutrient concentrations were determined in the overlying water column next to the sampling sites. Samples for nutrient concentrations and Chl-a as an indicator for phytoplankton biomass were taken at most sites, as this could vary with the respective catchments of estuaries. Sediment characteristics describe habitat conditions for endofauna living in the sediments, and parameters determined include grain size and organic matter, as well as Chlorophyll-a as a proxy for microphytobenthic biomass (this includes benthic diatoms and other photosynthetically active microorganisms which constitute the main primary producers in otherwise unvegetated sediments). Sediment samples taken for benthos were analysed for species diversity, abundance and biomass (only a few sites in spring 2007). Further detailed taxonomic work is needed on several invertebrate taxa and a complete species list will be provided at a later date after confirmation of identifications with museum staff. An overview on the entire sampling scheme is given in Table 3.

Table 3: Overview of the amount of samples taken at each site in the estuaries and tidal flats surveyed over summer 2006/07 and spring 2007. Note that the spatial extent of the sites differed and the number of replicates was adjusted respectively. PSU=practical salinity units; o.m.=organic matter; n=number of replicates.

site	sampling dates	water samples			sediment characteristics			benthic samples	
		°C., O_2-conc., O_2-%, PSU	nutrients	Chl-a	grain size	o.m.	Chl-a	replicates per strata	total n
Fleurieu Peninsula									
Hindmarsh	Feb-07	√	3	4	3	3	4	3	9
	Sep-07	√	3	3	3	3	3	3	9
Inman River	Feb-07	√	3	4	3	3	4		5
	Sep-07	√	3	3	3	3	3		5
Bungala River	Feb-07	√	3	4	3	3	4	3	6
	Sep-07	√	3	3	3	3	3	3	6
Onkaparinga	Feb-07	√	3	6	9	9	9	5	15
	Sep-07	√	3	7	9	9	9	5	15
Gulf St. Vincent					9	9			
Section Bank	Mar-07			3	3	9	9	5-6	16
	Nov-07	√	9	9	9	9	9	6	18
Port Gawler	Dec-06	√	3	3	9	9	9	4, 6	16
Port Arthur	Jan-07	√			12	12	12	3-6	15
Tiddy Widdy	Jan-07	√			6	6	6	3-4	13
Coobowie Bay	Jan-07	√	3	3	8	8	8	6	12

Water characteristics

Temperature, salinity, conductivity and oxygen (concentration and saturation) were measured in the water column at least 10 cm above the sediment with a YSI 85 electrode and data recorded in the field. At some sites, when readings for parameters would not stabilise, several recordings were taken and mean values presented.

For nutrient concentrations, three replicate water samples were collected in plastic bottles (250 ml). These samples were frozen until being analysed photometrically with an Aquaspex LF 2400 Nutrient Analyser.

For phytoplankton Chlorophyll-a, each sample consisted of 100 ml water (taken by filling a 50 ml syringe twice) filtered through a Whatman GF/C Filter. Each filter was placed in a vial with 5 ml methanol, wrapped in alufoil, and frozen until further analysis. Chl-a concentrations were determined using a Turner 450 fluorometer. To correct for phaeophorbides, 0.01 M HCl was added to the samples and a second reading taken.

Sediment characteristics

For grain size, samples were taken using a cut-off 20 ml syringe as corer to 3-5 cm sediment depth. Sediment was transferred into plastic bags and frozen until further analysis. The frequency of particle sizes was analysed by laser diffraction with a Malvern Mastersizer 2000, and median and sorting coefficients calculated.

For sediment organic matter (as a bulk parameter for available carbon and nutrients in the sediments), samples were taken using a cut-off 3 ml syringe as corer to 1 cm sediment depth. These samples were also stored frozen in individual plastic bags. The organic matter content was determined by combustion, after drying samples for 24 hrs at 80 °C, followed by combustion at 450 °C for 4 hrs, and is expressed in % dw.

To evaluate sediment Chl-a, the thread height of 5 ml vials was inserted to about 1 cm in the sediment. The vials were then filled up with methanol, thoroughly shaken, wrapped in alufoil and frozen until further analysis (see above for Chl-a analysis) (Seuront & Leterme 2006).

Benthos samples

Sediment samples for benthos were collected with a corer of 10.4 cm diameter (85 cm^2 surface area), which was inserted to about 15-20 cm sediment depth, depending on the substrate quality (e.g. impossible to push corer through shell grit layers). Samples were sieved in the field through a sieve of 0.5 mm mesh size, and sorted live within the next few days. Specimens were pickled in ethanol for later taxonomic identification. Taxonomic resolution of identifications accomplished so far varies with phyla, reflecting the availability of taxonomic keys or other literature. Amphipoda and several other crustaceans were not identified beyond the class level, while polychaetes were identified to family and mostly genus. Further taxonomic work is in progress and several identifications will be confirmed by museum staff. The voucher specimens will also be deposited at the SA Museum.

Biomass

Macrobenthic biomass was determined when the estuaries around the Fleurieu Peninsula and Section Bank were sampled again in spring 2007. Following species identification and counting, specimens were grouped into major phyla and dried an oven at 80 ºC for at least 24 hours to a constant dry weight (d.w). The weight of each sample was then recorded before being placed in the muffle furnace at 450 ºC for 4 hrs. At this temperature, smaller gastropods were burned with shell, but the larger bivalves were removed from their shells. Samples were allowed to cool in a desiccator before weighing. Samples were then re-weighed to determine the total biomass as ash free dry weight (AFDW) of each phylum.

3.3 Data analysis

Diversity characteristics calculated included species number (S), species richness (Margalef's index d), eveness (Pielou's index J') and the Shannon-Wiener diversity index H' (log e). These analyses were carried out with the PRIMER v6 software.

Abundance and biomass data were tested for normality using the Kolmogorov-Smirnoff and Shapiro-Wilks test, and homogeneity of variance was tested with Levene's test. If both assumptions could be met after square root or log-transformation, one- or two way ANOVA were carried out to test for significant differences in abundances at the sites sampled within a location, or between regions, sites, subsites and months. If normality could not be achieved by transformation, non-parametric data analysis was carried out (Mann-Whitney U-test or Kruskal-Wallis H-test). These data analysis were performed using SPSS v14.

Community analysis to explore similarity in the species composition and their abundances within or between sites was performed using PRIMER v6. The multivariate analyses carried out include calculation of Bray-Curtis similarity and subsequent multidimensional scaling (resulting in a Multidimensional Scaling (MDS) plot) or cluster analysis (resulting in a dendrogram). Data were square root transformed unless indicated otherwise. If many outliers were encountered, this was usually due to replicate samples containing no specimens. These replicates were omitted from the analyses. Comparisons of communities across sites and over months were also carried out based on the mean values of the respective number of replicate samples per site. To test for statistical differences of communities, ANOSIM (Analysis of Similarity) was performed, either one way across sites or two way across sites and months. SIMPER analysis was carried out to identify discriminating species for differentiated benthic assemblages.

4. Results

4.1 Environmental conditions

4.1.1 Water quality

The survey took place during one of the hottest and driest summers in South Australia, and water temperatures exceeded 24 ºC at all sites, reaching up to 33 ºC (Table 4). In the open sand- and mudflats of the Gulf St. Vincent, salinities were higher than normal marine salinities. Apart from the Onkaparinga, the smaller estuaries sampled around the Fleurieu Peninsula were closed at the time of sampling in summer, and salinities respectively lower. Oxygen concentrations and saturation were lower at the estuaries around the Fleurieu Peninsula than in the water overlying the mudflats in the open tidal flats of the Gulf, where oversaturation was common (Table 4).

This general pattern did not change much when the estuaries and Section Bank were sampled again in spring 2007. Apart from lower water temperatures, as expected for the season, the salinities had dropped in the Inman and Bungala River. In the Inman, oxygen concentrations and saturation were twice as high as in the preceding summer. In all other cases, oxygen and salinity conditions were similar at the two sampling occasions.

Table 4: Water quality parameters recorded with a multiprobe in the overlying water at the study sites during the surveys in summer 2006/07, and spring 2007 (shaded, not all sites sampled again). The electrode was not available while sampling Section Bank in March. Port Gawler was sampled twice in December 2006.

Site	Sampling date	Temperature °C	O_2 concentration mg/l	O_2 saturation %	Salinity PSU
Fleurieu Peninsula					
Hindmarsh River	Feb. 07	24.6	5.4	72	15.4
	Sep. 07	15.7	6.9	75	13.8
Inman River	Feb. 07	30.0	3.3	46	29.0
	Sep. 07	18.0	6.4	72	10.2
Bungala	Feb. 07	24.3	7.8	111	30.3
	Sep. 07	18.9	6.5	90	18.8
Onkaparinga	Feb. 07	25.8	7.5	114	37.4
	Sep. 07	15.7	7.6	95	36.1
Gulf St. Vincent					
Section Bank	Nov. 07	30.0	6.5	124	39.8
Port Gawler	Dec. 07	27.1	11.4	180	46.1
	Dec. 07	31.5	9.5	168	51.4
Port Arthur	Jan. 07	32.6	9.1	158	41.1
Tiddy Widdy	Jan. 07	33.0	7.9	139	38.7
Coobowie Bay	Jan. 07	26.4	9.7	146	38.4

Nutrient concentrations in the overlying water or nearby creeks of the studied estuaries and mudflats were in general low (Table 5), with low concentrations for the nitrogen oxides, apart from a very high nitrate concentration in the Inman River estuary in spring. Ammonium and phosphate levels exceeded the ANZECC (2000) threshold for stressors in almost all cases.

Table 5: Nutrient concentrations (mg l^{-1}) in the overlying water at the study sites during the surveys in summer 2006/07, and spring 2007 (shaded, not all sites sampled again). Water samples for nutrients were not taken at two of the Yorke Peninsula sites in Gulf St. Vincent. Values at or above the trigger values for stressors according to the ANZECC Water Quality Guidelines (2000) are highlighted in bold.

Site	Sampling date	Nitrate NO_3^-	Nitrite NO_2^-	Ammonium NH_4^+	Phosphate PO_4^{3-}
Fleurieu Peninsula					
Hindmarsh River	Feb	0	0.01	**0.1**	**0.13**
	Sep	0	0	**0.06**	**0.13**
Inman River	Feb	0	0	0.04	**0.1**
	Sep	**1.1**	0.04	**0.17**	**0.13**
Bungala	Feb	0	0.03	**0.06**	0
	Sep	0	0.01	**0.25**	**0.3**
Onkaparinga	Feb	0	0	**0.05**	0.01
	Sep	0.01	0.04	0.02	0.09
Gulf St. Vincent					
Section Bank	Nov	0.02	0.01	**0.1**	**0.1**
Port Gawler	Dec	0	0	**0.08**	**0.2**
Coobowie Bay	Jan	0	0	0.03	**0.1**

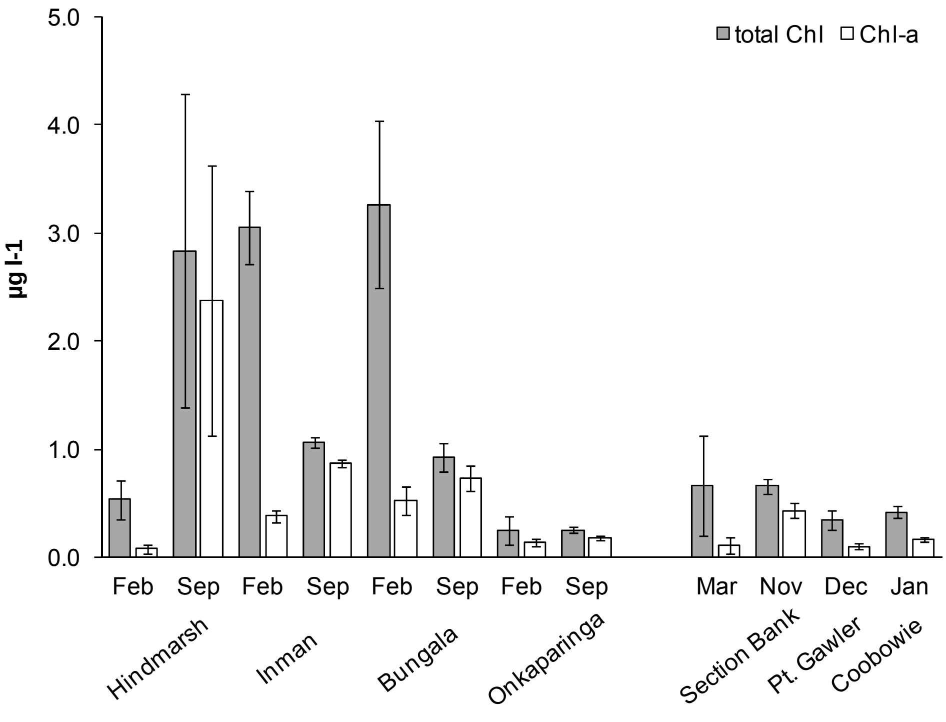

Figure 2: Chlorophyll concentrations (total pigment content and Chlorophyll-a) in the water column at study sites of the Fleurieu Peninsula and Gulf St Vincent. Some of the sampling sites were surveyed in summer 2006/07 and spring 2007.

Chlorophyll concentrations were lower than 1 µg l^{-1} at most sites (Figure 2) yet reached around 3 µg l^{-1} on average at the estuaries in the lower Fleurieu at one of the two sampling months. These higher values are corresponding to yellow-green water colours observed in the field and may be indicative of phytoplankton blooms.

4.1.2 Sediment characteristics

Sediments in the estuaries of the Fleurieu Peninsula consisted predominantly of fine and medium sands, with moderate sorting, indicating some slight spread in the grain size distribution. There was very little variation in these grain size attributes within the sites or over time (Table 6). In the Gulf St. Vincent, Section Bank and Tiddy Widdy Beach were characterised by fine sands, with some larger particles mixed in. The inclusion of larger shell fragments was even more pronounced at Port Gawler and Port Arthur, which had medium to coarse sands. Coobowie Bay consisted of medium sand, yet again with a larger spread of particles of all size classes as indicated by the poorer sorting.

The organic matter content in the sediments was low at the estuaries of the Fleurieu Peninsula, apart from higher values at the muddier site 1 at the Onkaparinga estuary (Table 7). Several of the sampling sites in the mudflats around the Gulf had higher values, which may result from possible seagrass or algal detritus in the sediment. There were no clear patterns between organic matter contents and grain size or habitat sampled. The high value recorded in the cockle bed at Port Gawler is an unexplained outlier.

Table 6: Sediment grain size distribution at the study sites, including different locations sampled within sites with more extensive intertidal soft sediment habitats. Not all sites were sampled twice. In November, mean values are presented from three replicate samples taken at random across the studied subsites on Section Bank. The table shows the percentages of the various grain size fractions (with the dominant fraction highlighted in bold), the median grain size with its verbal description, and the sorting coefficient. VCS=very coarse sand; CS=coarse sand; MS=medium sand; FS=fine sand; VFS=very fine sand; VCSilt= very coarse silt.

					grain sizes (µm)							
Location	Site/Time	>1000 VCS	>750 CS	>500 CS	>250 MS	>125 FS	>62.5 VFS	>3.9 VCSILT	>0.02 clay	Median	Verbal Description	Sorting
Fleurieu Peninsula												
Hindmarsh	Feb	1.29	0.02	4.91	**45.98**	39.76	4.74	3.20	0.12	**255**	Medium Sand	Moderately Well - Moderately
	Sep	1.43	1.36	10.64	**46.94**	36.56	4.36	0.00	0.00	**285**	Medium Sand	Moderately Sorted
Inman	Feb	1.24	0.64	2.48	33.59	**46.92**	15.20	1.16	0.00	**232**	Fine Sand	Moderately Sorted
	Sep	0.00	0.00	0.14	15.21	**48.56**	32.82	3.16	0.00	**241**	Fine Sand	Moderately Sorted
Normanville	Feb	1.94	1.27	8.33	**35.74**	28.97	7.74	16.29	0.98	**230**	Fine Sand	Well - Moderately
	Sep	1.58	1.58	20.34	**61.95**	16.03	0.09	0.00	0.00	**371**	Medium Sand	Moderately Sorted
Onkaparinga	S 1 Feb	0.69	0.09	0.89	18.75	**52.66**	20.68	6.23	0.09	**173**	Fine Sand	Moderately
	S 2 Feb	0.55	0.55	4.84	30.63	**37.90**	11.52	13.28	1.26	**205**	Fine Sand	Moderately Well
	S 3 Feb	0.22	0.22	9.65	**49.87**	29.29	4.61	6.06	0.30	**280**	Medium Sand	Moderately Well - Moderately
	mean Feb									**220**	Fine Sand	
	S 1 Sep	15.23	1.20	2.79	12.15	22.67	16.39	**26.29**	4.33	**135**	Fine Sand	Very Well - Well
	S 2 Sep	0.00	0.00	6.25	**67.47**	25.87	0.38	0.00	0.00	**318**	Medium Sand	Moderately Sorted
	S 3 Sep	2.85	0.30	3.99	31.36	**34.02**	10.56	15.48	1.62	**205**	Fine Sand	Well - Moderately
	mean Sep									**220**	Fine Sand	
Gulf St Vincent												
Section Bank	S 1 Feb	17.22	1.64	2.92	32.74	**35.39**	2.40	8.32	0.96	**274**	Medium Sand	Well - Moderately Well
	S 2 Feb	9.53	0.89	2.63	29.90	**31.82**	6.30	17.61	2.15	**219**	Fine Sand	Well - Moderately Well
	S 3 Feb	3.67	0.20	2.09	33.46	**41.46**	8.25	10.16	0.86	**217**	Fine Sand	Moderately Well - Well
	mean Feb									**237**	Fine Sand	
	mean Nov	7.00	0.37	3.79	**46.96**	37.89	2.89	1.06	0.04	**275**	Medium sand	Moderately sorted
Port Gawler	sandbank	2.90	6.98	19.79	**23.71**	12.48	14.09	0.62	0.00	**264**	Medium Sand	Very Well - Moderately Well
	mussel bed	13.58	2.23	6.58	11.63	12.96	**19.95**	8.41	0.38	**400**	Medium sand	Very Well Sorted
	cockle bed	**18.03**	10.52	11.79	14.36	10.96	6.84	2.93	0.02	**932**	Coarse Sand	Very Well - Well

	mean									**532**	Coarse Sand	
Pt Arthur	S 1a	13.45	12.96	**27.64**	19.19	8.60	16.74	1.34	0.00	**272**	Medium Sand	Very Well - Moderately Well
	S 1b	27.64	18.15	**31.27**	13.94	1.89	6.52	0.56	0.00	**459**	Medium Sand	Moderately Well
	S1b2	8.25	15.45	**36.89**	27.13	5.97	6.17	0.07	0.00	**303**	Medium Sand	Moderately Well
	S 1c	0.38	0.27	5.88	**39.65**	39.64	13.36	0.50	0.00	**119**	Very Fine Sand	Moderately Well - Moderately
	mean									**288**	Medium Sand	
Tiddy Widdy	mid-high	7.16	2.46	6.33	24.25	**37.14**	8.42	18.76	0.22	195	Fine Sand	Moderately Well
	low	4.73	3.02	7.08	20.30	**39.96**	23.91	3.80	0.00	182	Fine Sand	Moderately Well
	mean									**189**	Fine Sand	
Coobowie	mussel bed	15.63	2.12	8.40	**26.90**	20.99	13.46	14.02	0.48	**258**	Medium Sand	Well - Moderately Well
	sandflat	12.81	2.40	10.44	**29.53**	18.08	12.03	16.56	0.48	**270**	Medium Sand	Well - Moderately Well
	mean									**264**	Medium Sand	

Table 7: Organic matter content (mean and standard error SE) in the sediments at the study sites, including different locations sampled within sites with more extensive intertidal soft sediment habitats. Not all sites were sampled twice. For Section Bank from November the mean value is presented of three replicate samples taken at random across the subsites.

		organic matter [% dw]	
Location	Site/Time	mean	SE
Fleurieu Peninsula			
Hindmarsh	Feb	1.20	0.27
	Sep	1.39	0.26
Inman	Feb	1.48	0.05
	Sep	1.47	0.03
Normanville	Feb	0.92	0.15
	Sep	0.23	0.07
Onkaparinga	S 1 Feb	1.63	0.20
	S 2 Feb	1.34	0.12
	S 3 Feb	0.88	0.18
	mean Feb	1.28	0.14
	S 1 Sep	4.02	0.54
	S 2 Sep	0.74	0.13
	S 3 Sep	1.77	0.25
	mean Sep	2.18	0.52
Gulf St Vincent			
Section Bank	S 1 Feb	1.79	0.94
	S 2 Feb	4.33	1.43
	S 3 Feb	1.82	0.77
	mean Feb	2.65	0.69
	mean Nov	1.57	0.12
Port Gawler	sandbank	2.92	0.29
	mussel bed	3.24	0.06
	cockle bed	14.33	3.36
	mean	6.83	2.11
Pt Arthur	S 1a	3.76	0.49
	S 1b	2.31	0.16
	S1b2	0.98	0.06
	S 1c	1.51	0.06
	mean	2.14	0.33
Tiddy Widdy	mid-high	0.56	0.15
	low	0.79	0.16
	mean	0.68	0.11
Coobowie	mussel bed	1.48	0.34
	sandflat	7.93	5.93
	mean	4.70	3.01

Microalgal biomass in the sediments was low, with average Chlorophyll values lower than 10 mg m^{-2} (Figure 3). Spring values in the Inman, Bungala and Onkaparinga were only about twice as high as the summer values for microphytobenthic biomass, indicated by the total Chlorophyll values. Pronounced differences between the total pigment content and the Chl-a value is indicative of high grazing rates.

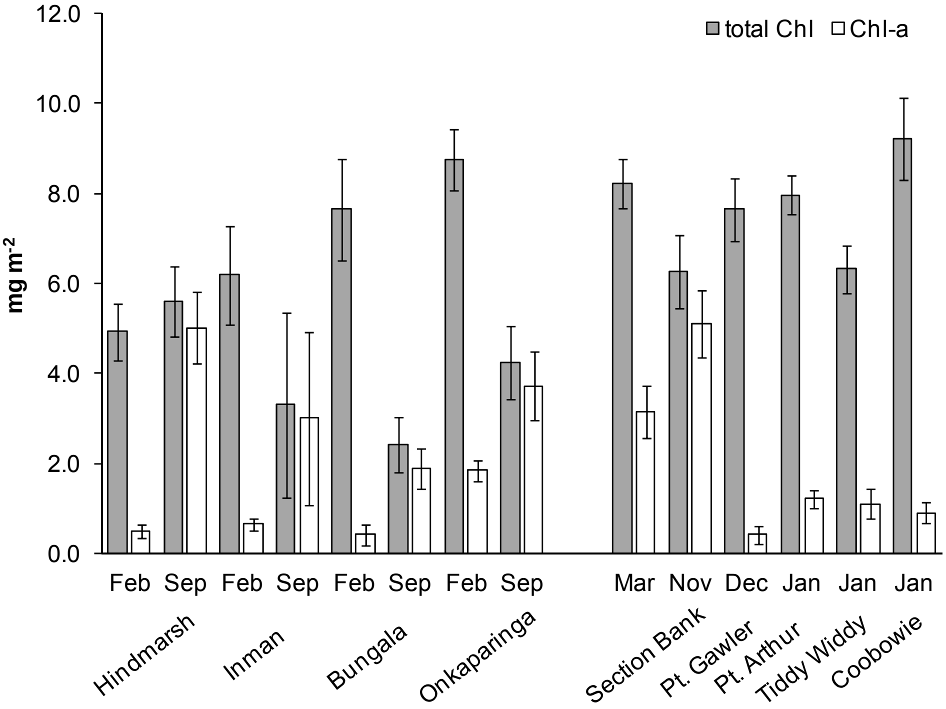

Figure 3: Chlorophyll concentrations (total pigment content and Chlorophyll-a) in the sediments at study sites of the Fleurieu Peninsula and Gulf St Vincent. Some of the sampling sites were surveyed in summer 2006/07 and spring 2007.

4.2 Benthic diversity, abundances and communities

4.2.1 Fleurieu Peninsula

4.2.1.1 Diversity

The mudflats of the four estuaries surveyed around the Fleurieu Peninsula were inhabited by few macroinvertebrate species. Although nearly 40 morphospecies were differentiated altogether (Table 8), the highest number of species recorded per survey was 14 at the Onkaparinga in February 2007 (Table 9). Polychaeta and Mollusca were represented with 13 and 9 morphospecies respectively, while very few crustaceans were encountered. Several different species of insect larvae were found, which are a temporary component of the benthos. While there was some variation in the species

Table 8: List of species encountered during the survey in several estuaries of the Fleurieu Peninsula, South Australia. The Hindmarsh and Inman River are located in Victor Harbour, the Bungala in Normanville, and the Onkaparinga at Port Noarlunga. Sampling was carried out in February (x) and November (o) 2007.

Phyla	taxa	Hindmarsh	Inman	Bungala	Onkaparinga
Annelida	*Capitella*	x o	o	x o	x o
	"*Heteromastus*"				x
	Capitellidae indet.	x			
	Nereididae sp1	x		x	x
	Nereididae sp2				x
	Simplisetia aequisetis	o			o
	Australonereis ehlersi				o
	Nephtys australiensis				x o
	Paraonidae				x
	Phyllodoce novaehollandiae	o			o
	Orbinidae	x			
	Oligochaeta		x		x o
Crustacea	*Macrophthalmus latifrons*				x
	Isopoda	x			
	Amphipoda	x o		x	
Mollusca	Mactridae juv.				x
	Tellina deltoidales				x o
	Soletellina alba	x o			
	Bivalve indet juv				x
	Katelysia peronii				o
	Arthritica helmsi	x o			
	Nassarius pauperatus				o
	Hydrobia sp. 2	o			
	Salinator sp.	x o		x	x
Insecta	Dolichopodidae (larvae)	x	x	o	x
	Chironomid (larvae) sp. 1	x o	x o	x	
	Chironomid (larvae) sp 2			x	
	Insect (larvae) indet.	x			x
	Insect (larvae) sp. 1	o			
	Insect (larvae) sp 2	o	x		
	Insect (larvae) sp 3		x	x	
	Insect (larvae) sp 4		x		
	Tabanid sp. *(larvae)*			o	
	Tipulid sp. (larvae)			o	o
	Zygoptera (larvae)			o	
	Stratiomyid sp. (larvae)				o

recorded at the sites at the two sampling occasions in summer and spring (Figure 5), a general pattern emerged with a more diverse benthic invertebrate assemblage at the Onkaparinga and Hindmarsh estuaries compared to a prevalence of several species of insect larvae in the Inman and Bungala estuaries (Table 8, Figure 4). Overall, the Inman estuary had the lowest species number (Figure 4), in particular in November when only two species were recorded here (Figure 5).

The overall species diversity was low (Table 9), with the highest Shannon-Wiener index (H') being 1.6 in the Onkaparinga, where species richness (Margalef index d) was also the highest of all sites. Eveness (Pielou, J') was higher at the species poor sites of the Inman and Bungala estuary (Table 9), which lacked the numerical dominance of capitellid polychaetes found at the other sites.

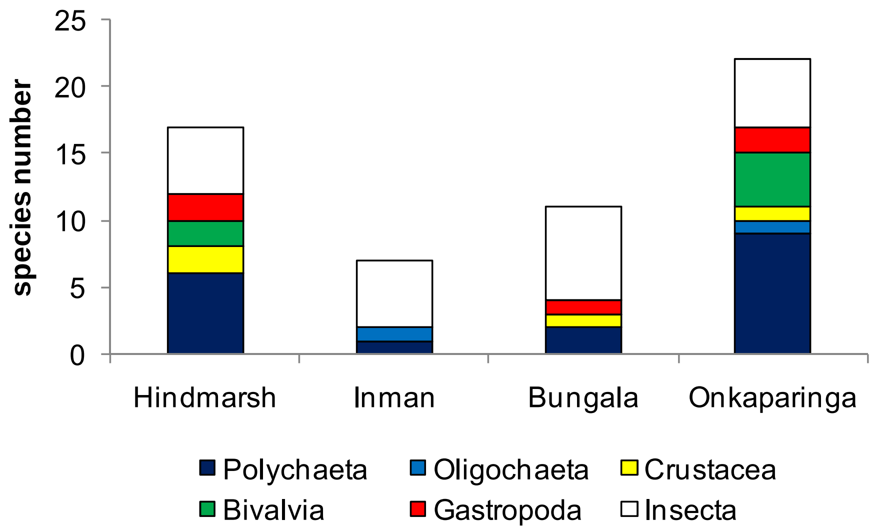

Figure 4: Species number and major taxonomic groups recorded in the mudflats of four estuaries around the Fleurieu Peninsula in the surveys from February and November 2007.

Table 9: Species number (S), species richness (d), eveness (J') and diversity (H') of the macroinvertebrate assemblage in the sediments of several estuaries of the Fleurieu Peninsula, South Australia, based on sampling in February and November 2007.

	Hindmarsh		Inman		Bungala		Onkaparinga	
	Feb	Nov	Feb	Nov	Feb	Nov	Feb	Nov
S	12	11	6	2	7	5	14	11
d	2.46	2.60	1.35	****	2.23	1.07	7.04	3.75
J'	0.55	0.41	0.58	0.92	0.80	0.33	0.61	0.26
H'(loge)	1.36	0.99	1.04	0.64	1.56	0.53	1.61	0.63

At the Bungala as well as some of the subsites sampled at the Hindmarsh and Onkaparinga estuaries there was some variation in the occurrence of major taxa at the two sampling occasions, but this was not consistent with regard to higher species numbers for certain major taxa in either of the sampling months. (Figure 5). At the Hindmarsh estuary, subsite 2 near the closed mouth, had a lower diversity than the muddier or muddy sand substrates (subsites 1 and 3). A similar situation was encountered at the Onkaparinga, where diversity was higher in the muddy sand substrate near the saltmarsh and footbridge, while only annelids occurred at the sandbar (subsite 3).

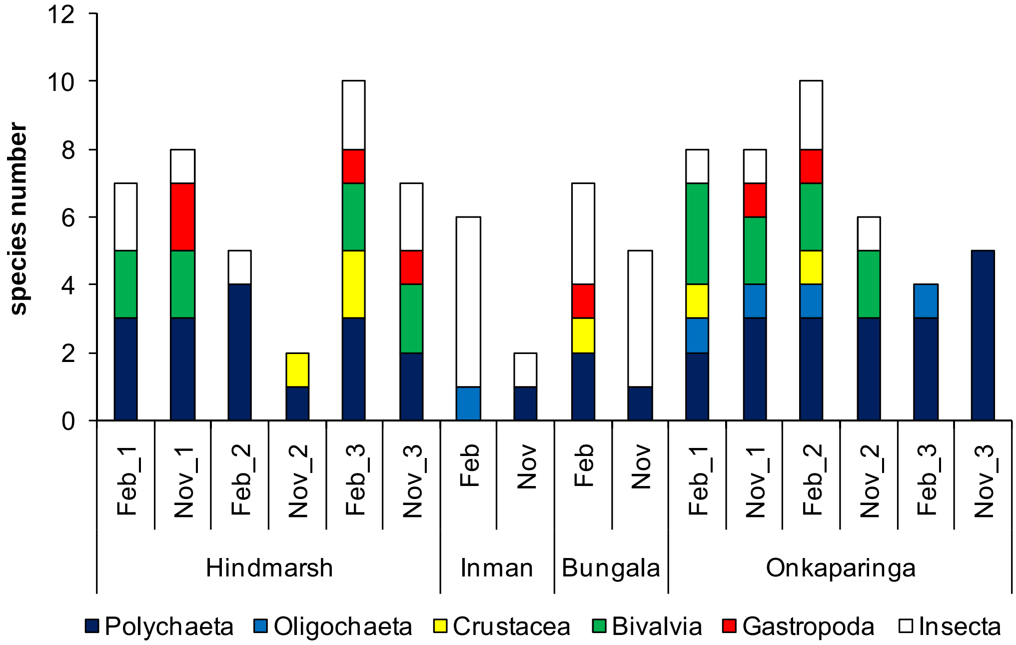

Figure 5: Species numbers and major taxonomic groups recorded in the mudflats of four estuaries around the Fleurieu Peninsula for February and November 2007. Three subsites (indicated by suffix _1 to _3) were differentiated at the Hindmarsh and Onkaparinga estuary.

4.2.1.2 Abundances

The mean abundance of total macrobenthos (all taxa) across the four estuaries on the Fleurieu Peninsula and both months was 3495.80 individuals m^{-2} (± 661.60 Standard Error SE), and similar in February (4861.18 ind. m^{-2} ± 1205.80 SE) and November (3015.13 ind. m^{-2} ± 773.87 SE). While variation was high between months, a significant difference in total macrobenthos abundances between February and November was only found for the Inman River estuary (Figure 6), where sediments were almost devoid of infauna in November. However, abundances of total macrobenthos differed significantly across sites in each month (H-Tests, $p<0.001$ Feb; $p<0.05$ Nov.). In February they were highest at the Hindmarsh estuary and in November at the Hindmarsh and Bungala estuary (Figure 6). Macrobenthic abundances were lowest at the largest estuary, the Onkaparinga, although diversity was highest here (Table 9).

The differences in macrobenthic abundances across sites were due to significant differences in polychaetes, in particular capitellid polychaetes (H-Tests, $p<0.01$ February, $p<0.05$ November), and the micromollusc *Arthritica helmsi* (H-Tests, $p<0.05$ February, $p<0.01$ November). Insect larvae and amphipods also accounted for significant differences across sites in February (H-Tests, $p\leq0.001$), but not in November.

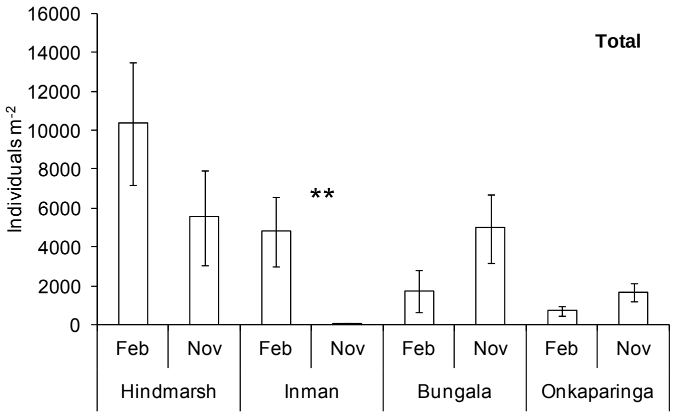

Figure 6: Abundances (mean ± SE) of total macrobenthos at the estuaries sampled around the Fleurieu Peninsula in February and November 07. The asterisks indicate results from U-Test ($p<0.01$).

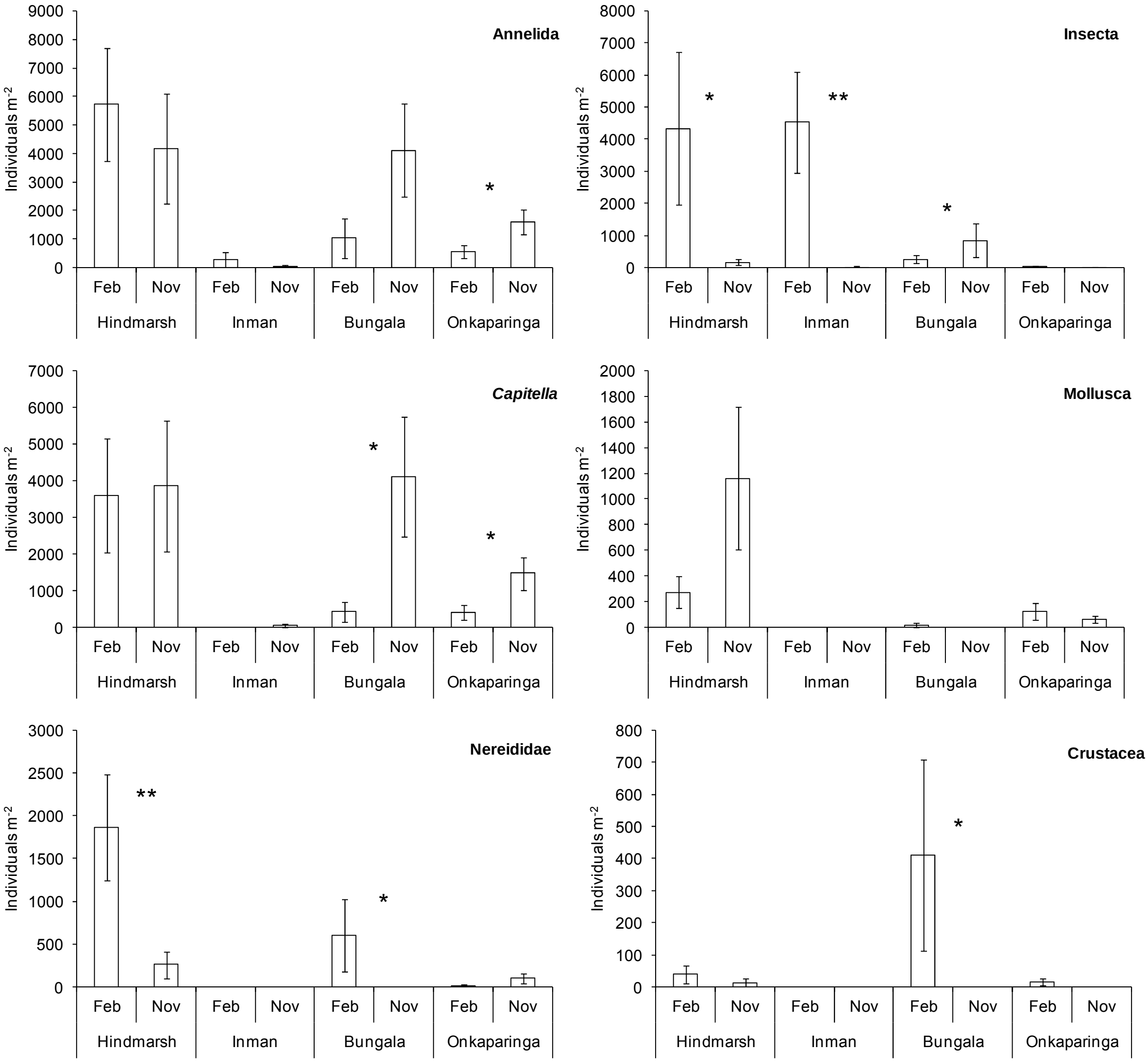

Figure 7: Abundances (mean ± SE) of major macrobenthic taxa at the estuaries sampled around the Fleurieu Peninsula in February and November 07. Note the different scales on the by-axes. The asterisks indicate results from U-Test (*=$p<0.05$; **=$p<0.01$).

The high abundances at the Hindmarsh and Bungala estuary resulted from high individual numbers of opportunistic capitellid polychaetes (Figure 7). At the Bungala, and also at the Onkaparinga, abundances of *Capitella* sp. were significantly higher in November than in February (U-Test, $p<0.05$). Nereidid polychaetes (*Simplisetia aequisetis* and Nereididae sp. 1) occurred in higher individual numbers only at the Hindmarsh and Bungala estuary, but their numbers had significantly decreased by November (Figure 7). Chironomid larvae dominated at the Inman estuary and were also abundant at the Hindmarsh estuary. This was only the case in February, and in both estuaries abundances of insect larvae dropped significantly between the two months (Figure 7). Insect larvae showed a significant increase between February and November at the Bungala (Figure 7). Bivalves (*Arthritica helmsi*, *Soletellina alba*) accounted for the high abundance of molluscs at the Hindmarsh estuary (Figure 7). Few crustaceans were encountered during the surveys and only amphipods were abundant at the Bungala in February, but had significantly decreased by November (Figure 7).

At the Hindmarsh estuary, a patchy distribution of benthic fauna became apparent when subsites were differentiated (Figure 8). The total macrobenthos was significantly different over time and subsites (Two-way ANOVA: month: df=1, MS=6369.98, F=11.892, $p<0.01$; subsite: df=2, MS=13405.07, F=25.025, $p<0.001$), but there was no interaction effect between months and subsite. This was similar for polychaetes (Two-way ANOVA: month: df=1, MS=1875.33, F=6.386, $p<0.05$; subsite: df=2, MS=12420.24, F=42.324, $p<0.001$). For the other taxa, normality and homogeneity of variance could not be achieved by data transformations. Non-parametric H-tests showed that *Capitella capitata* and *Arthritica helmsi* differed significantly across subsites in February as well as in November ($p<0.05$). In November, nereidid polychaetes and chironomid insect larvae were also different across the three subsites (H-Test, $p<0.05$). Specimens of amphipods and isopods were encountered in low numbers at the sandier subsites.

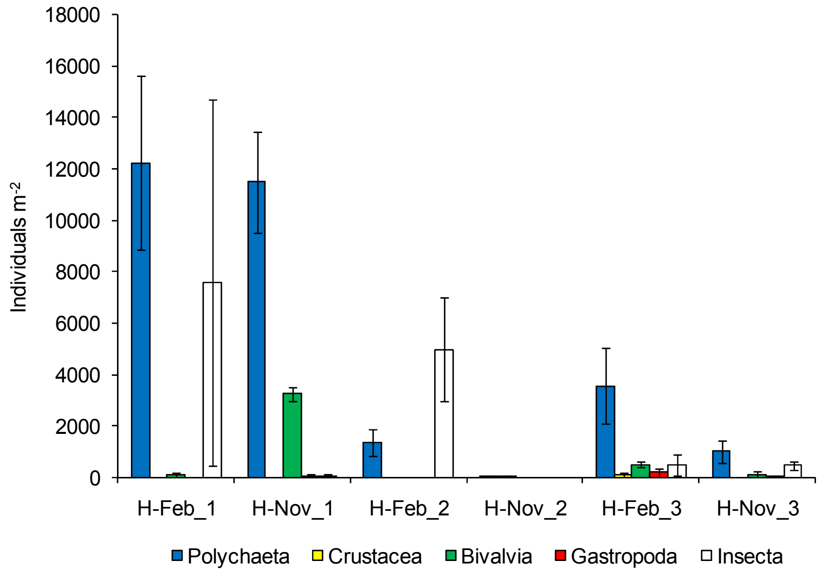

Figure 8: Abundances (mean ± SE) of major taxa at the three subsites (indicated by suffix) at Hindmarsh estuary in February and November 07.

Chironomid larvae, *C. capitata* and nereidid polychaetes were numerically dominant at the Hindmarsh estuary in February, and *C. capitata* continued to dominate in November (Figure 9). Yet the rank order of abundance of the following species had changed, with *A. helmsi* being the second most abundant organism. Several specimens of the large bivalve *Soletellina alba* were also encountered at this site.

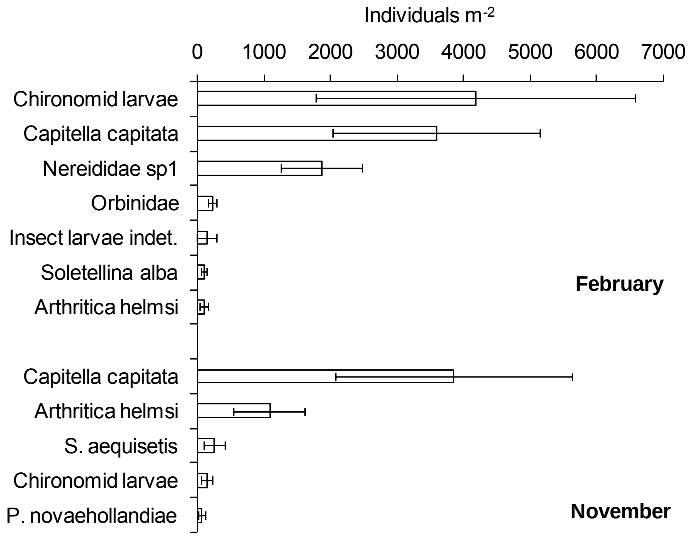

Figure 9: Abundances (mean ± SE) of species contributing >1% to total individual numbers at the Hindmarsh estuary in February and November 07, displayed in decreasing rank order of abundance for each month.

The benthic infauna at the Inman estuary was numerically dominated by insect larvae in February (Figure 10). Apart from insect larvae, only oligochaetes and capitellid polychaetes were encountered at this site. Only two species occurred here in November and they were present in very low abundances.

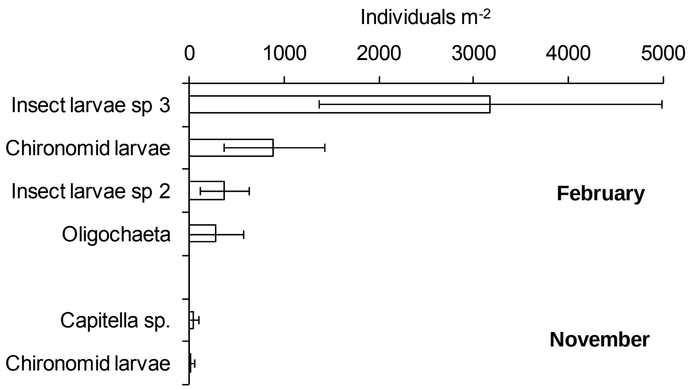

Figure 10: Abundances (mean ± SE) of species contributing >1% to total individual numbers at the Inman estuary in February and November 07, displayed in decreasing rank order of abundance for each month.

At the Bungala, several species occurred in low abundances in February, but in November abundances had increased and the macrofauna was numerically dominated by capitellid polychaetes and insect larvae (Figure 11). Patchiness was pronounced here as well, as the nereidid and capitellid polychaetes were numerous in one of the replicates only.

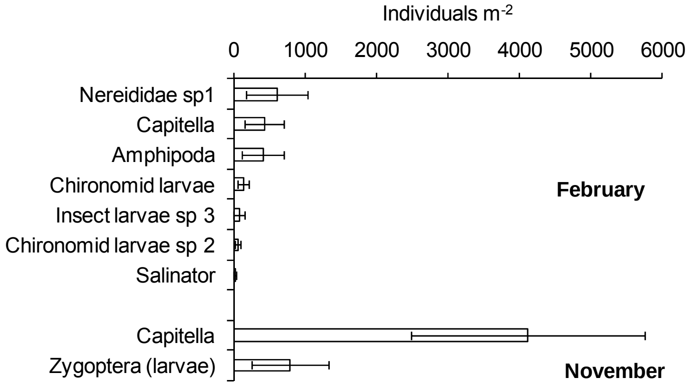

Figure 11: Abundances (mean ± SE) of species contributing >1% to total individual numbers at the Bungala estuary in February and November 07, displayed in decreasing rank order of abundance for each month.

The benthic community at the Onkaparinga estuary was numerically dominated by *Capitella capitata*, especially in November 2007, while many more species contributed >1% to the overall abundances in February (Figure 12). The bivalve *Tellina deltoidales* was among the more abundant species at this site. Compared to the other sites, insect larvae, especially chironomid larvae, were rare at the Onkaparinga.

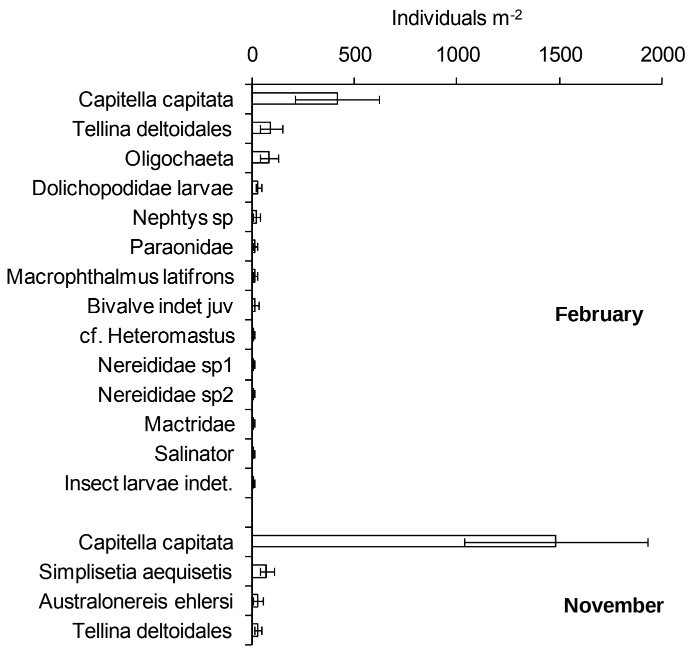

Figure 12: Abundances (mean ± SE) of species contributing >1% to total individual numbers at the Onkaparinga estuary in February and November 07, displayed in decreasing rank order of abundance for each month.

The dominance of *C. capitata* was apparent at all three subsites at the Onkaparinga, where polychaetes outnumbered all other infauna (Figure 13). In spite of their dominance throughout the Onkaparinga, the capitellid polychaetes were significantly different between the three subsites in each of the months (H-Tests, February and November $p<0.05$). None of the other species or higher taxa found differed significantly between the subsites. Only Annelida and total macrofauna were significantly different between months and subsites, but there was no interaction effect of months and subsites (Two-way ANOVA, total macrobenthos: month: df=1, MS=1275.48, F=5.352, $p<0.05$; subsite: df=2, MS=2575.56, F=10.8074, $p<0.001$; Annelida: month: df=1, MS=2294.88, F=9.050, $p<0.01$; subsite: df=2, MS=2434.82, F=9.601, $p<0.001$).

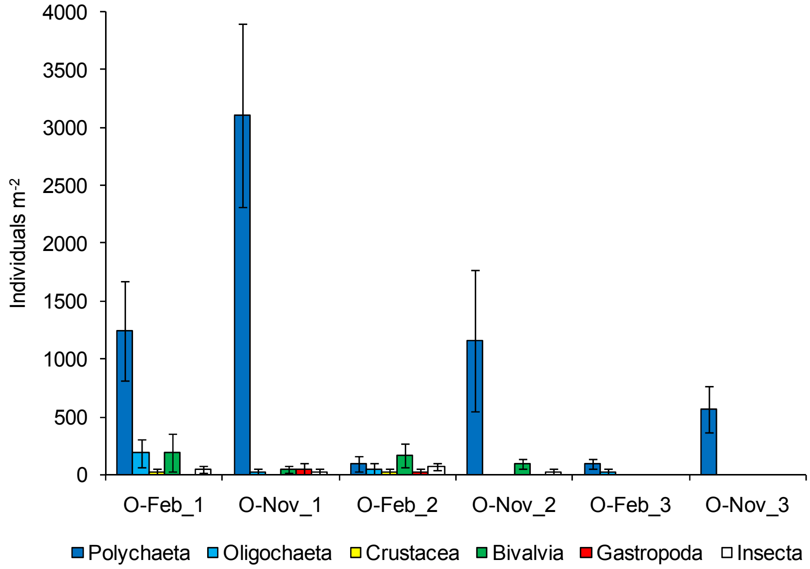

Figure 13: Abundances (mean ± SE) of major taxa at the three subsites (indicated by suffix) at the Onkaparinga estuary in February and November 07.

4.2.1.3 Communities

Benthic communities at the study sites formed distinct cluster for the Hindmarsh River estuary and the Onkaparinga estuary on both sampling occasions, while the benthic communities at the Bungala River estuary was more similar to the Onkaparinga in February, and to the Hindmarsh in November (Figure 14). The Inman River was characterised by a benthic community that shared less than 20% similarity to the other sites. Yet, the communities were not statistically different across sites (ANOSIM, R=0.191, $p< 0.01$) nor over time (ANOSIM, R=0.189, $p<0.001$). The multivariate analyses gave similar MDS plots and dendrograms based on single taxa or on family level. Considering each month, the sub-sites sampled at the Hindmarsh estuary and Onkaparinga appeared more similar to each other than to the other sites sampled that month (Figures 15), yet this was again not statistically significant (February: ANOSIM R=0.212, $p<0.005$; November R=0.197, $p<0.016$). Hence, there are no site specific differences in the benthic communities found in the four studied estuaries of the Fleurieu Peninsula.

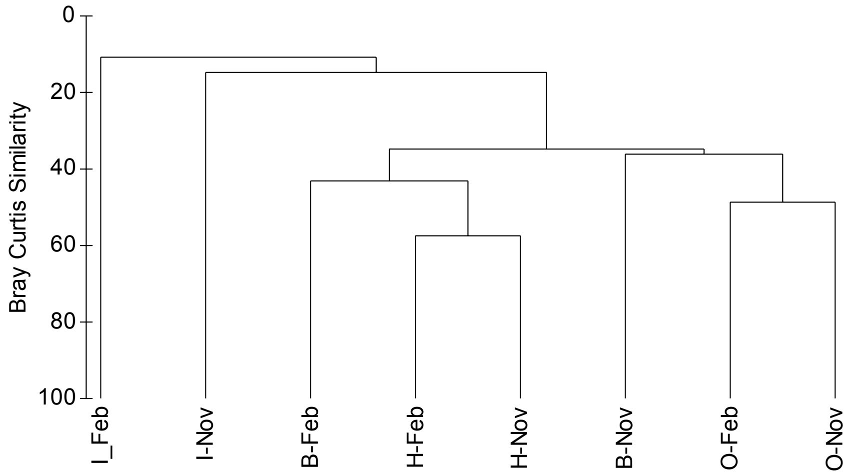

Figure 14: Dendrogram of a cluster analysis of benthic infauna at the four study sites around the Fleurieu Peninsula sampled in February and November 2007. The analysis is based on the mean values across replicates per site and on family level (where several taxa occurred per family, as for Capitellidae, Nereididae and Tellinidae). Data were square root transformed prior to analysis.

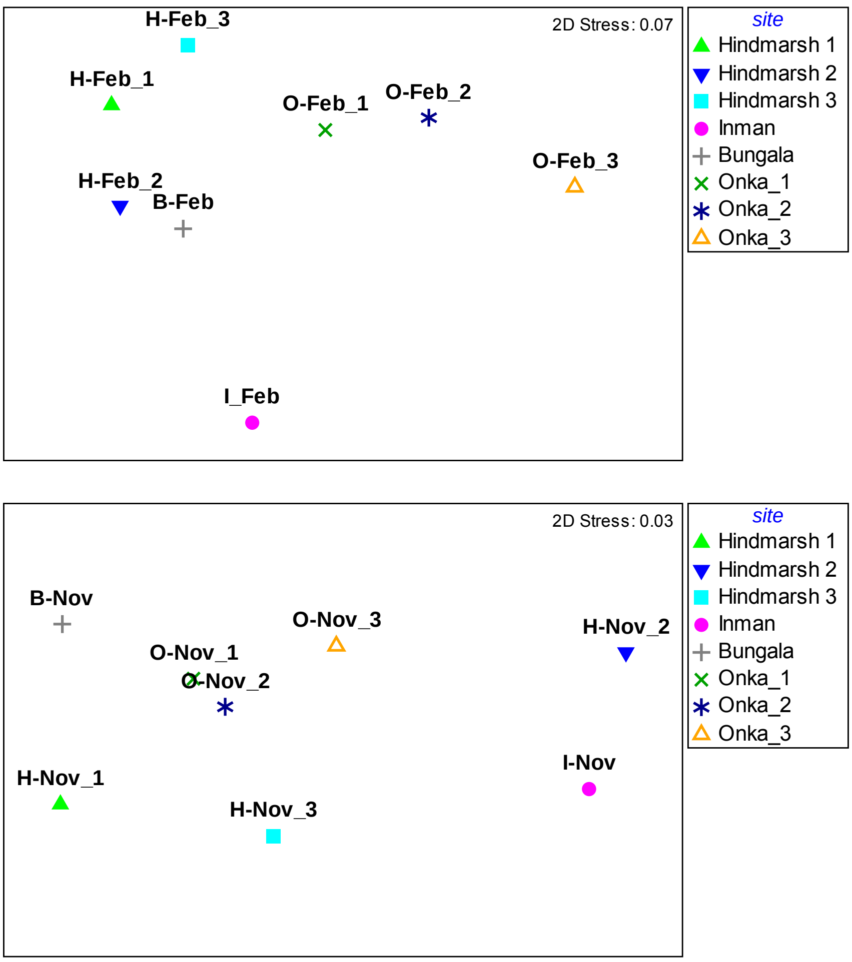

Figure 15: MDS plot of benthic assemblages in the estuaries of the four rivers around the Fleurieu Peninsula sampled in February (above) and November (below) 2007. The multidimensional scaling was based on mean values over replicates per (sub)sites, and on family where several taxa occurred per family (see Figure 7). Data were square root transformed prior to analysis.

4.2.2 Gulf St Vincent

4.2.2.1 Diversity

A total of 79 morphospecies was recorded in the mudflats around Gulf St. Vincent (Table 11). Annelids (polychaetes and oligochaetes) and molluscs were most diverse with 32 species each. The survey also gave records of rarer phyla like sipunculids or endobenthic holothurids. Nemerteans were encountered at most sites. Insect larvae were rarely found in samples of these more open and exposed mudflats. Collembola (springtails) were encountered at a few high tide locations. These tiny insects occurred in patches with high densities, but were not included in the benthic invertebrate counts here as they are terrestrial organisms.

In spite of the overall species richness in intertidal soft sediments around the Gulf St. Vincent, the species number at each of the sites was much lower, and ranged from 17 (Pt Arthur and Tiddy Widdy Beach) to 41 at Coobowie. Polychaetes accounted for most of the species at each site (Figure 16) and molluscs were in particular rich in species at Coobowie Bay.

Species richness (Margalef index) was highest at Coobowie and on Section Bank (Table 10), yet there was temporal variation on Section Bank, as less species were recorded in the spring sampling of November 2007. This resulted in Section Bank having the highest diversity (Shannon-Wiener Index H') in March, and the lowest of all sampled sites in November 2007.Eveness (J') had also dropped by November, as capitellid polychaetes were numerically dominating the infauna here at that time. Pt Gawler and Tiddy Widdy had relatively high diversity indices as well, reflecting the varied taxonomic composition and less dominance by single species. The lower eveness value at Coboowie Bay may be due to the abundance of mytilid bivalves in the mussel bed sampled there.

Table 10: Species number (S), species richness (d), eveness (J') and diversity (H') of the macroinvertebrate assemblage in the sediments of several mudflats of the Gulf St. Vincent, South Australia, based on sampling between December 2006 and November 2007.

	Section Bank		Pt Gawler	Port Arthur	Tiddy Widdy	Coobowie
	Mar	Nov				
S	29	20	34	17	17	41
d	9.02	5.73	7.22	5.16	5.60	8.19
J'	0.84	0.43	0.58	0.59	0.78	0.45
H'(loge)	2.83	1.30	2.06	1.67	2.20	1.68

Apart from this general pattern, a more detailed look at the species numbers and taxonomic composition at the various subsites sampled at each mudflat location reveal a high degree of within site variation in diversity (Figure 17). On Section Bank, species numbers were higher near the mangroves and subtidal in the March sampling, but in November species numbers, in particular of polychaetes and gastropods, were lower at subsite 1. At Pt Gawler, there was slight variation in diversity across the subsites, with polychaete species numbers increasing from the mussel bed towards the sandflat. At Pt Arthur and Tiddy Widdy, species numbers were slightly higher at the mid intertidal level. The mussel beds at Coobowie Bay harboured the majority of the molluscs encountered

Table 11: List of species encountered during the survey in several mudflats of the Gulf St Vincent, South Australia. See Figure 1 for site location. Sampling was carried between December 2006 and March 2007 (x) and for Section Bank also in November (o) 2007. Some species identifications are subject to further taxonomic work.

Phyla	taxa	Section Bank	Pt Gawler	Pt Arthur	Tiddy Widdy	Coobowie
Cnidaria	Anenome	x o	x			
Annelida	*Capitella*	x o	x	x		x
	Capitella sp. 2					x
	cf. Heteromastus	x	x	x	x	
	Heteromastus sp 2			x		
	Nereididae sp1 *(cf. Neanthes vaalii)*	x o	x	x	x	x
	Nereididae sp. 4	o				
	Nereididae sp. 7		x			
	Nereididae indet					x
	Australonereis ehlersi	x				
	Nephtys australiensis	x o	x	x	x	
	Nephtys sp. 2				x	
	Glyceridae	o				
	Paraonidae *(Aricidea)*	x			x	x
	Polydora sp.	x o	x			
	Prionospio sp.	x	x			
	Spio sp.	x o	x			
	Spionidae *(cf. Pygospio)*		x			
	Spionidae indet.	x				
	Lysaretidae	x			x	x
	Onuphidae	x o				
	Lumbrinereidae	x				x
	Amphinomidae?	o				
	Syllidae		x	x		x
	Maldanidae				x	
	Cirratulidae				x	
	Ampharetidae				x	
	Terebellidae					x
	Eunicidae *(Marphysa)*					x
	Opheliidae					x
	Orbiniidae (spp)	x o	x		x	x
	Questidae					x
	Oligochaeta		x			x
Crustacea	*Helograpsus haswellianus*		x			
	Brachyura sp. 2		x			x
	Portunus pelagicus	x				
	Isopoda		x			
	Amphipoda	x o	x	x	x	

	Cumacea	x o		x	x	x
	Mysidacea				x	
	Biffarius arenosus	x o		x		
Mollusca	*Mactridae indet.*	x	x			
	Mactridae (pink)					x
	Tellina deltoidales	x o	x	x		x
	Tellinidae indet (juv.)			x		x
	Soletellina alba	o				x
	Katelysia scalarina	x o	x			x
	Katelysia peronii	x o				
	Laternula	x				
	Xenostrobus inconstans		x			x
	"Musculista"		x			
	"Venerupis"		x			
	Dosinia? Or *Lucinidae*				x	x
	Psammobiidae					x
	Solemya					x
	Bivalve indet juv	x	x	x	x	x
	Nassarius pauperatus	x o		x		x
	Nassarius sp.2					x
	Nassarius sp. 3					x
	Salinator fragilis	x	x	x	x	x
	"Hydrobia"	x				x
	Austrocochlea constricta		x			x
	Laemodonta punctigera		x			
	Leuconopsis inermis		x			
	Trochidae		x			
	Turitellidae indet.		x			x
	Cerithidae					x
	Muricidae					x
	Gastropod indet (white)					x
	Neritidae					x
	"posthorn"					x
	Ophisthobranchia					x
	limpets					x
Nemertinea	*Nemertean brown*	x o	x	x		
	Nemertean sp. 2 (white)		x		x	
Holothurid				x		
Sipunculida				x		
Insecta	Insect larvae *(Dolichopodidae)*		x			x
	Insect larvae *(Chironomida)*		x			

in this survey. Especially the number of gastropods was much higher on the mussel bed than in the surrounding sandflat (Figure 17).

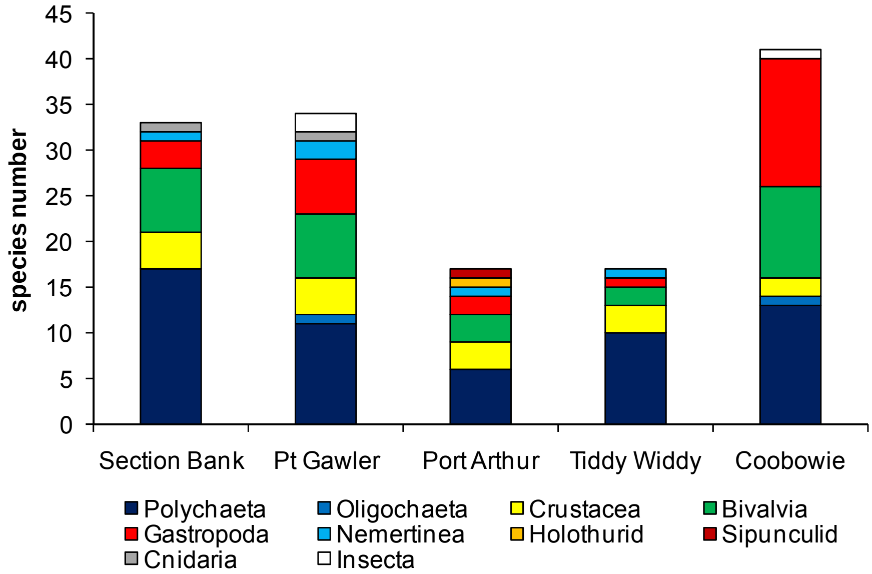

Figure 16: Species number and major taxonomic groups recorded in the mudflats of five study sites around the Gulf St. Vincent in the surveys from December 2006 to November 2007.

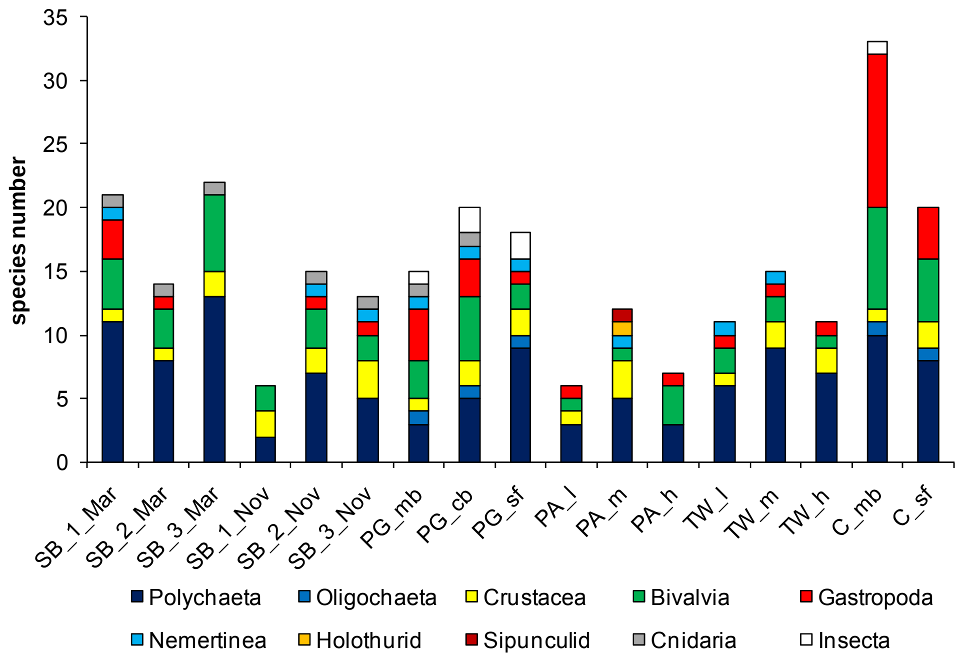

Figure 17: Species number and major taxonomic groups recorded at the various subsites (indicated by suffix) in the mudflats of five study sites around the Gulf St. Vincent in the surveys from December 2006 to November 2007. SB=Section Bank; PG=Pt Gawler; PA=Pt Arthur; TW=Tiddy Widdy Beach, C=Coobowie. Subsites 1-3 at Section Bank were near the mangroves (1), in the centre of the bank (2) and closer to the subtidal (3). Subsites at Pt Gawler were a mussel bed (mb), cockle bed (cb) and sandflat (sf). At Pt Arthur and Tiddy Widdy, subsites were in the low (l), mid (m) and high (h) intertidal. A mussel bed (mb) and a sandflat (sf) were sampled at Coobowie.

4.2.2.2 Abundance

At the five studied tidal flats in Gulf St. Vincent, the average density of the total macrobenthos was 6518.95 individuals m^{-2} (± 965.75 SE), yet significantly different across the sites (H-Test, p<0.001) with highest abundances at Port Gawler and Coobowie (Figure 18). This was a reflection of the significantly higher abundances of bivalves and gastropods at these two sites (H-Tests, p<0.001), as well as of higher annelid numbers at Port Gawler (H-Test, p<0.05) (Figure 19). Insect larvae occurred only at Pt. Gawler and Coobowie and their abundances were significantly different between sites (H-Test, p<0.001). Abundances of Crustacea and Nemerteans were not significantly different.

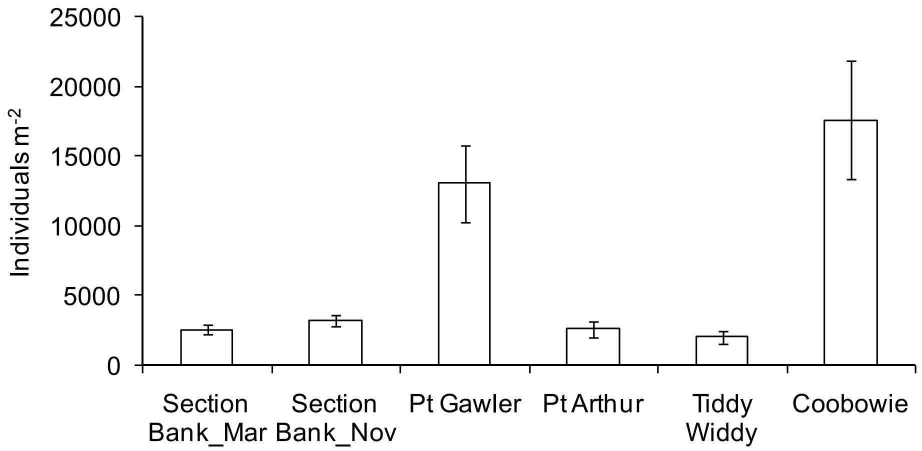

Figure 18: Abundances (mean ± SE) of total macrobenthos at the studied tidal flats around the Gulf St. Vincent, summer 2006/07. Section Bank was sampled again in spring 2007.

Like the higher taxonomic levels, abundances of almost all major macrobenthic species found in these surveys differed significantly across the five sites (Table 12). In most cases, abundances were highest at Port Gawler, Coobowie or Section Bank (in March). Not all taxa occurred at every site (see 4.2.2.1) and the particular species combinations and their densities result in site specific benthic communities (see 4.2.2.3).

In addition to variation in abundances between sites, there was also variation within each of the five study site. Subsites were differentiated in the stratified random sampling to assess the diversity and abundance of particular habitats, biogenic structures or along intertidal gradients. This design revealed distinct distribution patterns of the benthic fauna. Polychaetes were the most abundant taxon at several subsites of Section Bank, at Port Arthur, Tiddy Widdy and the sandflat at Port Gawler, while bivalves and gastropods were the most abundant taxa in the mussel and cockle beds at Port Gawler and Coobowie. Bivalves were also abundant in the mid intertidal at Tiddy Widdy, and the snail *Salinator cf. fragilis* dominated the abundances in the sandflat at Coobowie (Figures 21, 23, 25, 27, 29).

At Section Bank, which was sampled twice, total macrobenthic densities were not significantly different between summer and spring 2007 (U-Test, p>0.05), although mollusc (bivalves and gastropods) abundances were significantly lower in November (U-Test, p<0.05), when crustaceans were more abundant (U-Test, p<0.01) (Figure 19). The overall numbers of annelids were not significantly different between the two sampling occasions on Section Bank, yet capitellid polychaetes were more abundant in November (U-Test, p<0.001) and nereidid and spionid polychaetes in March (U-Tests, p<0.01 Nereididae, p<0.001 Spionidae).

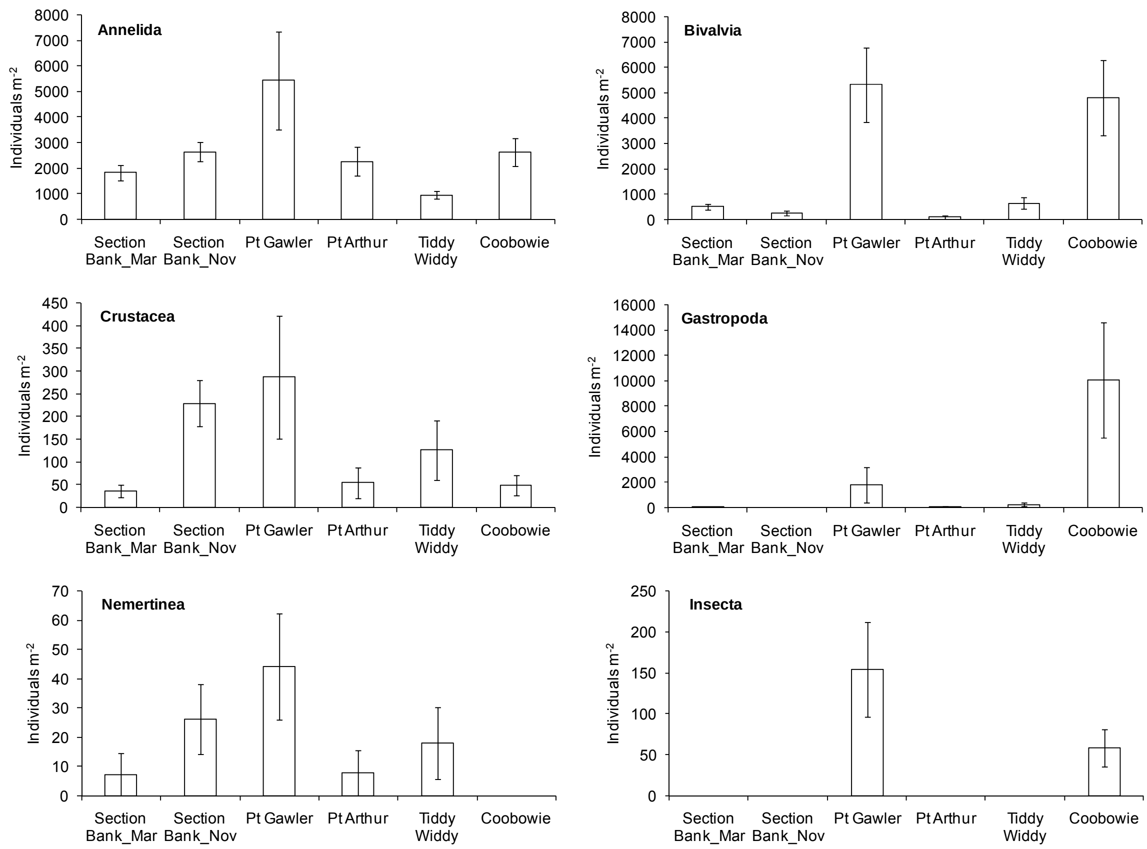

Figure 19: Abundances (mean ± SE) of major macrobenthic taxa at the studied tidal flats around the Gulf St. Vincent, summer 2006/07. Section Bank was sampled again in spring 2007. Note the different scales on the y-axis.

In March, no species dominated the macrobenthic assemblage at Section Bank and 16 species contributed >1% to the overall abundances (Figure 20). Seven of them were among the 10 species which contributed >1% to the abundances in November, yet *Capitella cf. capitata* was dominating at this time. *Capitella* was nearly 15 times more abundant than the second ranking species in November.

Within the subsites at Section Bank, polychaetes and bivalves were most abundant on all of them, and crustaceans were also abundant at subsites 2 (centre of bank) and 3 (towards subtidal) in November (Figure 21). Abundances of several polychaete taxa (H-Tests; March: Nereididae p<0.05, Nephtys australiensis p<0.05, Orbiniidae p<0.05, Polydora sp.p<0.05, Spionidae p<0.01; November: Nereididae p<0.05, Nephtys australiensis p<0.01) as well as molluscs (H-Tests; March: Mactridae indet. P<0.05; cf. Hydrobia p< 0.05; November: Katelysia scalarina p<0.01; Katelysia peronii p<0.05) and amphipods (H-Test; November: p<0.05) were significantly different between the three subsites (Figure 21).

Table 12: Abundances (individuals m^{-2}, mean ± Standard Error) of major macrobenthic taxa and species occurring at the studied tidal flats in the Gulf St Vincent, South Australia. No entry indicates that the respective species/taxon was not found at the site. The test results indicate the p-value from non-parametric Kruskal-Wallis H-Tests across all five sites.

	Section Bank		Port Gawler	Port Arthur	Tiddy Widdy	Coobowie	p
	March	November					
Anthozoa	147.06 (± 47.43)	39.22 (± 39.22)	132.35 (± 73.53)				<0.05
Polychaeta	1830.88 (± 311.26)	2653.59 (± 391.14)	4397.06 (± 1405.21)	2266.67 (± 560.64)	959.28 (± 160.32)	2303.92 (± 367.06)	<0.05
Capitella cf. capitata	257.35 (± 165.06)	2320.26 (± 387.73)	2397.06 (± 1066.74)	172.55 (± 101.31)		215.69 (± 96.96)	<0.001
Heteromastus sp.	345.59 (± 97.53)		7.35 (± 7.35)	478.43 (± 118.47)	81.45 (± 36.20)		<0.001
Capitellidae	602.94 (± 166.33)	2320.26 (± 387.73)	2404.41 (± 1066.64)	674.51 (± 200.66)	81.45 (± 36.20)	235.29 (± 105.43)	<0.001
Nereididae sp. 1	242.65 (± 118.36)	6.54 (± 6.54)					≤0.001
Neanthes vaalii			764.71 (± 176.47)			1117.65 (± 184.03)	<0.001
Nereididae	382.35 (± 120.79)	65.36 (± 25.56)	794.12 (± 173.01)	1309.80 (± 433.99)	298.64 (± 71.26)	1264.71 (± 160.69)	<0.001
Nephtyidae	169.12 (± 51.47)	156.86(± 52.96)	22.06 (± 16.00)	274.51 (± 82.53)	190.05 (± 41.14)		<0.01
Polydora sp.	132.35 (± 51.37)	13.07 (± 13.07)	7.35 (± 7.35)				<0.05
Spionidae	308.82 (± 76.60)	19.61 (± 14.27)	44.12 (± 37.01)				<0.01
Orbinidae	257.35 (± 88.70)	58.82 (± 52.31)	897.06 (± 462.66)		108.60 (± 38.75)	9.80 (± 9.80)	<0.05
Syllidae			102.94 (± 38.54)	7.84 (± 7.84)		558.82 (± 290.40)	<0.001
Oligochaeta			1044.12 (± 702.27)			333.33 (± 251.59)	<0.001
Amphipoda	14.71 (± 10.05)	137.25 (± 51.44)	7.35 (± 7.35)	15.69 (± 15.69)	27.15 (± 19.55)		ns
Brachyura			117.65 (± 42.96)			39.22 (± 22.12)	<0.001
Xenostrobus inconstans			4750.00 (± 1546.69)			4421.57 (± 1525.87)	<0.001
Tellina deltoidales	227.94 (± 43.58)	156.86 (± 55.46)		15.69 (± 15.69)		29.41 (± 15.36)	<0.001
Mactra sp.	102.94 (± 67.82)		455.88 (± 283.10)			9.80 (± 9.80)	ns
Bivalve indet. Juv.	29.41 (± 22.78)		14.71 (± 14.71)	94.12 (± 70.96)	624.43 (± 212.04)	196.08 (± 140.65)	<0.001
Turritellidae			191.18 (± 114.61)			862.75 (± 408.14)	≤0.001
Salinator cf. fragilis	14.71 (± 14.71)		1610.29 (± 1288.03)	62.75 (± 44.27)	280.54 (± 176.99)	8764.71 (± 4421.17)	<0.001
Nassariidae	22.06 (± 16.00)	6.54 (± 6.54)		7.84 (± 7.84)		58.82 (± 49.11)	ns

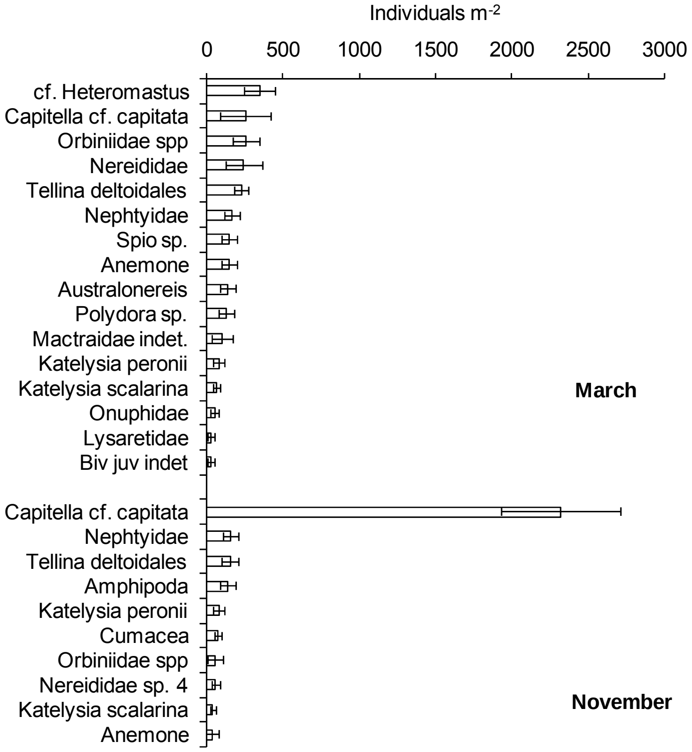

Figure 20: Abundances (mean ± SE) of species contributing >1% to the total individual densities in the tidal flat of Section Bank, March and November 2007, displayed in decreasing rank order of abundance for each month.

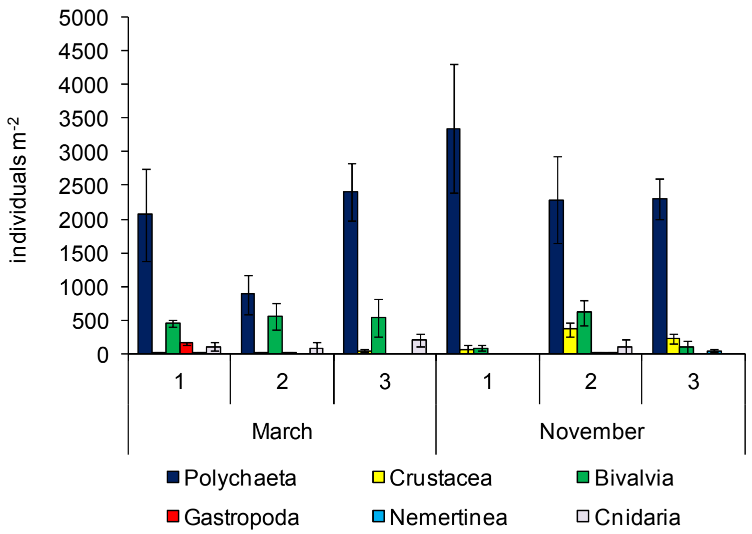

Figure 21: Abundances (mean ± SE, n = 5 for site 1 and 2 in March and n=6 for all other sites) of major macrofaunal taxa in the tidal flats at Section Bank, March and November 2007.

At Port Gawler, one of the studied subsites was a mussel bed created by the small mytilid bivalve *Xenostrobus inconstans*, which occurred in high densities and dominated overall abundances of benthic fauna at this site (Figures 22, 23). The cockle bed was made up of cockles of the family Mactridae. The distribution of these two habitat forming bivalves caused overall bivalve abundances to be significantly different across the three subsites at Pt. Gawler (H-Test, p<0.01). The cockle bed had relatively high abundances of most major benthic taxa (Figure 23). Almost all of the most abundant species at Pt. Gawler (Figure 22) were significantly different in abundance across the three subsites sampled (H-Tests: *X. inconstans* p<0.01; p<0.05 for: *Capitella*, Orbiniidae, *Neanthes vaalii*, Mactridae, Turritellidae). Less abundant species were also not evenly distributed, as abundances of *Nephtys australiensis*, Orbiniidae, Syllidae, *Prionospio sp.*, and Chironomid larvae were all significantly different across subsites (H-tests, all p<0.05). Species records confined to the cockle bed were Oligochaeta, *N. vaalii*, Turritelidae and Isopoda; and the following taxa occurred in the sandflat as well: *S. cf. fragilis*, *C. cf capitata* and Orbiniidae. The snail *S. cf. fragilis* was very patchily distributed. The small sessile anenomes found on the bivalve shells occurred in the cockle bed and mussel bed. Yet, the total macrobenthic abundances were the same across the sampled subsites at Pt Gawler (H-Test, p>0.05).

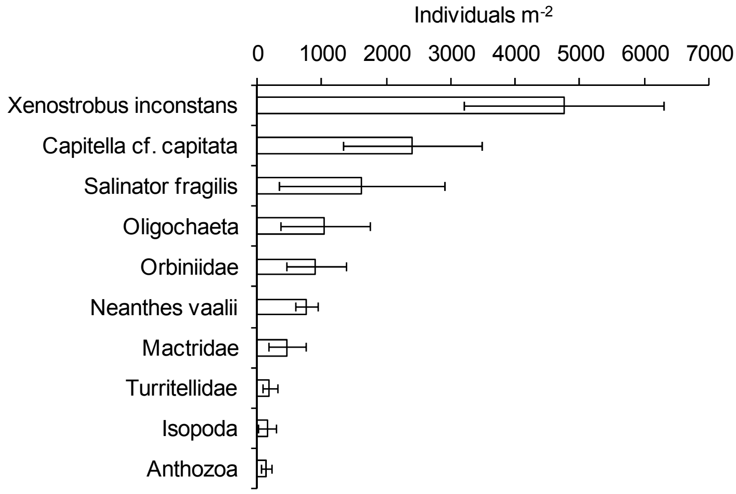

Figure 22: Abundances (mean ± SE) of species contributing >1% to the total individual densities in the tidal flat of Port Gawler, December 2006, displayed in decreasing rank order of abundance.

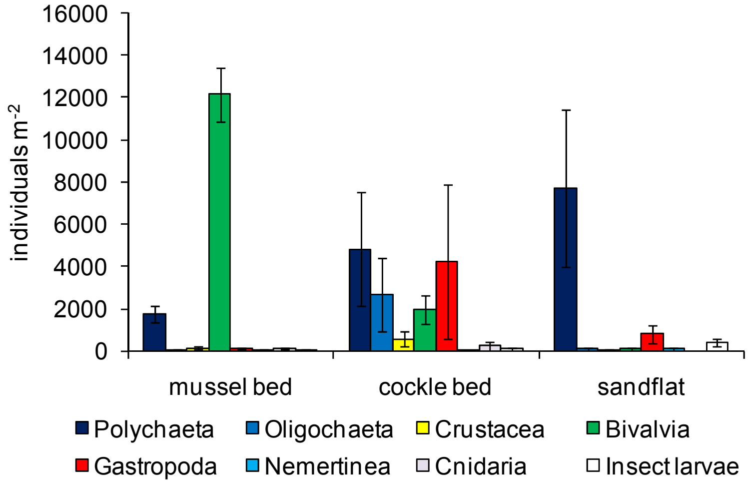

Figure 23: Abundances (mean ± SE, n = 6 for mussel and cockle bed, n=4 for sandflat) of major macrofaunal taxa in the tidal flats at Port Gawler, December 2006.

At Port Arthur, polychaetes accounted for the most abundant species found in the sediments, together with endobenthic holothurids and the snail *Salinator cf. fragilis* (Figure 24). The Nereididae and capitellid polychaetes (genera *Heteromastus*, *Capitella*) were significantly more abundant at the high intertidal location (H-Test $p<0.01$) (Figure 25). The Nephtyidae were confined to the mid and low intertidal, and also significantly different in their abundance across the three subsites (H-Test $p<0.01$). The crab *Macrophthalmus latifrons* which occurred in the high intertidal at Pt. Arthur was not caught in the samples, but recorded from additional digging at the site. The holothurids and sipunculids were only found in the mid intertidal area characterised by the presence of burrows of the callianassid shrimp *Biffarius arenosus*.

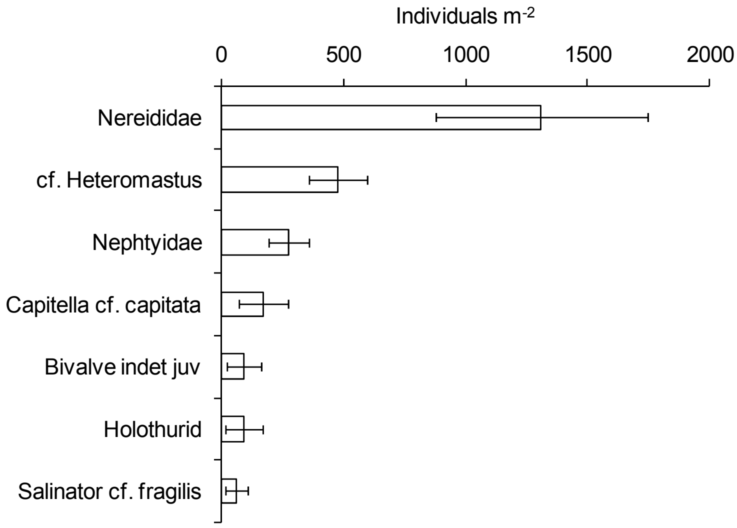

Figure 24: Abundances (mean ± SE) of species contributing >1% to the total individual densities in the tidal flat of Port Arthur, January 2007, displayed in decreasing rank order of abundance.

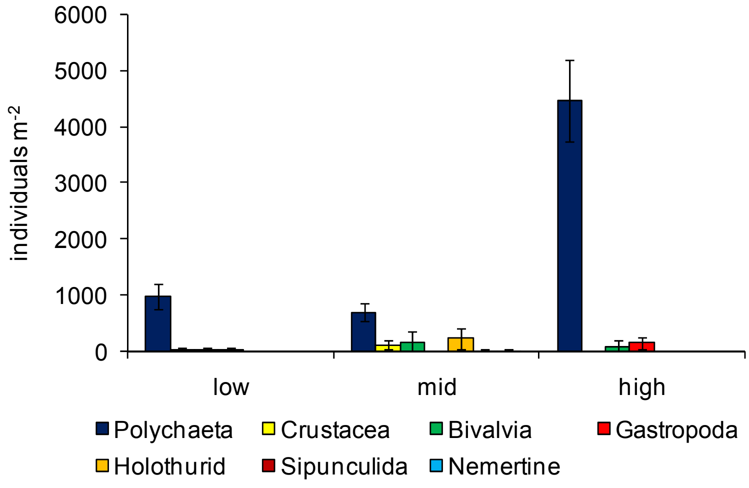

Figure 25: Abundances (mean ± SE, n = 3 at the low intertidal, n=6 for mid and high intertidal) of major macrofaunal taxa in the sandflats at Port Arthur, January 2007.

Along the transect from the low to the high tide line in the foreshore sandflat at Tiddy Widdy Beach, a mix of species from various phyla accounted for the most abundant benthic organisms (Figure 26). Unidentified juvenile bivalves were most numerous, especially in the mid intertidal (H-Test $p<0.01$), followed by nereidid polychaetes, which occurred throughout the transect. *Nephtys australiensis* occurred mainly in the low intertidal and accounted for the high polychaete numbers there (H-Test $p<0.05$) (Figure 27). The further polychaetes among the top ranking species (Maldanidae, Orbiniidae, cf. Heteromastus, *Aricidea sp*. and Cirratulidae) were all more abundant in the mid intertidal, but significantly so only for the Maldanidae (H-Test $p<0.01$). The occurrence of cumaceans (comma shrimps) was significantly different across the subsites at Tiddy Widdy (H-Test $p<0.05$) and they, too

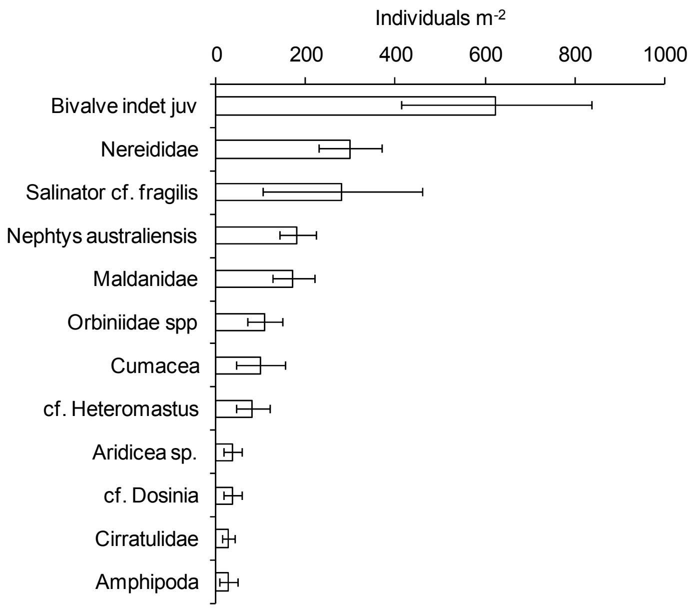

Figure 26: Abundances (mean ± SE) of species contributing >1% to the total individual densities in the tidal flat of Tiddy Widdy near Ardrossan, January 2007, displayed in decreasing rank order of abundance.

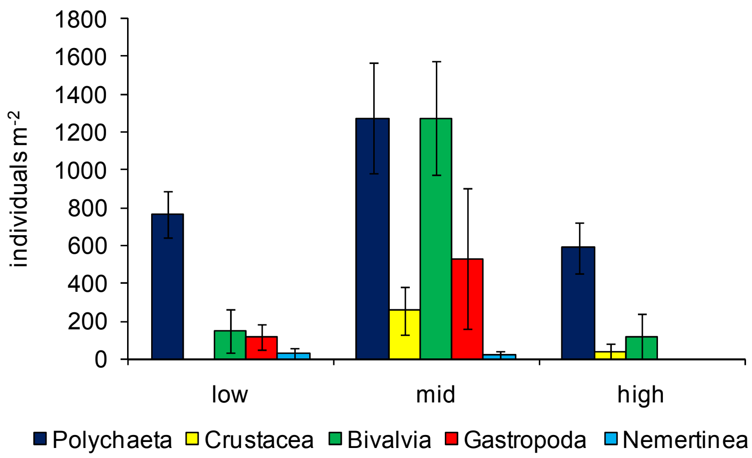

Figure 27: Abundances (mean ± SE, n = 4 at the low, n=6 for mid and n=3 for high intertidal) of major macrofaunal taxa in the sandflats at Tiddy Widdy, January 2007.

were most numerous in the mid intertidal (Figure 27). The amphipods were very patchily distributed and found in one replicate each from the mid and high intertidal subsite only.

In Coobowie Bay, molluscs were dominating benthic abundances (Figure 28). The snail *Salinator cf. fragilis* was significantly more abundant in the sandflat (U-Test $p<0.05$), while *Xenostrobus inconstans* made up the majority of the individuals in the mussel bed, where it was significantly more abundant (U-Test $p<0.001$) (Figure 29). Several of the other gastropod species encountered at this site were only found on the mussel bed (e.g. Cerithiidae U-Test $p<0.05$), while specimens of several other bivalve species were only encountered in the sandflat. Polychaetes of the family Syllidae were only found in the mussel bed (U-Test $p<0.05$) and most of them occurred between the byssus threads of *X. inconstans*. Oligochaetes and also capitellid polychaetes were also primarily found in the mussel bed, whereas some more rare polychaetes (Paraonidae, Lysaretidae, Opheliidae) were only recorded in the sandflat. The more numerous nereidid polychaete *Neanthes cf. vaalii* was significantly more abundant in the sandflat (U-Test $p<0.01$). A few insect larvae occurred only in the mussel bed (U-Test $p<0.01$). The two subsites sampled at Coobowie were thus very different in their faunal assemblage.

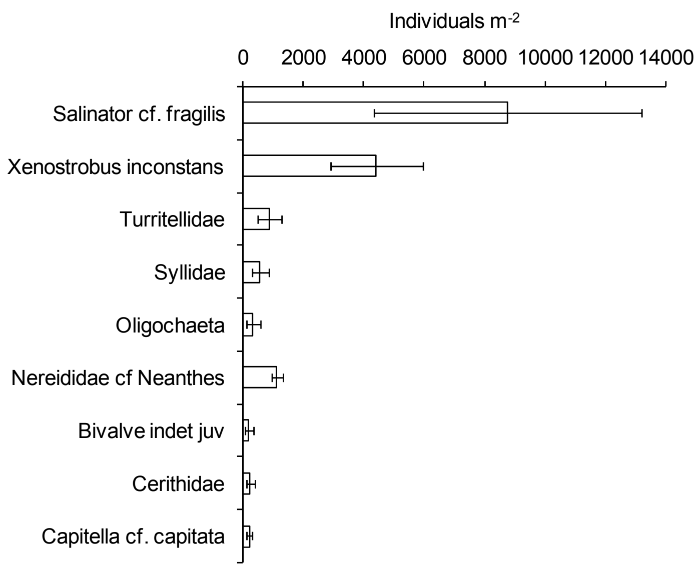

Figure 28: Abundances (mean ± SE) of species contributing >1% to the total individual densities in the tidal flat of Coobowie, January 2007, displayed in decreasing rank order of abundance.

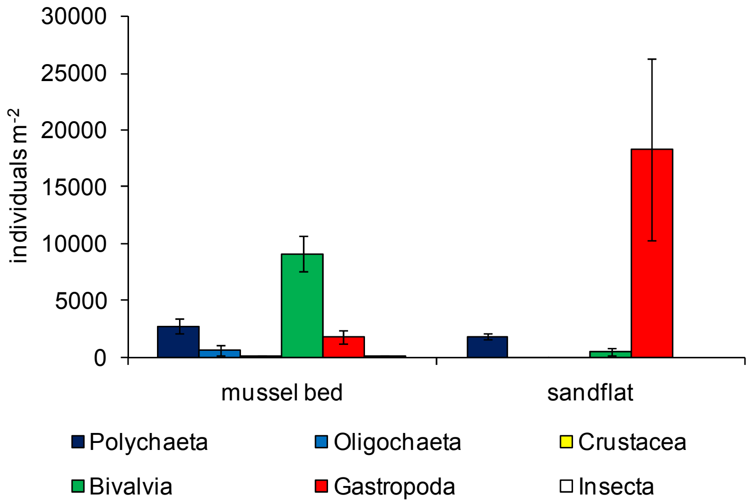

Figure 29: Abundances (mean ± SE, n = 6 for mussel bed and sandflat) of major macrofaunal taxa in the sandflats at Coobowie, January 2007.

4.2.2.3 Communities

The mudflats around the Gulf St. Vincent were characterised by defined benthic communities, with a high similarity of the Section Bank during the summer and spring sampling (Figure 30). The two sites which contained mussel beds (Pt Gawler and Coobowie) were more similar to each other than to the further mudflats around the Gulf. Based on the summer survey only, this pattern of distinct communities is also apparent based on all replicates and taxa (Figure 31). These community differences were significant (ANOSIM R=0.695, p=0.001).

A list of 15 species emerged which characterised the benthic community at a respective sites or discriminated between sites (Table 13). This list contains mainly polychaetes and molluscs, whereby capitellid and nereidid polychaetes as well as the mytilid bivalve *Xenostrobus inconstans* and the pulmonate snail *Salinator cf fragilis* contributed most to similiarities or dissimilarities. It was mainly the species contributing most to the similarity within sites which also accounted for their discrimination.

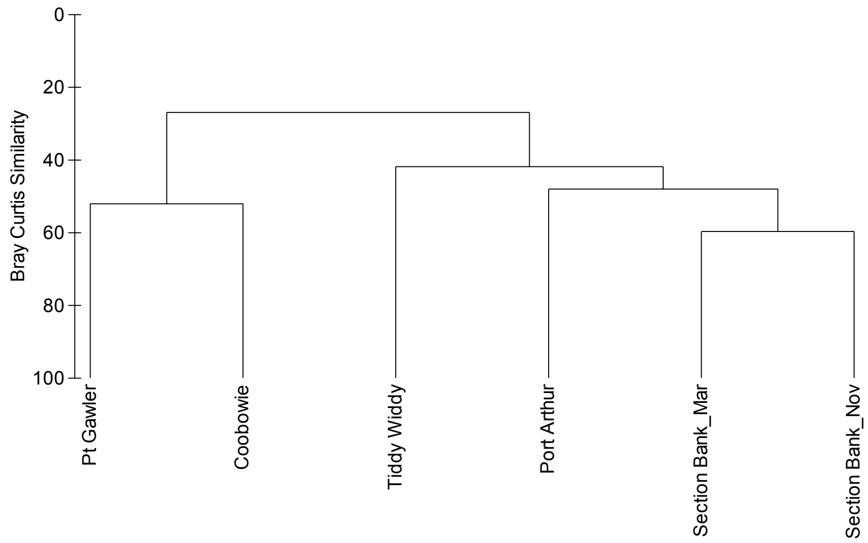

Figure 30: Dendrogram of a cluster analysis of benthic infauna at the studied mudflats around the Gulf St. Vincent sampled between December 2006 and November 2007 (Section Bank only). The analysis is based on the mean values across replicates per site and on family level (where several taxa occurred per family, as for Capitellidae, Nereididae, Nassariidae; and combined insect larvae). Data were square root transformed prior to analysis.

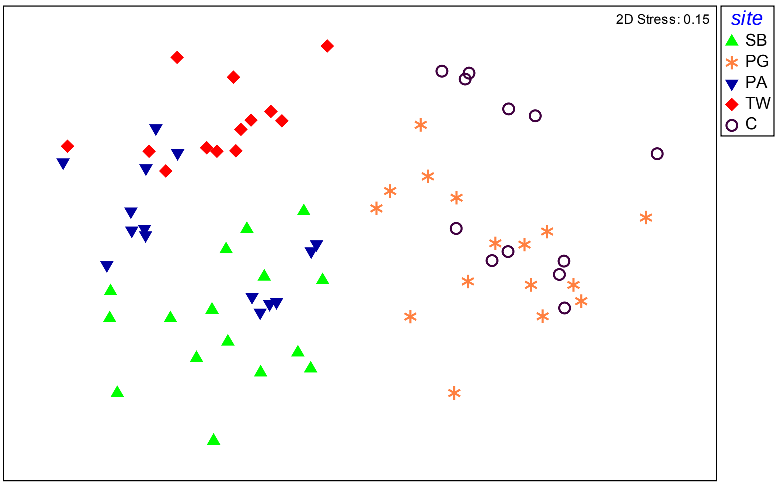

Figure 31: MDS plot of benthic assemblages at the studied mudflats around the Gulf St. Vincent sampled in summer 2006/07. The analysis is based on all replicates per site and all species. Data were square root transformed prior to analysis.

Table 13: Results of a similarity and dissimilarity analysis (SIMPER) of macrobenthic assemblages at the studied mudflats of the Gulf St. Vincent, South Australia, based on the summer survey (December 2006 – March 2007). The table lists the species contributing >5 % to the similarity within a site, and those contributing >5 % to the dissimilarity between two sites. The values shown are the respective percentages for each species. SB=Section Bank, PG=Pt Gawler, PA=Pt Arthur, TW=Tiddy Widdy, C=Coobowie. The species are arranged in the same taxonomic order as in Table 10 (note, taxonomic cross-check whether Nereididae sp. 1 = Neanthes vaalii not yet completed for all sites).

	SB	PG	PA	TW	C	SB-PG	SB-PA	SB-TW	SB-C	PG-PA	PG-TW	PG-C	PA-TW	PA-C	TW-C
Average similarity	33.48	32.64	36.73	39.37	31.37										
Average dissimilarity						92.50	79.50	86.62	97.09	94.99	95.49	73.42	75.33	97.05	94.66
Anthozoa	6.83														
Capitella cf capitata		19.59				9.44	5.74			9.96	10.39	8.63			
Heteromastus sp.	21.43		30.07				8.39	8.14		6.31			12.91	6.23	
Nereididae sp1			36.32	26.87			14.03	7.18		9.48	5.33		15.46	9.05	5.23
Neanthes vaalii		23.84			39.15	7.94			10.48	9.1	8.64			12.79	12.4
Australonereis ehlersi	7.22						5.04								
Nephtys australiensis	8.77		25.92	22.25			7.57	5.37					8.47	5.12	
Spio sp.	8.47						5.33								
Maldanidae				11.33									7.08		
Orbiniidae	8.14			6.71		5.26	6.09	5.74			5.02				
Tellina deltoidales	18.23						7.63	6.73							
Xenostrobus inconstans		31.12			19.15	16.17			11.27	18.39	17.49	17.08		12.79	12.64
Bivalve indet juv				17.04				8.26			5.81		11.96		5.81
Salinator cf fragilis		4.64		5.61	16.67				13.44	5.15	5.9	15.53	7.01	15.31	15.22
Turritellidae indet					5.45										

Apart from these differences in benthic communities on a regional scale, there were also differences within the study sites and, in the case of Section Bank, changes in community structure over time. On Section Bank, community differences between the sampling events were more pronounced than between the three subsites sampled on the bank (ANOSIM, March-November: R=0.772, p=0.001); subsites: R=0.449, p=0.001) (Figure 32). Capitellid polychaetes (*Capitella capitata* and *Heteromastus sp.*) contributed together 30% to the dissimilarity over time (SIMPER analysis). These two species as well as *Tellina deltoidales*, *Nephtys australiensis*, Orbiniidae, the mud cockle *Katelysia peronii* and, to a lesser degree, amphipods and *Polydora* sp. contributed further to both the similarity within subsites as well as discrimination between them.

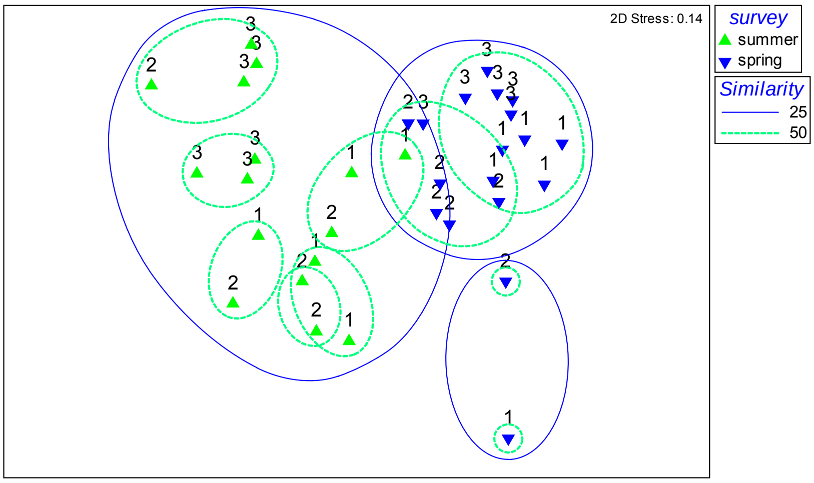

Figure 32: MDS plot of benthic assemblages on Section Bank, sampled in March and November 2007. The analysis is based on all replicates and all species. The numbers indicate the three subsites sampled on Section Bank. Data were square root transformed prior to analysis. The circles indicate an overlay Cluster analysis, with Bray-Curtis similarity levels.

The three subsites differentiated in the stratified random sampling approach at Port Gawler, had distinct benthic communities (ANOSIM R=0.628, p=0.001). The mussel bed near the saltmarsh and mangroves had a very different benthic assemblage compared to the sandflat at the outer edge of the mangrove forest (ANOSIM R=1, p=0.006), while the cockle bed, which occurred in the vicinity of the mussel bed, shared similarities with both mussel bed and sandflat (Figure 33). The species differentiating these assemblages were the bivalves *Xenostrobus inconstans* and *Mactra* sp., the nereidid polychaete *Neanthes vaalii*, polychaetes of the families Capitellidae, Orbinidae and Syllidae, and the snail *Salinator cf. fragilis* (SIMPER analysis).

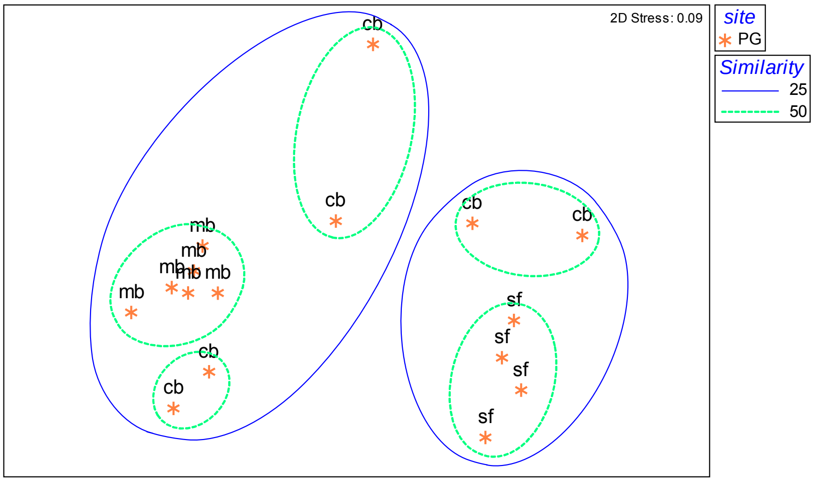

Figure 33: MDS plot of benthic assemblages at Port Gawler, sampled in summer 2006/07. The analysis is based on all replicates and all species. The subsites differentiated were a mussel bed (mb), a cockle bed (cb) and a sandflat (sf). Data were square root transformed prior to analysis. The circles indicate an overlay Cluster analysis, with Bray-Curtis similarity levels.

At Port Arthur, two distinct communities occurred, in the mid to low intertidal near the seagrass beds, and in a high intertidal mudflat occupied by the crab *Macrophthalmus latifrons* (subsite 3, Figure 34). The differences in the assemblage composition between these subsites were significant (ANOSIM, R=0.691, p=0.002). The polychaetes *Nephtys australiensis*, Nereididae, *Heteromastus sp*. and *Capitella cf. capitata* as well as unidentified juvenile bivalves, holothurids, callianassid shrimps and the snail *Salinator cf. fragilis* accounted for these differences between subsites (SIMPER analysis).

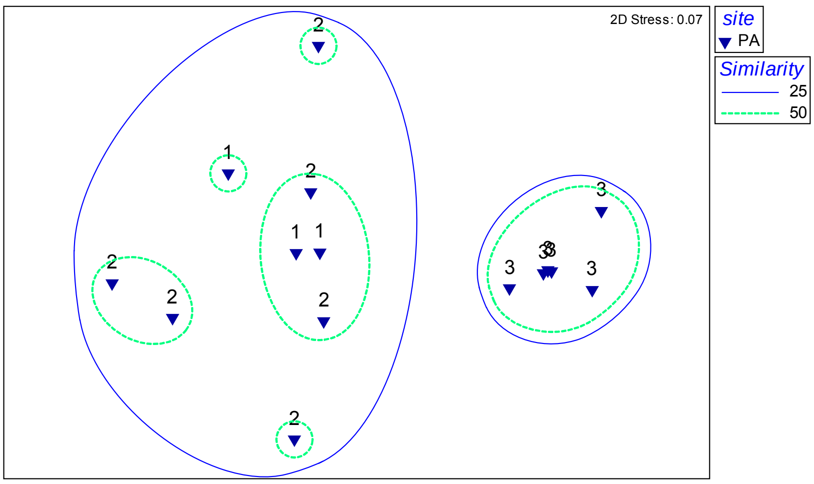

Figure 34: MDS plot of benthic assemblages at Port Arthur, sampled in summer 2006/07. The analysis is based on all replicates and all species. The three subsites differentiated are indicated by numbers. Data were square root transformed prior to analysis. The circles indicate an overlay Cluster analysis, with Bray-Curtis similarity levels.

Along the transect on the foreshore sandflat at Tiddy Widdy Beach, differences in assemblages were less pronounced between the three low to high intertidal sampling sites (ANOSIM R=0.518, p=0.001) (Figure 35). While some replicates shared more similarity in their benthic fauna (e.g. the mid intertidal station labelled 2 in Figure 35), this was not clearly related to the distance from shore. The polychaetes *Nephtys australiensis*, Nereididae, Orbinidae, Maldanidae, the molluscs *Salinator cf. fragilis* and unidentified juvenile bivalves, as well as Cumacea (Crustacea) were characteristic for the benthic assemblages within and between the subsites at this location (SIMPER analysis).

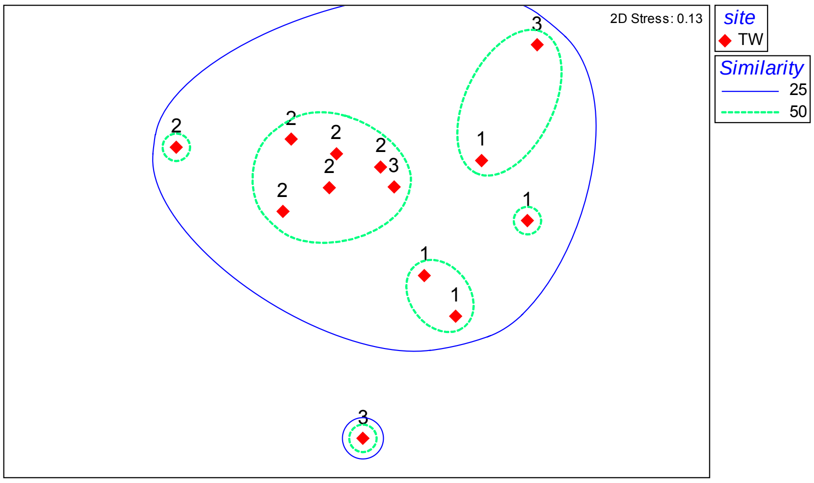

Figure 35: MDS plot of benthic assemblages at Tiddy Widdy Beach near Ardrossan, sampled in summer 2006/07. The analysis is based on all replicates and all species. The three subsites differentiated are indicated by numbers. Data were square root transformed prior to analysis. The circles indicate an overlay Cluster analysis, with Bray-Curtis similarity levels.

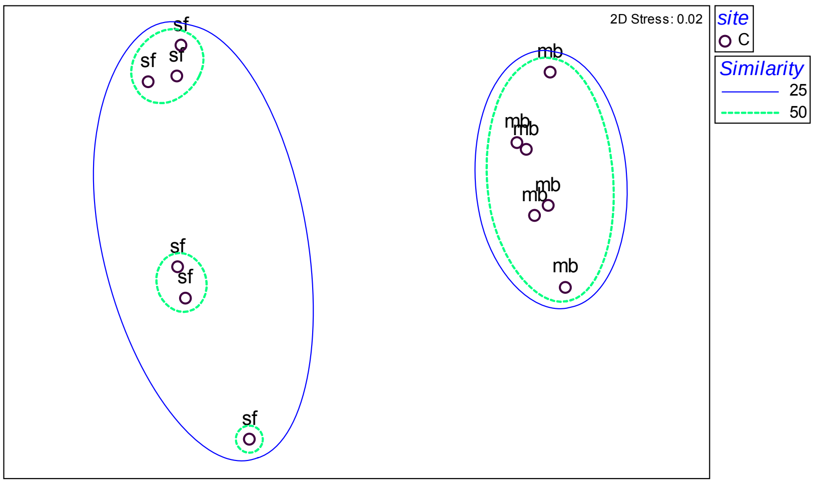

Figure 36: MDS plot of benthic assemblages at Coobowie, sampled in summer 2006/07. The analysis is based on all replicates and all species. The two subsites differentiated are a mussel bed (mb) and a sandflat (sf). Data were square root transformed prior to analysis. The circles indicate an overlay Cluster analysis, with Bray-Curtis similarity levels.

The two habitats differentiated by the stratified random sampling approach at Coobowie Bay revealed very distinct benthic communities at the mussel bed and sandflat (ANOSIM, R=0.891, p=0.002) (Figure 36). The dissimilarity between these two communities was 83.73% (SIMPER analysis) with the molluscs *Xenostrobus inconstans*, *Salinator cf. fragilis* and Turritellidae together with *Capitella cf capitata* and syllid polychaetes discriminating these habitats.

These results reveal two levels of benthic community differentiation, within and between sites. In some cases the within site community differences were higher than between sites, indicating that mudflats contain very distinct habitats for benthic fauna. In particular, the mussel beds sampled at Pt Gawler and Coobowie were inhabited by unique faunal assemblages, resulting in the pattern seen in Figure 30).

4.2.3 Comparison of mudflat communities between the Fleurieu peninsula and Gulf St. Vincent

4.2.3.1 Diversity

The open and extensive tidal flats around the Gulf St. Vincent were inhabited by a much more diverse benthic fauna than the mudbanks lining the estuaries of the Fleurieu Peninsula (Figure 37). The average number of macrobenthic species found in the mudflats around the Fleurieu Peninsula was 9, compared to 26 around the Gulf St. Vincent. Species numbers and the Shannon-Wiener diversity index (H') were significantly different across the regions, and H' also across the two sampling times of summer and spring (but note that the sites around the Gulf St. Vincent were only sampled in summer, apart from Section Bank) (Table 14).

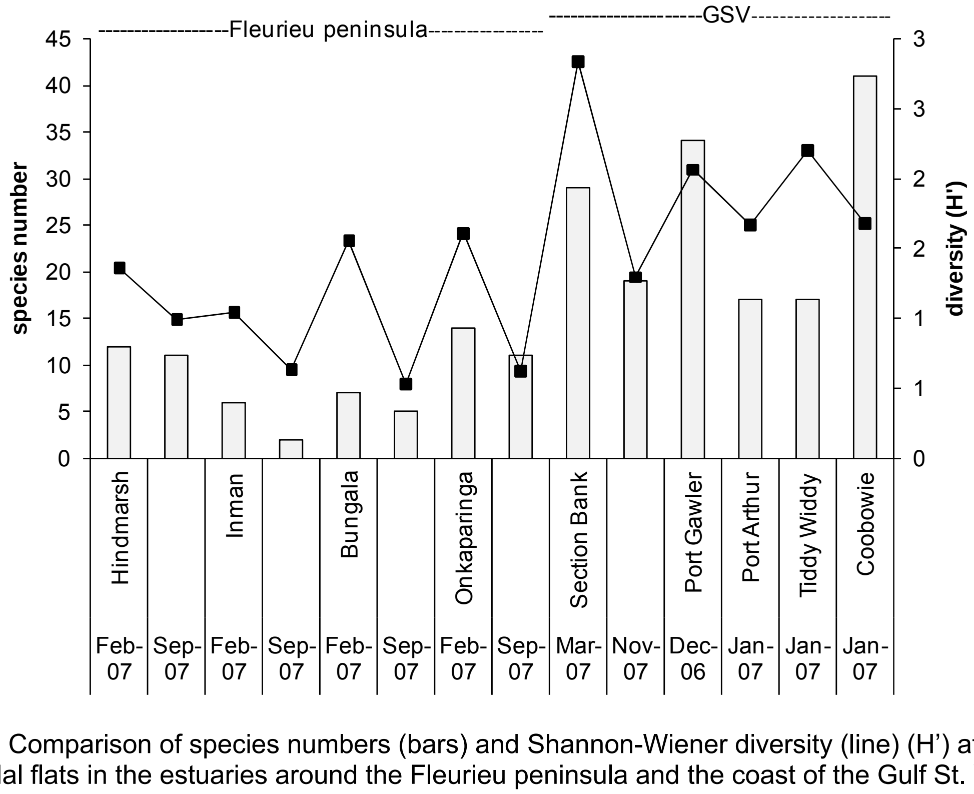

Figure 37: Comparison of species numbers (bars) and Shannon-Wiener diversity (line) (H') at the studied tidal flats in the estuaries around the Fleurieu peninsula and the coast of the Gulf St. Vincent.

Table 14: One way ANOVA for the summer survey across regions, and two way ANOVA with region (Fleurieu peninsula and Gulf St. Vincent) and season (summer and spring) as factors, to test for significant differences in species numbers and Shannon-Wiener diversity (H'). Note that of the Gulf St. Vincent sites only Section Bank was sampled in both seasons. Signficant results are highlighted in bold.

		df	MS	F	p
Summer					
Species number	region	1	708.050	10.075	**0.016**
	Error	7	70.279		
Diversity (H')	region	1	1.076	6.773	**0.035**
	Error	7	0.159		
Summer and spring					
Species number	region	1	515.388	9.325	**0.012**
	season	1	72.476	1.311	0.279
	region * season	1	21.888	0.396	0.543
	Error	10	55.270		
Diversity (H')	region	1	0.988	7.996	**0.018**
	season	1	1.304	10.555	**0.009**
	region * season	1	0.005	0.044	0.838
	Error	10	0.124		

4.2.3.2 Abundances

Abundances of benthic macrofauna was highly variable between sites, irrespective of their location (Figure 38). Two of the three sites with mean abundances over 10000 individuals m^{-2} were located in the Gulf (Port Gawler and Coobowie) and one on the Fleurieu Peninsula (Hindmarsh river estuary). A two-way ANOVA with region and season as factors showed no significant results for seasonal differences, nor any interaction effects of region and season. As not all of the sites around the Gulf were sampled again in spring, one-way ANOVA analyses were carried out for the total macrobenthos

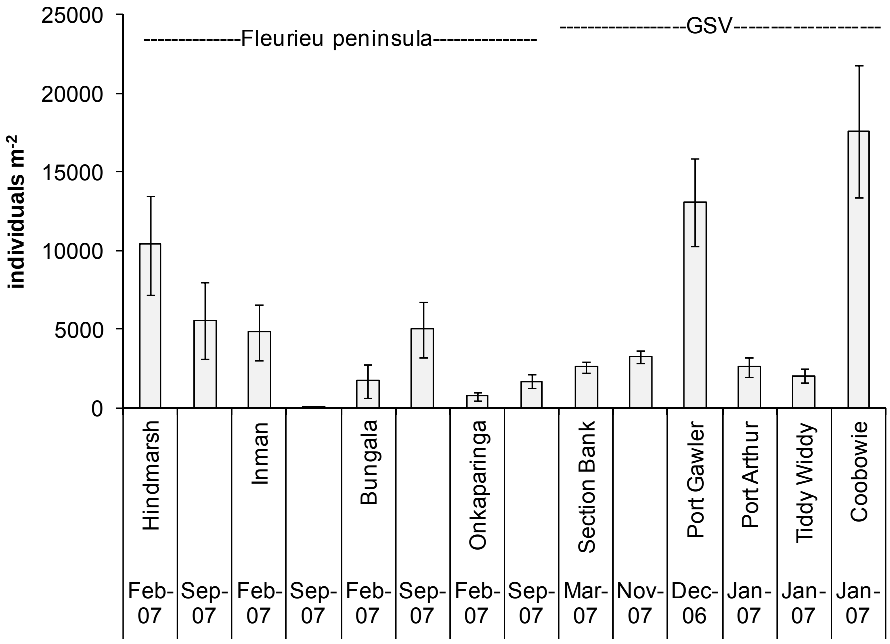

Figure 38: Comparison of macrobenthic abundances (means ± SE) at the studied tidal flats in the estuaries around the Fleurieu peninsula and the coast of the Gulf St. Vincent.

and major phyla of the summer survey. Only molluscs, which were more abundant at the tidal flats in the Gulf, and insects, which were more abundant in the estuaries around the Fleurieu peninsula, were significantly different across regions (Table 15).

Table 15: One way ANOVA with region (Fleurieu peninsula and Gulf St. Vincent) as factor, to test for significant differences in abundances The abundances of the total macrobenthos and Crustacea were square-root transformed prior to analysis, and those of mollusc and insects log-transformed. Signficant results are highlighted in bold.

		df	MS	F	p
Total benthos	region	1	1494.683	1.322	0.273
	Error	12	1130.696		
Annelida	region	1	647511.783	0.176	0.682
	Error	12	3681623.552		
Crustacea	region	1	138.908	3.798	0.075
	Error	12	36.571		
Mollusca	region	1	55.289	9.406	**0.010**
	Error	12	5.878		
Insecta	region	1	54.576	10.472	**0.007**
	Error	12	5.211		

4.2.3.3 Communities

The benthic communities in the mudflats of the estuaries around the Fleurieu Peninsula and the Gulf St. Vincent shared only about 30% similarity (Figure 39), and were significantly different from each other (ANOSIM: R=0.59, p=0.001). In the comparison across all survey sites, the similarity between sites stayed the same as in the analyses for each region (see Figures 14 and 30), with the Inman

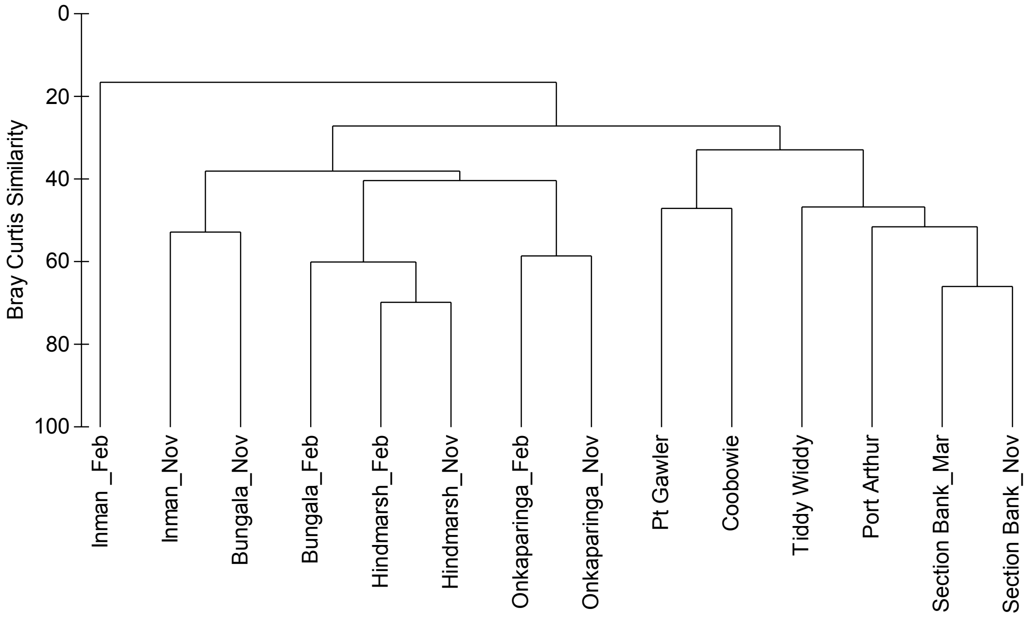

Figure 39: Dendrogram of a cluster analysis of benthic infauna at all study sites around the Fleurieu Peninsula and Gulf St. Vincent sampled between December 2006 and November 2007. The analysis is based on the mean values across replicates per site and on family level (where several taxa occurred per family, as for Capitellidae, Nereididae, Nassariidae, and combined insect larvae). Data were fourth root transformed prior to analysis.

River samples from February constituting an outlying situation. The average dissimilarity between the two regions (Fleurieu and Gulf St. Vincent) was 75.67 (SIMPER analysis), with insect larvae, polychaetes of the families Nereididae, Nephtyidae, Capitellidae and Orbiniidae as well as the pulmonate snail *Salinator cf. fra*gilis contributing most to this dissimilarity. In total, 43 species/higher taxa played a part in reaching 90% of cumulative contribution to this dissimilarity. Mudflats in these two regions or habitat types (estuarine *vs*. coastal) were inhabited by very distinct macrobenthic communities.

4.3 Biomass

Biomass was determined during the survey in spring 2007. Benthic biomass was nearly 16 x higher on Section Bank (31.73 g afdw m^{-2}) than in the estuaries around the Fleurieu peninsula (average for the four estuaries: 2.05 g afdw m^{-2}) (Figure 40). Polychaetes and molluscs, in particular bivalves, accounted for most of the biomass, and the higher abundances of these taxa caused the respective biomass pattern across sites (Figure 40). The burrowing callianassid shrimp *Biffarius arenosus*, makes up the crustacean biomass on Section Bank. Apart from insect larvae, which contributed very little, the biomass values were significantly different across the five sites (H-Tests: Annelida $p<0.001$; Crustacea $p<0.001$; Bivalvia and Mollusca $p<0.01$; total benthos $p<0.001$).

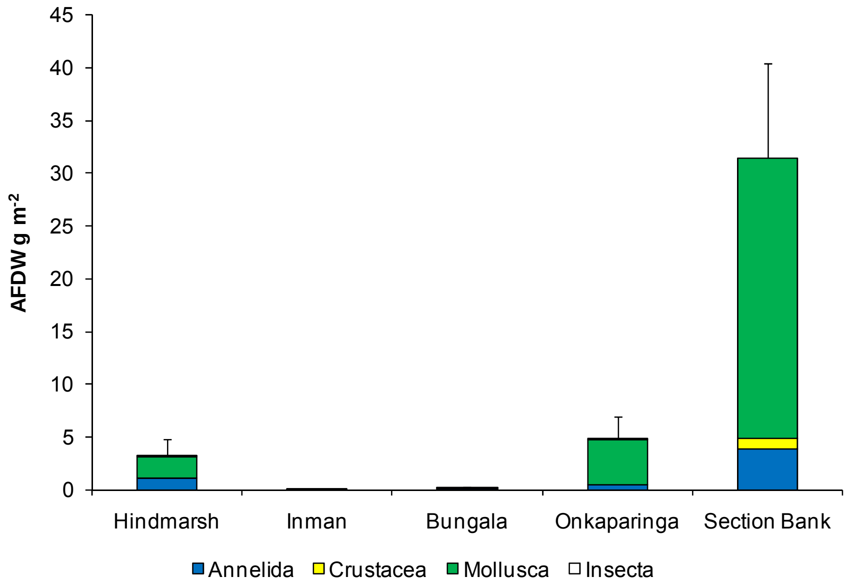

Figure 40: Biomass (Ash-free dry weight AFDW m^{-2}, mean ± SE) of macrobenthos and the major constituting phyla from the Fleurieu Peninsula and Section Bank mudflats sampled in spring 2007.

5. Discussion

Infaunal communities in intertidal soft sediment habitats of the Gulf St. Vincent have not been surveyed to this detail before. The majority of benthic organisms encountered in this study were similar to species occurring in estuarine and intertidal sediments around southern Australia, at least on family or genus level (compare for example Edgar et al. 1999; Macfarlane & Booth, 2001; Hirst 2004; Winberg et al. 2007), with detailed taxonomic identifications and confirmations for several species still outstanding. Yet there was site specific idiosyncrasy in species composition and especially many of the rarer polychaetes were encountered at single sites only. The occurrence of rarity has been reported for temperate and tropical mudflats around Australia (Dittmann 2007), and can be due to the site specific histories as well as the biogeography of biota in Australia's coastal ecosystems.

The usefulness of higher taxonomic levels for benthic monitoring has been discussed and several studies have found that site discrimination on species or family level does not differ (Olsgard & Somerfield 2000; Macfarlane & Booth 2001; Terlizzi et al. 2003). In the investigations presented here, the multivariate analyses gave the same assemblage structures based on species or family level. While this can lead to the conclusion that higher taxonomic levels may suffice for monitoring changes in communities, other research questions still necessitate species specific studies (Vanderklift et al. 1998). Therefore, the taxonomic level chosen has to be decided based on the objective of a study.

The suspension-feeding bivalve *Soletellina alba* is common in estuaries around southern Australia and was found in particular at the Hindmarsh estuary, but in lower numbers also on Section Bank and at Coobowie. In Victoria, abundances of this species were found to vary over time in relation to salinity, dissolved oxygen, and drought conditions were more favourable than winter floods which reduced salinity in the estuary (Matthews 2006). This can be corroborated by the findings in the Hindmarsh estuary over the two sampling occasions of this study. The effects of drought on estuarine and coastal benthos can be more complex with species specific responses (Attrill & Power 2000; Kanadjembo et al. 2001). In particular, the opening of estuaries is of importance for the estuarine benthic communities and can be a management tool (Teske & Woolride 2001; Dye & Barros 2005). Our understanding of seasonal or temporal variation, recruitment and adaptations of benthic fauna in southern Australia is very limited and further investigations in this area are advised to evaluate future changes in relation to climate change or other man made modifications of coastal habitats.

Another bivalve which was found to be increasingly common in estuaries in South Australia (this study and own observations) is the deep-dwelling deposit-feeding *Tellina deltoidales*, which may be a useful indicator for estuarine pollution (King et al. 2004; Honkoop, pers. comm.). The prevalence of capitellid polychaetes can also be seen an indication for stressed conditions, possibly due to the higher nutrient concentrations recorded at the sites (Grassle & Grassle 1976; Pearson & Rosenberg 1978). None of the estuaries investigated for this study was pristine, they were all located in the vicinity to human settlements and recreational usage was apparent at all sites.

The species numbers found in the estuaries and tidal flats of this study fall within the lower ranges of records from estuaries in other parts of the world (Attrill et al. 2001; Dittmann et al. 2006). The same applies to abundances and biomass values, whereby only Section Bank provides benthic biomass in comparable amounts as the richer foraging grounds along the flyway of migratory waders (Riccardi & Bourget 1999; Dittmann et al. 2006).

Some of the highest abundances and diversity values recorded in this study were linked to the occurrence of mussel and cockle beds. Dense aggregations of these bivalves create biogenic structures with specific habitat value (Buschbaum et al. in press; Reise 2002). There was little overlap in the benthic assemblages found in the mussel beds and bare sandflats, resulting in an overall increase in diversity of a tidal flat. The presence or absence of such ecosystem engineering species can thus determine the overall biodiversity occurring at a site. Another group of species found during this survey with the ability to provide biogenic structures which are known to have positive effects on associated infauna are callianassid shrimps like *Biffarius arenosus* (Dittmann, 1996; Bird et al. 2000). It should be explored further whether such ecosystem engineers can be used as surrogates for benthic biodiversity.

We carried out a detailed study extracting the benthic fauna from the sediment. Approaches using underwater video or diver transects have become increasingly popular, yet they are only providing information on epifaunal organisms, or benthic organisms protruding above the sediment surface like the razorshell *Pinna bicolor*. While such methods are appropriate to map sediment type and seagrass distribution, they are insufficient to assess the diversity of organisms living inside the sediment (Hewitt et al. 1998). This can result in a misjudgement of the habitat value of an area and planning advice given (Stevens & Connolly 2004). For example, based on video and diver transects Cheshire et al. (2002) concluded that the central part of Section Bank near the Port River had a low conservation value and consisted mainly of bare sand. The study presented here, however, revealed that one of the highest biodiversities of intertidal soft sediment habitats found along the Gulf coast occurred at this location. Assessments of conservation value should clearly be made on comprehensive community assessments considering both epi- and infaunal organisms.

While this study has shown a greater similarity within the estuarine and exposed tidal flats than between them, the analysis for each of the two regions has also highlighted very site-specific faunal communities. A similar heterogeneity of estuarine macrofauna was recorded by Hirst (2004) and Edgar et al. (1999) for estuaries across New South Wales, Victoria and Tasmania respectively, and for tropical mudflat communities by Dittmann & Vargas (2001). Such idiosyncrasy in benthic communities on local and regional scales implies a need for site specific assessment of conservation and management needs. Furthermore, the stratified random sampling approach used here revealed within site variation, comparable to the reported heterogeneity within tidal flats in New South Wales (Winberg et al. 2007). This has got implications for conservation efforts, which need to consider the comprehensiveness, adequacy and representativeness of marine seascapes for the design of marine reserves. For the conservation of tidal flat biodiversity this necessitates a network of several extensive tidal flats along the coastline.

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6. References

Attrill, M.J. & Power, M. 2000. Effects on invertebrate populations of drought-induced changes in estuarine water quality. Marine Ecology Progress Series 203: 133-43.

Attrill, M.J., Stafford, R. & Rowden, A.A. 2001.Latitudinal diversity patterns in estuarine tidal flats: indications of a global cline. Ecography 24: 318-24.

Banks, S.A. & Skilleter, G. 2002. Mapping intertidal habitats and an evaluation of their conservation status in Queensland, Australia. Ocean & Coastal Management 45: 485-509.

Benkendorff, K., Fairweather, P. & Dittmann, S. 2008. Intertidal Shores: Life on the Edge. Chapter 10 In: Natural History of Gulf St Vincent. Eds.: S.A. Shepherd, S. Bryars, I. Kirkegaard, P. Harbison, & J.T. Jennings. Royal Society of South Australia Inc., Adelaide. pp 121-131.

Bird, F.L., Boon, P.I. & Nichols, P.D. 2000.Physicochemical and microbial properties of burrows of the deposit-feeding thalasinidean ghost shrimp *Biffarius arenosus* (Decapoda: Callianassidae). Estuarine, Coastal and Shelf Science **51**: 279-91.

Buschbaum, C., Dittmann, S., Hong, J.-S., Hwang, I-S., Strasser, M., Thiel, M., Valdivia, N., Yoon, S.-P. & Reise, K. in press. Mytilid mussels: idiosyncratic habitat engineers in coastal sediments. Helgoland Marine Research

Cheshire, A.C., Miller, D.J., Murray-Jones, S., Scriven, L. & Sandercock, R. 2002. The Section Bank: Ecological Communities and Strategies for the Minimization of Dredging Impacts. A Report to the Office for Coast and Marine, National Parks and Wildlife South Australia. Department for Environment and Heritage. SARDI Aquatic Sciences, Adelaide 60 pp.

Dittmann, S. 1996. Effects of macrobenthic burrows on infaunal communities in tropical tidal flats. Marine Ecology Progress Series 134: 119-30.

Dittmann, S. 2007. Soft Sediments. Chapter 16. In: Marine Ecology. Eds.: S.D. Connell & B.M. Gillanders. Oxford University Press, South Melbourne. pp 428-456.

Dittmann, S. & Vargas, J.A. 2001. Tropical tidal flat benthos compared between Australia and Central America. In: Ecological Comparisons of Sedimentary Shores. Ed K. Reise. Springer, Berlin, pp. 275-93

Dittmann, S., Cantin, A., Noble, W., Pocklington, J. 2006. Macrobenthic survey 2004 in the Murray Mouth, Coorong and Lower Lakes Ramsar site, with an evaluation of food availability for shorebirds and possible indicator functions of benthic species. Department for Environment and Heritage, Adelaide. ISBN: 1921018828. 55 pp.

Dye, A. & Barros, F. 2005.Spatial patterns of macrofaunal assemblages in intermittently closed/open coastal lakes in New South Wales, Australia. Estuarine, Coastal and Shelf Science 64: 357-71.

Dyer, K.R. 1998. The typology of intertidal mudflats. In: Sedimentary Processes in the Intertidal Zone. Eds.: K.S. Black, D.M. Paterson and A. Cramp. Geological Society, London. pp. 11-24.

Edgar, G.J., Barrett, N.S. & Last, P.R. 1999. The distribution of macroinvertebrates and fishes in Tasmanian estuaries. Journal of Biogeography 26: 1169-89.

Edyvane, K. 1999. Coastal and marine wetlands in Gulf St. Vincent, South Australia: understanding their loss and degradation. Wetlands Ecology and Management 7: 83-104.

Freeman, S.M. & Rogers, S.I. 2003. A new analytical approach to the characterisation of macro-epibenthic habitats: linking species to the environment. Estuaries, Coastal and Shelf Science 56: 749-764.

Grassle, J.F. & Grassle, J.P. (976. Sibling species in the marine pollution indicator *Capitella* (Polychaeta). Science 192: 567-569.

Gillanders, B.M., Elsdon, T.S. & Hammer, M. 2008. Estuaries of the Gulf St. Vincent, Investigator Strait, and Backstairs Passage. Chapter 14. In: Natural History of Gulf St Vincent. Eds.: S.A. Shepherd, S. Bryars, I. Kirkegaard, P. Harbison, & J.T. Jennings. Royal Society of South Australia Inc., Adelaide. pp 177-196.

Hall, S.J., Gray, S.A. & Hammett, Z.L. 2000. Biodiversity-productivity relations: an experimental evaluation of mechanisms. Oecologia 122: 545-555.

Hewitt, J.E., Thrush, S.F., Cummings, V.J. & Turner, S. 1998. The effect of changing sampling scales on our ability to detect effects of large-scale processes on communities. Journal of Experimental Marine Biology and Ecology 227: 251-64.

Hewitt, J.E., Thrush, S.F., Legendre, P., Funnell, G.A., Ellis, J. & Morrison, M. 2004. Mapping of marine soft-sediment communities: integrated sampling for ecological interpretation. Ecological Applications 14: 1203-1216.

Hirst, A. 2004. Broad-scale environmental gradients among estuarine benthic macrofaunal assemblages of south-eastern Australia: implications for monitoring estuaries. Marine and Freshwater Research 55: 79-92.

Kanandjembo, A.N., Platell, M. E. & Potter, I.C. 2001. The benthic macroinvertebrate community of the upper reaches of an Australian estuary that undergoes marked seasonal changes in hydrology. Hydrological Processes 15: 2481-2501.

King, C.K., Dowse, M.C., Simpson, S.L. & Jolley, D.F. 2004. An assessment of five Australian polychaetes and bivalves for use in whole sediment toxicity tests: toxicity and accumulation of copper and zinc from water and sediment. Archives of Environmental Contamination and Toxicology 47: 314-323.

Levin, L.A., Boesch, D.F., Covich, A., Dahm, C., Erséus, C., Ewel, K.C., Kneib, R.T., Moldenke, A., Palmer, M.A., Snelgrove, P.V.R., Strayer, D. & Weslawski, J.M. 2001. The function of marine critical transition zones and the importance of sediment biodiversity. Ecosystems 4: 430-51.

Macfarlane, G.R. & Booth, D.J. 2001. Estuarine macrobenthic community structure in the Hawkesbury River, Australia: Relationships with sediment physicochemical and anthropogenic parameters. Environmental Monitoring and Assessment 72: 51-78.

Matthews, T. G. 2006. Spatial and temporal changes in abundance of the infaunal bivalve *Soletellina alba* (Lamarck, 1818) during a time of drought in the seasonally-closed Hopkins River Estuary, Victoria, Australia. Estuarine, Coastal and Shelf Science 66:13-20

Olsgard, F. & Somerfield, P.J. 2000. Surrogates in marine benthic investigations – which taxonomic unit to target? Journal of Aquatic Ecosystem Stress and Recovery 7: 25-42.

Pearson ,T.H. & Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography Marine Biology Annual Review 16: 229-311.

Raffaelli, D., Emmerson, M.C., Solan, M., Biles, C. & Paterson, D.M. 2003. Biodiversity and ecosystem processes in shallow coastal waters: an experimental approach. Journal of Sea Research 49:133-41.

Reise, K. 2002. Sediment mediated species interactions in coastal waters. J. Sea Res. 48: 127-41.

Ricciardi, A. & Bourget, E. 1999.Global patterns of macroinvertebrate biomass in marine intertidal communities. Marine Ecology Progress Series 185: 21-35.

Roff, J.C., Taylor, M.E. & Laughren, J. 2003. Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities. Aquatic Conservation: Marine and Freshwater Ecosystems 13: 77-90.

Seuront, L. & Leterme, C. 2006. Microscale patchiness in microphytobenthos distributions: evidence for a critical state. In: Functioning of Microphytobenthos in Estuaries. Royal Netherlands Academy of Arts and Science. pp 167-185

Snelgrove, P.V.R. 1998. The biodiversity of macrofaunal organisms in marine sediments. Biodiversity and Conservation 7: 1123-32

Snelgrove, P.V.R., Blackburn, T.H., Hutchings, P.A., Alongi, D.M., Grassle, J.F., Hummel, H., King, G., Koike, I., Lambshead, P.J.D., Ramsing, N.B. & Solis-Weiss, V. 1997. The importance of marine sediment biodiversity in ecosystem processes. Ambio 26:, 578-83.

Stevens, T. & Connolly, R. 2004. Testing the utility of abiotic surrogates for marine habitat mapping at scales relevant to management. Biological Conservation 119: 351-362.

Terlizzi, A., Bevilacqua, S., Fraschetti, S. & Boero, F. 2003. Taxonomic sufficiency and the increasing insufficiency of taxonomic expertise. Marine Pollution Bulletin 46: 556-561.

Teske, P.R. & Wooldride T. 2001. A comparison of the macrobenthic faunas of permanently open and temporarily open/closed South African estuaries. Hydrobiologia 464: 227-43.

Thrush, S.F., Hewitt, J.E., Norkko, A., Nicholls, P.E., Funnell, G.A. & Ellis, E.I. 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecological Progress Series 263: 101-112.

Valiela, I. 2006. Global Coastal Change. Blackwell Publ., Oxford, 376 pp.

Vanderklift, M.A., Ward, T.J. & Phillips, J.C. 1998. Use of assemblages derived from different taxonomic levels to select areas for conserving marine biodiversity. Biological Conservation 86: 307-15.

Winberg, P.C., Lynch, T.P., Murray, A., Jones, A.R. & Davis, A.R. 2007. The importance of spatial scale for the conservation of tidal flat macrobenthos: An example from New South Wales, Australia. Biological Conservation 134: 310-320.