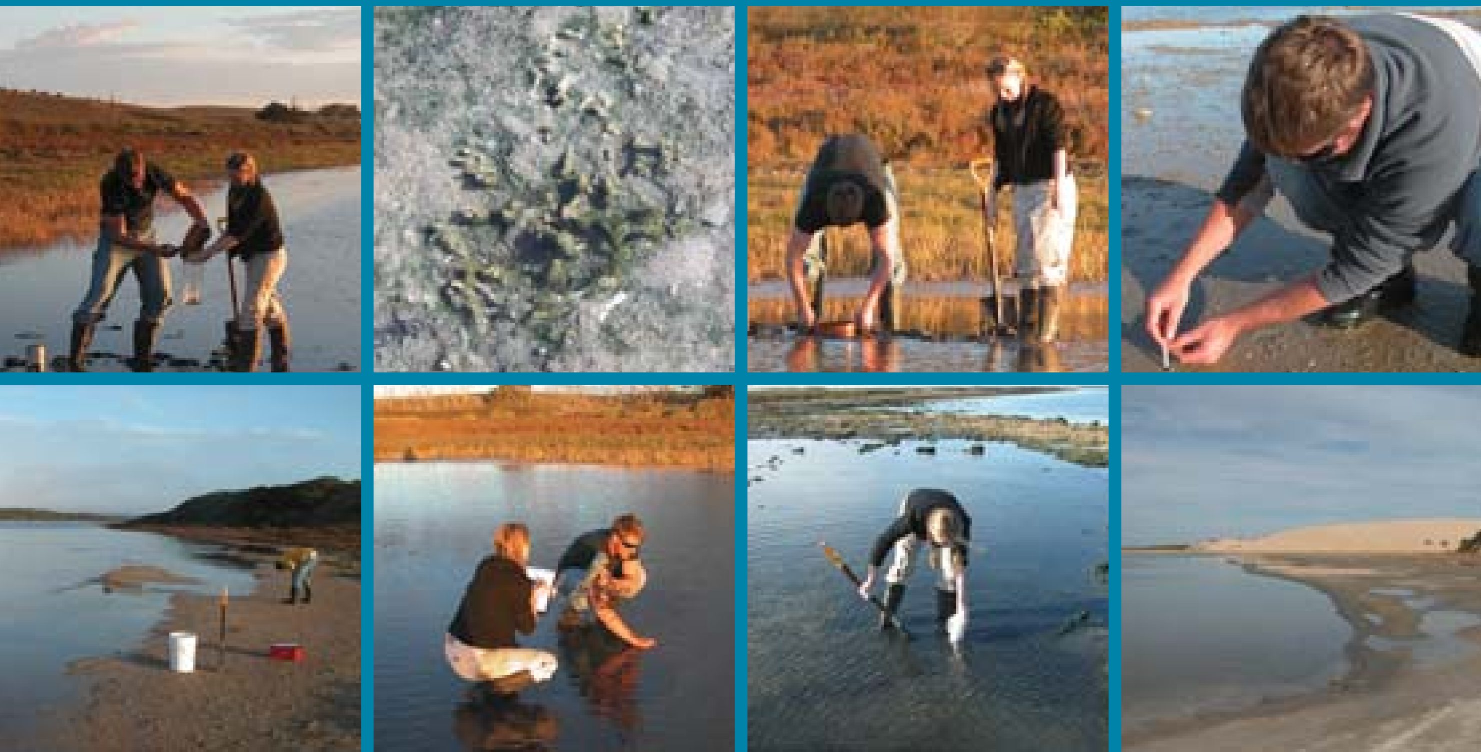
Department for Environment and Heritage

Macrobenthic Survey 2004



Murray Mouth, Coorong and Lower Lakes Ramsar site

Includes an evaluation of food availability for shorebirds and possible indicator functions of benthic species

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Appendices

*These tables are not included here but are available upon request.

1. Executive summary

Study

This report provides results from two surveys on the mudflat macrofauna at 26 sites along the Coorong, Murray Mouth region and Lake Alexandrina, carried out in winter (7th to the 10th June) and summer (13th to the 17th December) 2004. The objective was to assess the spatial distribution of food availability for migratory shorebirds. Data from bird surveys were provided by the DEH, yet the data set was discovered to be incomplete during the analysis. Macrobenthic diversity, abundances, biomass, community structure and several sedimentary and water quality parameters were determined. This is the first investigation on benthos and links between birds and benthos extending from the South Lagoon to the Goolwa barrage, and the Murray Mouth region turned out to be the ecologically most valuable region of the study area.

Environmental conditions

The environmental conditions at the sites ranged from freshwater to hypersaline. The sites with highest abundances of macrofauna were located in the marine/estuarine part of the study area where salinity ranged from 26 to 32 ppt. The hypersaline lagoons of the Coorong with salinities over 100 ppt were almost devoid of macrofauna. Water temperatures were on average 15°C in June and 25°C in December. In the Coorong, high salinities coincided with temperatures over 30°C, creating a thick and soft brine. Oxygen concentrations in the water were low, especially in summer, when oxygen saturation levels were also lower at most sites. Sediments were usually fine to medium sands and well sorted, with coarser sediment in the South Lagoon and muddier sediment occurring at some lake sites. Contents of organic matter in the sediment were low to moderately high (0.13 to 6.7 % d.w.) and varied within and between sites. Organic matter contents at the Lake sites were 3 x higher than in the other study regions.

Diversity and abundances

Diversity in mudflat macrofauna was low. A total of 48 benthic species was distinguished, yet 19 thereof were insects and no typical estuarine macrobenthos. Species richness was highest near the Murray Mouth between the Goolwa Barrage and the northern end of the North Lagoon (29 species), where abundances were also high (> 27,000 individuals m^{-2}). Abundances in this region are comparable to densities recorded in estuarine mudflats in other subtropical locations. Mean abundances of total macrofauna near the Murray Mouth were 5 to 37 x higher than in the South Lagoon or at the lake sites. The South Lagoon had the lowest number of species and individuals and many sites were devoid of macrofauna. This large scale distribution pattern was persistent over both sampling occasions and corroborates other findings on the critical state of the Coorong. On a smaller scale, abundances increased in the moister sediments towards the water line compared to dryer sediment conditions near the shoreline. This is affecting the availability and accessibility of benthic food for waders.

Indicator functions of macrofauna

Near the Murray Mouth, the benthos was dominated by amphipods and polychaetes, whereas insects prevailed in the South Lagoon and lake. Based on a literature review and this study, preference curves were set up for several species. Most species occurring in estuaries are tolerant towards a wide range of environmental conditions, complicating their usefulness as indicators. Yet, the pronounced boundary in the distribution of marine macrofaunal species north and south of site 21 at the northern end of the Coorong coincides with the sharp increase in salinity. An extension of the distribution range of the estuarine macrofauna into the Coorong could be a useful indication for improved environmental conditions. Correspondingly, the decrease in abundances of macrofauna at sites 21 and 22 in December could be linked to the northward extension of the unfavourable hypersaline conditions in the Coorong in summer. Yet, further information is required on temporal fluctuations in abundances.

Benthic communities

Benthic communities in the four regions were significantly different, although fairly dissimilar from each other at several sampling sites. Two well defined benthic communities were identified, one in the Murray Mouth region, characterised by the polychaete *Simplisetia aequisetis* and the bivalve *Arthritica helmsi*, and one in the South Lagoon, characterised by insects (Chironomidae). The similarities were especially high between sites located in front of the barrages (Boundary Creek to Pelican Point), and site 20 (Pelican Point) has to be ecologically considered as part of the Murray Mouth region.

Biomass

Although abundances of macrofauna were high in the Murray Mouth region, the biomass available for bird consumption was low. The average biomass in this region was 2.58 g ash-free dry weight (afdw) per m^2, and less than 1 g afdw m^{-2} were recorded in the other regions, with the lowest values from the lake sites (0.3 g afdw m^{-2}). Polychaetes, which accounted for most of the biomass, were confined in their distribution to the Murray Mouth. Despite for these polychaetes with larger individual sizes, most of the potential food items for the waders in the study area were small in size. Compared to other estuaries along the flyway of the shorebirds, biomass in the study area was about 10 x lower. The benthic food available for migratory shorebirds in mudflats of the Coorong as revealed by this study may not sustain their food requirements.

Birds

The Coorong and estuary of the Murray River is an overwintering site for over 20 species of shorebirds, of which more than half are migrating to the northern hemisphere to breed. The migration pattern is apparent in the phenology, with highest numbers of waders between October and April, and most pronounced in the Murray Mouth region, where wader numbers were also higher than in the Coorong. Shorebird numbers around Lake Alexandrina were low, irrespective of migration periods. In 2004, waders were concentrated near the Murray Mouth and Parnka Point in the Coorong. While macrofaunal food was available in the Murray Mouth region, the distribution pattern of the shorebirds did not completely match the spatial pattern of macrofauna abundances and biomass. Yet the mere presence of birds gives no indication of their foraging activity and further studies are needed on the feeding behaviour and food uptake rates.

Recommendations for future management

The environmental conditions in the study area are currently characterised by sharp, man-made environmental gradients. Unlike in natural estuaries, the continuous mixing and exchange between sea- and freshwater is inhibited. The resulting salinity gradients are further accelerated by low water levels and saline groundwater influx into the Coorong. This study demonstrated a link between these environmental conditions and the mudflat macrofauna, confining the estuarine species to sites near the Murray Mouth which are still under some marine influence. These findings may be an indication that not only further water release over the barrages is needed to raise the water level in the Coorong, but an increased water exchange between the ocean, Coorong and Lakes is equally important for the health of this estuary.

Recommendations for future monitoring

With continuing anthropogenic influences in the Murray and Coorong as well as under future climate change scenarios, it is important to follow the response in the numbers and distribution patterns of macrobenthos and shorebirds. Discussions on the bird data set have already contributed to a revision of the frequency of the bird survey. Synchronous bird counts in all regions of the study area should be a future goal. The high similarity in the macrobenthic communities between several nearby sites allows a reduction in the number of sampling sites in the Murray Mouth and South Lagoon. This study has indicated some variation between June and December, yet whether these were due to seasonality, bird predation or other factors remains unknown until long-term data with a higher temporal resolution become available. To assess the amount of macrobenthic food available for the shorebirds upon arrival from the northern hemisphere, it is recommended to carry out an annual monitoring on a larger spatial scale in spring. Alternatively or additionally, a survey in autumn after the bird departure can provide information on the standing stock of benthic food in the mudflats. As to which parameters to assess, the respective objectives have to be considered. Shorebirds will not differentiate between single amphipod species as prey; therefore no species specific distinction of this taxon is needed for food availability studies. The same applies to the various insect larvae which constituted the only macrofauna at sites in the Coorong and lakes. Polychaetes on the other hand, which differ in size and depth distribution, have to be recorded on species level to evaluate their contribution to the harvestable food for certain shorebird species. A separation of sediment horizons is recommended for the future to provide information on the amount of food available for shorebirds with different bill lengths. Both abundance and biomass determinations are crucial for monitoring of food availability for higher trophic levels. Long-term monitoring can be combined with further investigations on specific ecological or management questions.

2. Introduction

Estuaries are critical transition zones between the land and the sea (Levin et al. 2001) and worldwide under environmental pressure (Wolff 1990). Modifications of estuaries result from urban development, port expansion, and coastal protection (Doornbos & Groenendijk 1986, Smaal & Nienhuis 1992). Many estuaries throughout northern Europe have been blocked by storm surge barriers to prevent flooding of the hinterland at extreme storm events (Smaal & Nienhuis 1992). Other estuaries or bays have been dammed for land reclamation purposes or preventing saltwater intrusion into river basins (Doornbos & Groenendijk 1986, Shuttleworth et al. 2005).

Barrages across the estuary of the Murray River were set up in the 1940´s (Shuttleworth et al. 2005). Years of drought and poor water management further upstream in the Murray-Darling river system (Goss 2003), reduced water levels, saltwater incursion in the south-east, and poor environmental conditions in the Coorong Lagoon and Murray estuary have raised concerns about the health of this wetland and its function as an overwintering site for shorebirds (Geddes 2003, 2005a, b, Paton 2003, Gosbell & Christie 2005). Over 20 species of shorebirds occur in this wetland, yet shorebird numbers have declined in recent years (Gosbell & Christie 2005). The Coorong and Lakes Alexandrina and Albert have the status of a Wetland of International Importance since 1985 and a review of the Ramsar management plan is currently in progress (Phillips et al. 2005).

Changes in estuarine and wetland habitats, as well as in the benthos as their major food, have been shown to effect shorebird numbers and distributions (Raffaelli 1999, Stillman et al. 2005). Shorebirds can thus be used to indicate the health of a system (Martinez Fernandez et al. 2005, West et al. 2005). Coastal wetlands in the southern hemisphere constitute non-breeding habitats for many species of migratory shorebirds (Piersma et al. 1993a). These migratory shorebirds rely on sufficient food supply in the mudflats along their flyways. Coastal wetlands containing high (> 100,000) numbers of shorebirds are characterised by extensive sand- and mudflats in the vicinity of regions with high coastal zone productivity (Butler et al. 2001). The estuary of the Murray River, South Australia, is located near the Bonney upwelling in an otherwise oligotrophic southern ocean (Kaempf, 2004). The exchange with the adjacent southern ocean is, however, obstructed by the closure of the Mouth, which is now kept artificially open (Shuttleworth et al. 2005).

The shores of the Murray estuary and Coorong Lagoon are fringed towards the subtidal by sand- and mudflats of several meters to hundreds of meters in width. The extent of these habitats varies seasonally, being more subject to wind and evaporation over summer rather than tides as in other estuaries or open coastlines. The extent is also subject to artificial variations in water level depending on the water release over the barrages.

For proper management of estuaries, biotic and abiotic variables have been tested as indicators for the environmental state or the ecosystem health (Wilson 1994, Hiscock et al. 2003). Among them are benthic organisms, which proved useful in indicating conditions in estuaries and lagoons (Gilliland & Sanderson 2000, Bustos-Baez & Frid 2003). The objective of this study was to investigate seasonal variations in food supply for shorebirds and whether the abundance and biomass of macrofauna in the mudflats of this estuary would provide enough food for shorebirds in comparison to other sites along their flyway. We also examined relationships between the distribution patterns of benthos and waders in this complex estuary, which is highly modified by barrages.

Previous studies on birds and benthos were confined to the Coorong and did not include the area between the Tauwitchere and Goolwa barrage. Furthermore, no biomass determinations had been made to allow comparison with other overwintering and stop-over sites for migratory shorebirds, and a comprehensive analysis of macrobenthic assemblages in the mudflats of the entire area had not been approached before.

This study surveyed macrobenthic diversity, abundance and biomass at 26 sites in the area, at which concurrent bird surveys were carried out by the DEH (Department for Environment and Heritage). Two sampling seasons were chosen, June for a winter perspective and December for the summer situation, when migratory birds are overwintering in the area.

Environmental characteristics (water temperature, salinity, and oxygen content and saturation) were also recorded at the sampling sites and sediment samples were taken to determine grain size composition and organic content. A further aim of this investigation was to provide recommendations for future monitoring of mudflat macrobenthos in this Ramsar site and to analyse links between shorebirds and their benthic prey.

3. Study area and sampling sites

The estuary of the Murray river is located in South Australia (35° 33' S, 138° 53' E) and composed of the Lower Lakes (Lake Alexandrina and Lake Albert); the Coorong Lagoon of ~100 km length, which is separated into a North and South Lagoon about halfway at Parnka Point; and the Murray Mouth region between the Tauwitchere and Goolwa barrages near the mouth of the estuary. Sampling was carried out at 26 sites around the Murray Mouth (8 sites), Coorong (13 sites) and Lower Lakes (5 sites) (Fig. 1). Details on the sampling sites and dates are provided in Appendix 1. The locations of the sites were chosen by their relevance for shorebirds, based on ornithological studies in previous years.

The Murray Mouth and Coorong region is microtidal and water level determined more by wind, evaporation, and water release over the barrages than by tides. The mudflats are therefore a habitat with strong seasonal fluctuation in extent. Several sites were under water during the winter survey, when samples were sometimes taken in up to 30 cm water depth. In summer, wide areas of mudflat were exposed, but due to infrequent flooding characterised by very dry and compacted sediment. Samples were taken at several locations between the shoreline and the water line, referred to here as high, mid or low tide levels. At the low tide level, samples were often taken in ~ 10 – 30 cm water depth. Due to the seasonal variation in exposure of the mudflats, only one or two locations could be sampled in June, whereas samples were taken at all three locations at most sites in December. The distance between the shoreline and water line varied with shore profile, tide and water level from 1 to over 100 m between sites, being narrower near the Murray Mouth (2 to 15 m) and wider (> 100 m) throughout most of the Coorong Lagoon. The southernmost site in the Coorong was a saltpan, slightly water covered after rainfall during the sampling in June.

Around Lake Alexandrina, only one location was sampled per site. The sampling sites here varied from small embayments, little ponds in paddocks, to an artificial wetland area. Following rainfall in winter and spring, the water level was higher at most of the sampling sites around the lake in December compared to June.

Figure 1: Map of the study area with the location of the sampling sites for surveys in June and December 2004. Map courtesy of Russell Seaman, DEH.

4. Methods

Two sampling campaigns were carried out, from the 7th to the 10th of June (winter) and the 13th to the 16th of December 2004 (summer). Sampling dates and daytime for each site can be obtained from Appendix 1. The sampling sites covered a wide area (Fig. 1) and travelling time between several sites was substantial, yet was accomplished within several days for each survey.

4.1 Environmental parameters

Water quality parameters were determined using a hand held YSI 85 electrode for oxygen content and saturation, conductivity, salinity and water temperature. The readings were taken in shallow water and within 10 cm above the sediment surface near the sampling locations.

Sediment characteristics determined included grain size composition and sorting coefficient as well as organic content. For grain size, three replicate samples were taken at each location to about 10 cm sediment depths using a corer (surface area of corer used: 40.72 cm^2 in June, 19.63 cm^2 in December). Three replicates per tidal level were taken to account for small-scale variability, yet they were pooled into one bag (sacrificial pseudoreplication). Samples for sediment organic matter were taken using a cut-off syringe of 0.64 cm^2 surface area. In June, three replicate samples, accounting for spatial variability, were pooled into one vial, whereas the replicates were kept separate in the summer sampling campaign, as variations between tidal levels had been found in June. All samples for sediment characteristics were frozen until further analysis. In addition, verbal descriptions were recorded of sediment properties, presence of vegetation or microbial mats and the depth of the oxidised sediment layer, roughly indicated by a lighter colouration of the sediment.

To determine grain size, frozen samples were thawed and placed into a bucket. The silt fraction (< 63 µm) was separated by wet sieving, applying repeated suspension with fresh water and decantation through a 63 µm mesh. The fraction < 63 µm was collected in a bucket and allowed two to three days settlement time. Overlying water was then siphoned off and the silt fraction transferred to an aluminium tray for drying (see below) and weighing. The wet sieving also reduced the salt content in the sediment, preventing clogging of particles for later determination. The remaining sediment was dried at 80qC for 24 hours and then dry sieved, using a shaker with the mesh sizes 0.063 mm, 0.125 mm, 0.250 mm, 0.5 mm, 0.71 mm, 1 and 2 mm. After weighing each fraction, the percentage contribution of each grain size was calculated. Median and quartiles were obtained from plotting cumulative curves. Sediment sorting was calculated according to (M75 – M25)/2. The classifications for sorting coefficients are: very well sorted (< 0.35), well sorted (0.35 – 0.5), moderately well sorted (0.51–0.7), moderately sorted (0.71–1), poorly sorted (1.01–2). Very or extremely poorly sorted sediment was not encountered.

Sediment organic matter was determined by combustion at 450qC. Samples were dried to constant weight at 60–80qC to obtain the dry weight (d.w.) before being placed in a muffle furnace at 450qC for 4–6 hours. Samples were allowed to cool in a desiccator before weighing. Organic matter is the weight difference between the ash free dry weight and the dry weight, expressed in % d.w.

4.2 Macrofauna

Macrofauna was sampled using hand-held corers, followed by sieving of the sediment and subsequent sorting, identification and counting of the organisms. The corer used in June had 84 cm^2 surface area, whereas corers of either 83.32 cm^2 or 19.63 cm^2 surface area were employed in December. The smaller corer was used at several sites in the Murray Mouth and Northern Lagoon (sites 4, 5, 6, 7, 20, 21, 22, 23) where the June survey had yielded high macrofaunal densities. At these sites, six replicate samples were taken at each tidal location with the smaller corer to increase the accuracy and precision of the assessment. At all other sites, three replicate samples were taken per location with the large corer. Corers were inserted 12-15 cm into the sediment and dug out with a shovel. When the sampling sites were water covered, a lid was placed on the corer before retrieving the sample. All samples were sieved in the field through 0.5 mm mesh size and transferred into ziplock bags. In June, all samples were preserved in 70% ethanol, while most samples could be sorted alive within 1-2 days in the December survey. Only for sites 4 to 7 and 20 to 23, where many replicates had to be processed, some replicates per location were pickled with 70% ethanol until later sorting. Samples from the Lake sites were also pickled due to shortage of time for sorting during the field campaign.

In the lab, specimens were extracted from sorting trays and specimens were identified to the lowest possible taxonomic level (sometimes morphospecies) and counted for assessments of species diversity and abundance. Specimens from each sample were retained for later biomass determination.

Biomass (AFDW) was determined for higher taxa per site and location. The respective specimens are dried at 60qC for 24 h to obtain the dry weight (d.w.) before being placed in a muffle furnace at 450qC for 4 hours. At this temperature, molluscs were burned with shell. Samples were allowed to cool in a desiccator before weighing. The weight difference between the dry and ash weight is the ash-free dry weight (AFDW).

4.3 Shorebird data

A dataset with observation records for shorebirds and waterbirds was supplied by the DEH. The field observations were carried out by David and Margaret Dadd. Bird surveys were carried out fortnightly over summer and at monthly intervals during winter. The surveys were point based using a telescope. From this fixed position, a 180° sweep from the left to the right shoreline was carried out. Birds could be accurately counted up to 800 m away; at larger distances up to 1 km the number, but not the species identity of birds was recorded.

This dataset covered the time from April 2001 to December 2004, but only since October 200 more frequent bird surveys were run. Sampling intervals varied between season and region and were incomplete, as discovered during the analysis. Interpretations of this dataset presented in results and discussions are therefore temporary until the full data set becomes available for analysis.

4.4 Data analysis

Both abiotic and biotic data are displayed in the results in a north-south sequence from the Murray Mouth towards the southern end of the Coorong, followed by the lake sites.

The following diversity indices were calculated using PRIMER software: Shannon-Wiener diversity ($H' = -\Sigma_i\, p_i \log(p_i)$, using $\log_e$); Margalef's index ($d = (S-1)/\log N$ for species richness, with higher values indicating higher species numbers per individual numbers); Pielou's index ($J' = H''/\log S$ for equitability, with $J' = 1$ if all species are occurring with the same number of individuals and low values for J' indicating dominance of a few species); and the Simpson index ($1\text{-lambda}' = 1-\{\Sigma_i N_i(N_i-1)\}/\{N(N-1)\}$, an eveness index independent of sampling effort and adjusted to small sample sizes, with larger values indicating that all species occur with the same abundance).

Tests for significant differences between sites and season were carried out with the non-parametric U-Test. Multivariate statistics were used to identify macrobenthic assemblages. After square root transformation, the Bray-Curtis similarity index was calculated to perform cluster analysis or non-metric multidimensional scaling (MDS). Sites where no specimens were found had to be deleted for this analysis. Significant differences between assemblages in the study regions were tested by one-way ANOSIM and discriminating species analysed using SIMPER. All multivariate analyses were performed using the PRIMER software.

5. Results

5.1 Environmental conditions

The environmental conditions in the study area are characterised by sharp gradients in salinity. Seasonal variation between the winter and summer survey were most pronounced for water temperature, salinity in the North Lagoon, and oxygen saturation and content at the lake sites. Raw data for all environmental parameters recorded are compiled in Appendix 2.

Water temperature in June ranged from about 11 to 17°C, with slightly higher temperatures up to 22°C in the Lower Lakes (Fig. 2). In December, water temperatures were warm to hot with a lowest value of 19.6°C recorded at site 22 and a top of 34°C recorded at site 19 (Fig. 2). Sites 16 and 17 in the South Lagoon, showing lower temperatures than the nearby sites, were sampled early in the morning. Temperature variations between the two surveys in June and December were on average 8°C in the Murray Mouth, 11°C in the Coorong, and 6°C at the Lake sites.

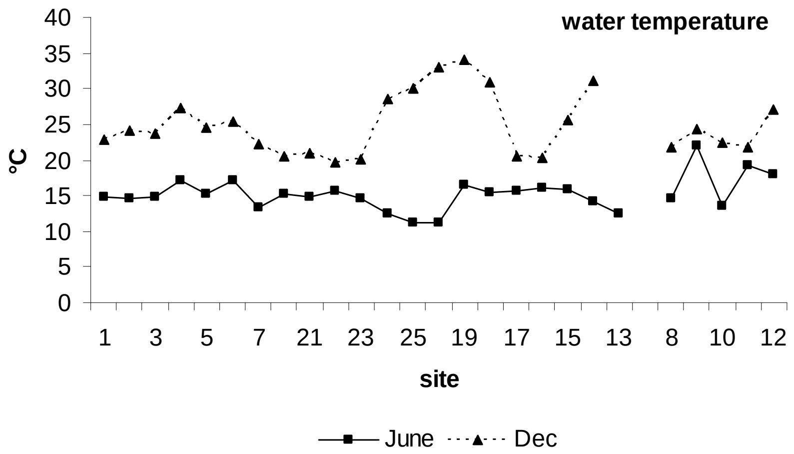


Figure 2: Temperature in the water overlying the mudflats or in water nearby the sampling sites, during the two sampling campaigns in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

The prominent environmental factor in the study region is salinity, varying from fresh- or brackish water in the Lakes to hypersaline conditions in the South Lagoon (Fig. 3). In the Murray Mouth region, salinities were marine at both the winter and summer sampling campaign. Salinities rose rapidly in the Coorong to reach hypersaline salinities of > 100 ppt. The onset of these hypersaline conditions, which characterised the South Lagoon in winter, had shifted northward into the North Lagoon of the Coorong in summer (Fig. 3). At Salt Creek (site 15), water entered the South Lagoon with a salinity of 25 ppt, which resulted in a localised reduction of hypersaline conditions to marine salinities.

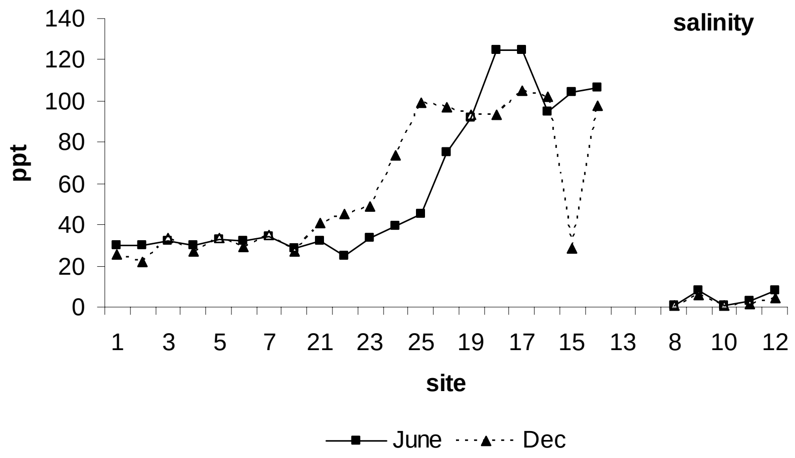


Figure 3: Salinity in the water overlying the mudflats or in water nearby the sampling sites, calculated from conductivity and temperature measurements, during the two sampling campaigns in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

Oxygen concentrations averaged about 8 mg l^{-1} near the Murray Mouth in both June and December, with a high value recorded at site 1 in December, where microphytobenthic activity was apparent in the field (Fig. 4). In the Coorong, oxygen concentrations were lower, with 5 mg l^{-1} on average in June and only 3 mg l^{-1} in December. An even more pronounced seasonal decrease in oxygen concentrations was observed at the lake sites, where values in summer were about 3 x lower than in winter.

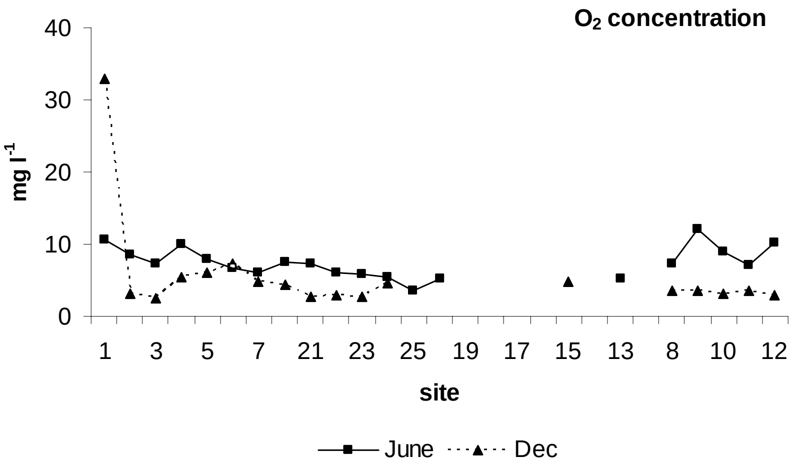


Figure 4: Oxygen concentration (mg l-1) in the water overlying the mudflats or in water nearby the sampling sites, during the two sampling campaigns in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina. Missing values result from failed readings with the electrode.

Oxygen saturation varied between sites and revealed no consistent pattern between seasons at single sites or study regions (Fig. 5). Only at the lake sites, O_2 saturation was consistently lower in summer than winter. Lower O_2 saturations in December than June were also observed at sites 1 to 4 between the Murray Mouth and Goolwa, and at sites 20 to 23 in the North Lagoon. Over-saturation (> 100 %) was detected at several sites near the Murray Mouth, Salt Creek in the South Lagoon and some lake sites in June, whereas the water at only one site each in the Murray Mouth and South Lagoon respectively reached over-saturation in December.

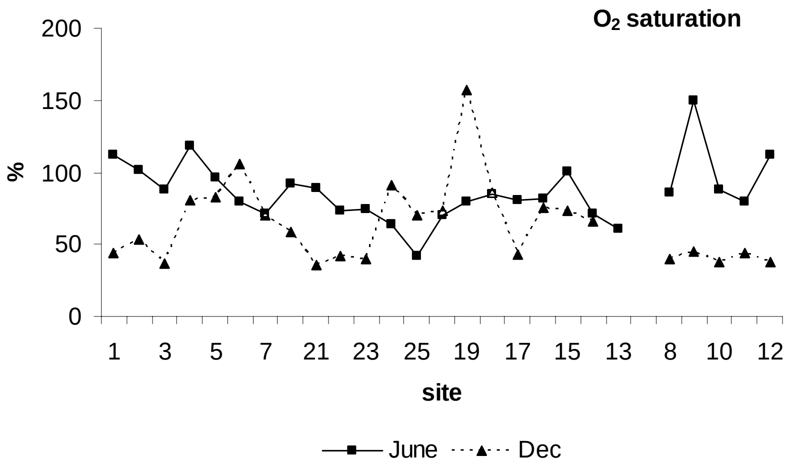


Figure 5: Oxygen saturation (%) in the water overlying the mudflats or in water nearby the sampling sites, during the two sampling campaigns in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

The sediments at most sites were fine to medium sands, equivalent to a median particle size diameter of 125 to 250 µm (Table 1), and very to moderately well sorted. Coarser sediment prevailed at some sites in the Coorong Lagoon (sites 21, 22, 15, 16, and 18). Sediments at the sites around the lake were inconsistent and less well sorted with either larger components of coarse or very fine to mud particles mixed with fine sand. Appendix 2 provides detailed sediment characteristics for all sites and sampling locations therein. In June, when water levels were higher and sampling was confined closer to the shoreline, variations in grain size between tidal levels were encountered for several sites in the Murray Mouth and Coorong, with sediment near the high tide line being coarser than further towards the water line. Yet, variations in the grain size characteristics with tidal level were in general negligible. Compared between winter and summer, sediments were finer in December than June at several sites in the Murray Mouth and Coorong, as the median grain size has shifted from medium to fine sand at most study sites (Table 1).

Table 1: Sediment characteristics at the study sites during the surveys in June (J) and December (D) 2004, given as the median grain size per site (averaged over all sampling locations). Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

	Mud	Sand				
Site	Silt	Very fine	Fine	Medium	Coarse	Very coarse
1			J; D			
2			D	J		
3			D	J		
4			D	J		
5			D	J		
6			J; D			
7			D	J		
20				J; D		
21			D	J		
22				J; D		
23			D	J		
26			J; D			
25			D	J		
24			D	J		
19			J; D			
18			D			J
17			D	J		
16			D		J	
15			J	D		
14			D	J		
13		D	J			
8		D	J			
9			J; D			
10			J	D		
11			J; D			
12	D		J			

The organic matter content in the sediments was variable, with low to moderately high values generally between 0.13 to 6.7 %, and no apparent spatial pattern across sites or locations within (Appendix 2). The high degree of patchiness in organic matter at all sites was inconsistent as to an increase or decrease towards the water line. Site 10, which was a beach location at the lake, had the lowest contents of all sampling sites. Sediments at the lake site 9 (Tulderol Game Reserve) displayed the highest content of organic matter (55 % in June and 15 % in December). All other lake sites were characterised by higher sediment organic matter in December than in June. In the Murray Mouth and Coorong, either higher or lower contents in December than June were recorded at sites or locations within, with high organic matter content found at site 13 (9.5 %) and at the low tide location of site 4 (23 %) . For the four major regions in the study area, mean values were similar for the sites located in the Murray Mouth, north and South Lagoon of the Coorong with average per region between 2 and 4 % organic matter, but about 3 x higher for the lake sites in both June and December (Table 2).

Table 2: Organic matter content in the sediment (% dry weight after combustion) in the four study regions MM = Murray Mouth, NL = North Lagoon, SL = South Lagoon and LL = Lower Lakes during the surveys in June and December 2004, given as the mean value and standard error (SE) and calculated based on mean values per site if several locations were sampled.

	June		December	
region	mean	SE	mean	SE
MM	2.21	0.43	2.58	0.95
NL	2.21	0.47	1.88	0.35
SL	2.87	0.71	3.84	1.08
LL	12.49	10.73	10.02	2.82

Other than sites characterised by coarser sediment, most sites had a very thin layer of oxidized sediment with the black, anoxic sediment horizon extending almost to the sediment surface. Anoxic spots of the sediment were observed especially in the North Lagoon and in front of the barrages, often in combination with decaying macroalgal mats or cow pads. Microbial mats and green filamentous algae were found at sites 1 and 2, as at sites 6 and 7. At site 1, where the primary productivity by benthic cyanobacteria and diatoms was apparent by oxygen bubbles at the sediment surface, high oxygen concentrations were recorded. Traces of burrows or tubes by infaunal organisms as well as tracks left by epibenthic snails and worms were apparent at most sites in the Murray Mouth, but traces of animal activity were rare or absent throughout the Coorong.

5.2 Benthic diversity

The number of macrobenthic taxa distinguished in both the June and December survey amounted to 48 taxa. Insects were richest in species, with 19 taxa recorded, most of them as larval stages. Crustacea were present with 14 taxa, including 10 morphospecies of amphipods. The taxonomy of amphipods is difficult and the species identifications made are subject to confirmation by experts. Molluscs were represented by nine taxa, with seven of them being gastropods. Five polychaetes and one oligochaete were further distinguished. Appendix 3A provides an overview on the species found at single sites during the two surveys. Key morphological characteristics of the macrofaunal species distinguished are presented in Appendix 3B, together with photographs or drawings of specimens.

The species were not equally distributed in the study region. Sites near the Murray Mouth and northern end of the North Lagoon as well as some lake sites contained more species than sites along the Coorong (Fig. 6). The total number of taxa recorded in the four study regions was 29 in the Murray Mouth, 28 in the North Lagoon, 16 in the South Lagoon, and 27 around Lake Alexandrina. On average, however, species densities were lower. The mean number of species encountered at the study sites in the Murray Mouth was 14, in the North Lagoon eight, four in the South Lagoon and 11 at the lake. These mean values were slightly lower for each survey separately.

While the macrobenthos in the mudflats near the barrages was mainly composed of crustaceans, polychaetes and molluscs, insects were prevailing throughout the Coorong and Lower Lakes (Appendix 3A). All of these species found have known distributions in estuarine and other mudflat or wetland environments. The snail *Coxiella striata*, which is adapted to hypersaline habitats, was found in the South Lagoon. Several insect taxa recorded in June (often as larvae) were not found again in December, when further taxa were distinguished. This was most pronounced at the lake sites, which were also richer in amphipod taxa in December than in June. This seasonal effect of the occurrence of insects or their larvae is also reflected in the total number of species found per region in June and December and their respective taxonomic composition, which varied most in the South Lagoon and lake (Fig. 7 a and b). In the Murray Mouth and the two northernmost sites of the North Lagoon, little variation in species records occurred between the surveys in June and December.

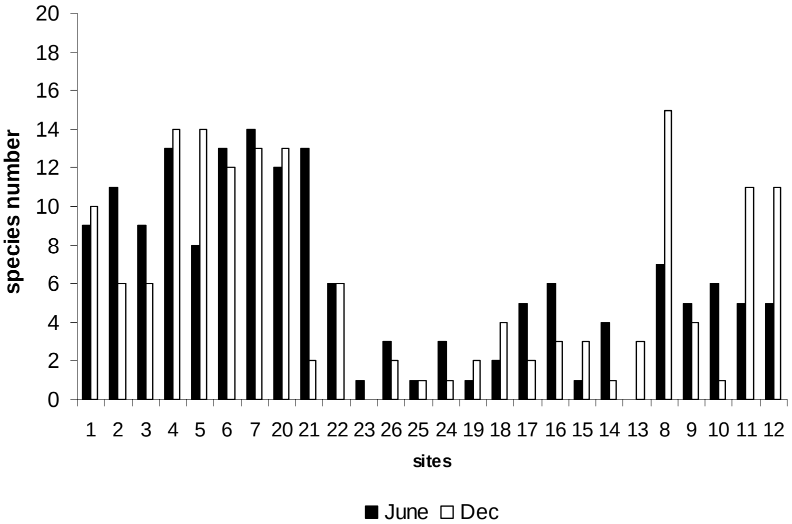


Figure 6: Total number of species of macrofauna recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

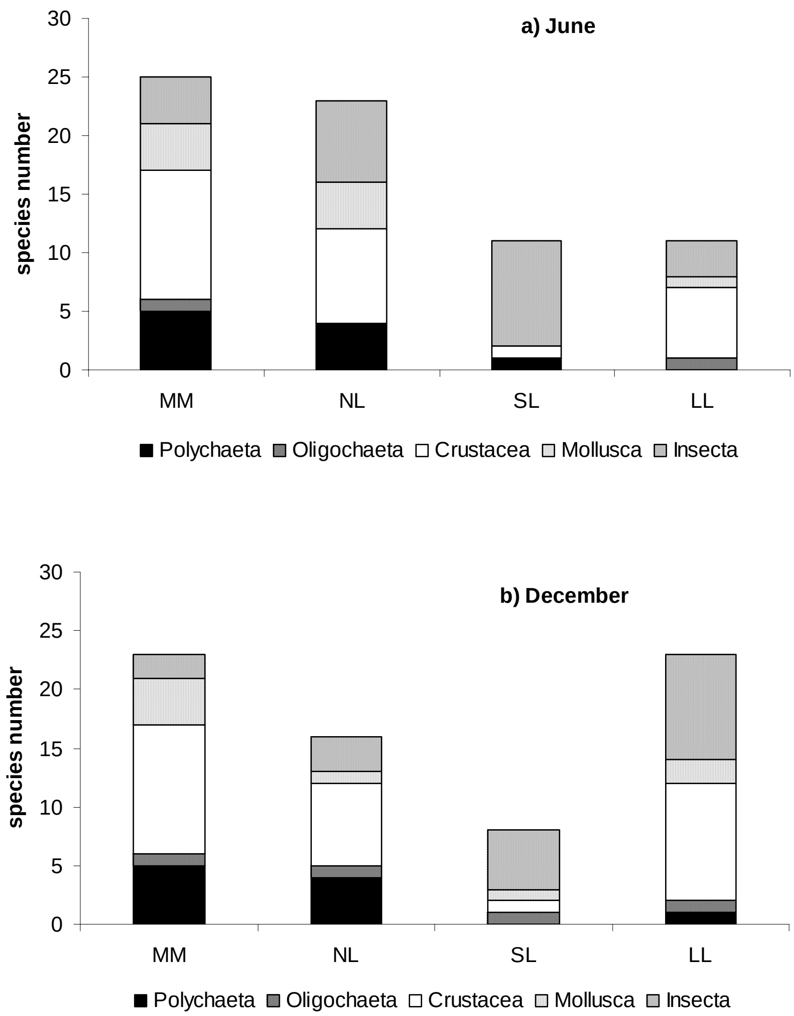


Figure 7: Number of species of major macrofaunal taxa recorded at the sampling sites during the surveys in a) June and b) December 2004. The study regions are MM = Murray Mouth, NL = North Lagoon, SL = South Lagoon, LL = Lower Lakes.

The low diversity of the macrofauna in the study area is also reflected in the low values for Shannon-Wiener diversity and Margalef´s index (Table 3). Diversity values were especially low throughout the Coorong, while some of the highest values per site were found near the Murray Mouth. Indices for eveness varied between sites, yet the values indicate that several sites in the Coorong were dominated by single or a few species in either month. Diversity and eveness values for the Lake sites were somewhat in between those for the Murray Mouth and Coorong.

Table 3: Diversity indices for the sampling sites of the mudflat benthos monitoring in June and December (Dec) 2004. H'(log$_e$) = Shannon –Wiener diversity, d = Margalef's index, j' = Pielou's index, 1-Lambda' = Simpson index. Zero or missing values result from no or single specimens found only. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

	H'(log$_e$)		d		J'		1-Lambda'	
site	June	Dec	June	Dec	June	Dec	June	Dec
1	0.97	1.01	1.49	1.39	0.44	0.44	0.42	0.47
2	1.85	1.52	2.73	1.64	0.77	0.85	0.78	0.77
3	1.56	1.39	1.61	1.38	0.71	0.78	0.74	0.72
4	1.70	1.78	1.66	1.83	0.66	0.67	0.77	0.78
5	1.50	1.91	1.09	1.87	0.72	0.72	0.72	0.82
6	1.74	1.64	1.59	1.51	0.68	0.66	0.77	0.74
7	1.55	1.45	1.70	1.82	0.59	0.56	0.72	0.62
20	1.56	0.95	1.52	1.64	0.63	0.37	0.74	0.46
21	0.53	0.56	1.51	0.72	0.21	0.81	0.20	0.50
22	0.17	1.07	0.76	1.15	0.09	0.59	0.06	0.59
23	0			0		0.00		
26	0.87	0.38	0.61	0.48	0.79	0.54	0.55	0.25
25	0	0						
24	0.94	0	0.91		0.85		0.64	
19	0	0.16		0.25		0.23		0.07
18	0.69	0.18	1.44	0.67	1.00	0.13	1.00	0.07
17	1.35	0.45	1.38	0.40	0.84	0.65	0.74	0.30
16	1.48	0.96	1.17	1.03	0.83	0.87	0.76	0.67
15	0	0.37		0.65		0.33		0.18
14	0.36	0	0.76		0.26		0.15	
13		0.66		0.44		0.60		0.38
8	1.35	2.11	1.69	3.22	0.69	0.78	0.67	0.83
9	1.10	1.15	0.97	0.97	0.68	0.83	0.63	0.67
10	1.08	0	0.84		0.60		0.54	
11	0.90	1.52	1.20	1.79	0.56	0.63	0.47	0.67
12	1.10	1.55	1.61	1.71	0.68	0.65	0.58	0.74

5.3 Benthic abundances

Abundances of macrobenthos varied throughout the study area, yet a large-scale distribution pattern emerged that was persistent in both surveys (Fig. 8 and Table 4). Few organisms were found between the Goolwa barrage and Murray Mouth (mean abundances for sites 1 to 3 were 2962.61 ind. m^{-2} ± 5026.40) and in the Coorong from site 22 (Mulbin Yerrok Point) to 13 (Cantara) (mean abundances 1200.48 ind. m^{-2} ± 3653.98). Samples from several sites in both the north and South Lagoon contained no macrofauna at all. At the lake sites, abundances were low and more variable between seasons at single sites (Fig. 8 and Table 4). Macrofauna was only abundant in the study area between sites 4 and 21 in the vicinity of the barrages (mean abundances 37135.89 ind. m^{-2} ± 38836.10). While abundances were higher near the Tauwitchere barrage in June (sites 7 and 20), mudflats near the Ewe Island barrage (sites 5 and 6) contained more macrofauna in December. A significant decrease in abundances between June and December occurred at site 21 ($p<0.001$, U-test), while site 5 contained significantly ($p<0.05$, U-test) more macrofauna in December than in June. Detailed accounts of abundances per site and taxa are provided in Appendix 3C.

Table 4: Mean macrobenthic abundances (Ind m^{-2}) and standard deviations (SD) in the four study regions MM = Murray Mouth, NL = North Lagoon, SL = South Lagoon and LL = Lower Lakes during the surveys in June and December 2004, and over both sampling dates.

	June		Dec		both months	
region	mean	SD	mean	SD	mean	SD
MM	19365.08	22038.15	31240.58	38709.7	27177.91	34302.01
NL	15262.52	37674.87	9567.80	22836.03	11373.44	28354.31
SL	439.56	1137.01	1018.62	2243.47	729.09	1790.76
LL	4119.05	9420.87	5688.91	7145.039	4903.98	8254.04

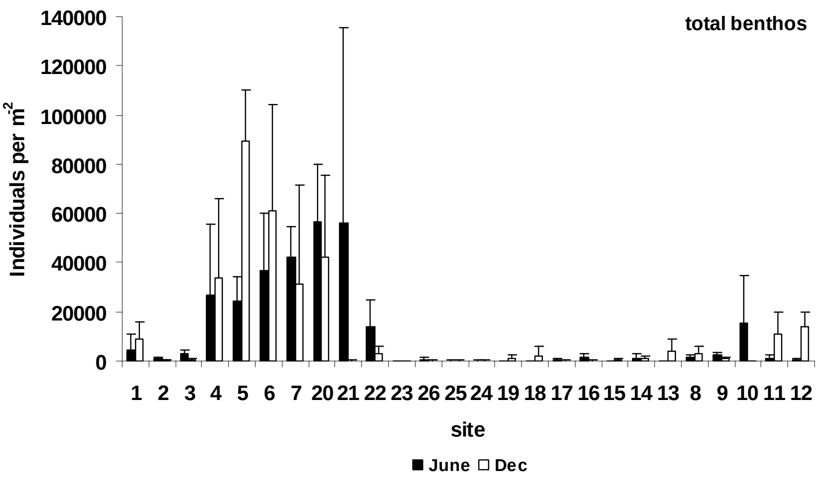


Figure 8: Mean abundances and standard deviation of macrofauna recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

The high variation at the study sites reflects the sampling design, with two to three locations from the high towards the low intertidal. The moister sediment (MT and LT locations) closer to the water line contained higher abundances of macrofauna at sites near the Murray Mouth and northern end of the Coorong (Fig. 9). At several sites in the South Lagoon, where no marine macrofauna occurred, but insect (larvae) prevailed, abundances were higher near the shoreline (Table A3Ce in Appendix 3C). The waterlevel varied between the two surveys and the exposure of the mudflats in the study area is not only determined by tides (chapter 3). Due to the topography of sites, a clear arrangement of the sampling locations with tidal level was not always possible, and distances between these sampling locations were often small (few meters). The increase in abundances from the shoreline towards the water line was especially pronounced at sites near the barrages in December (Fig. 9b).

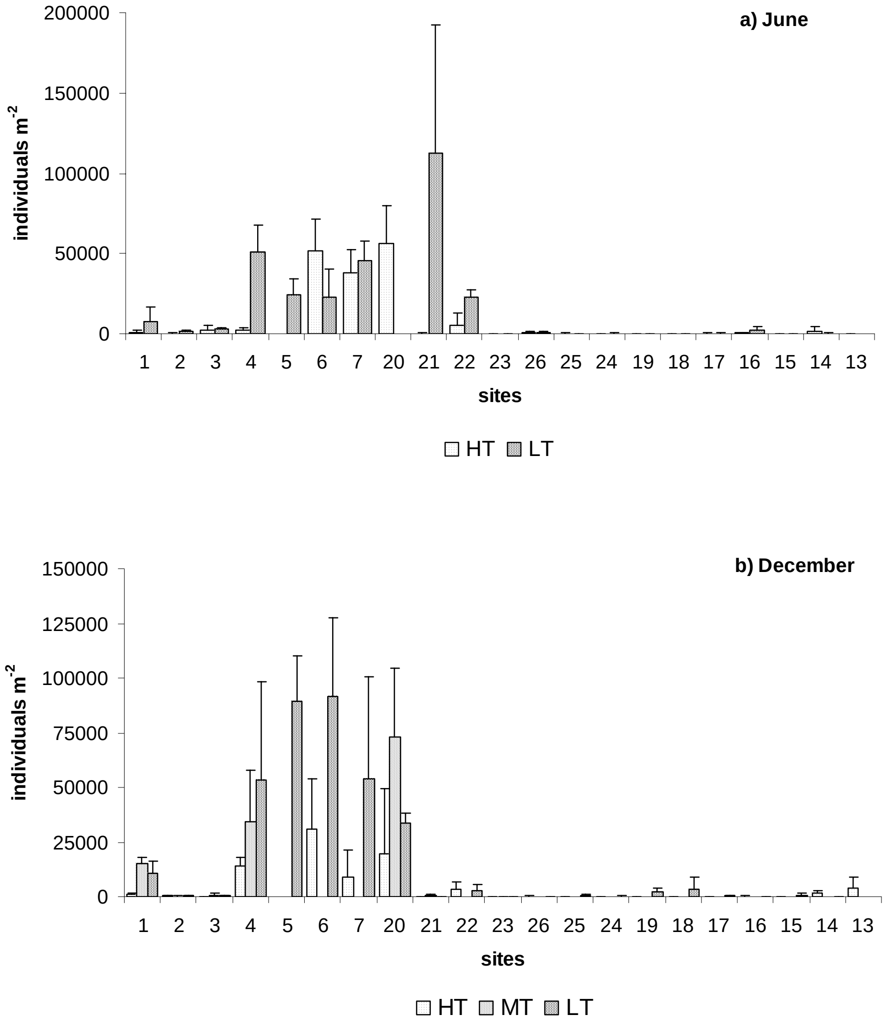
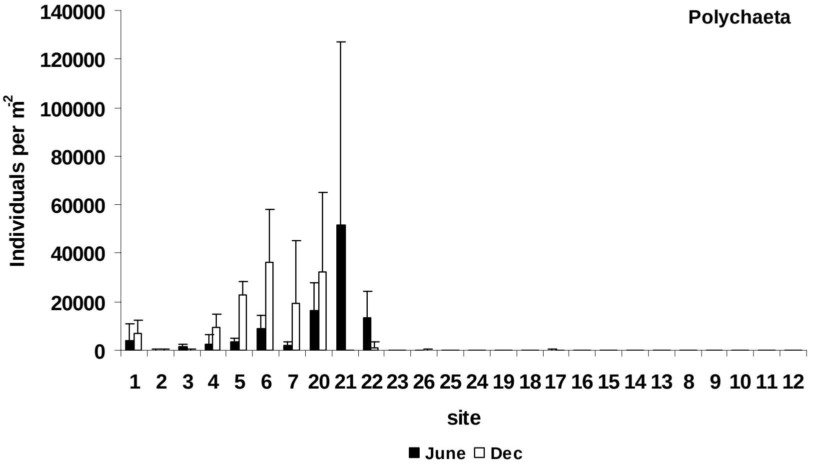
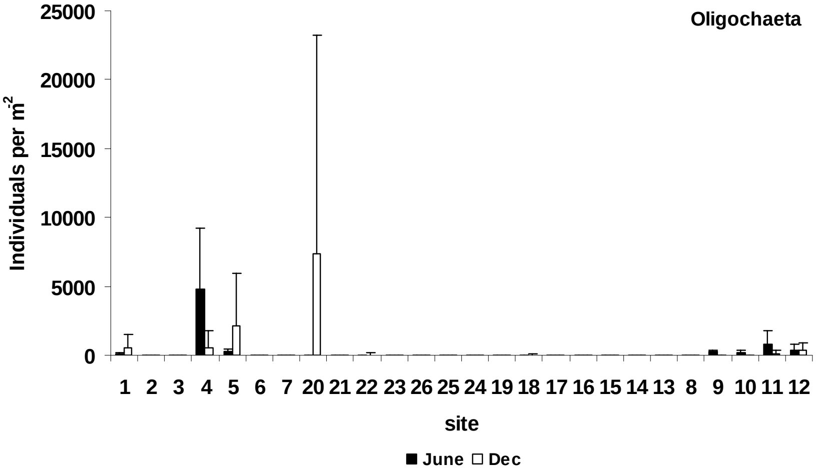
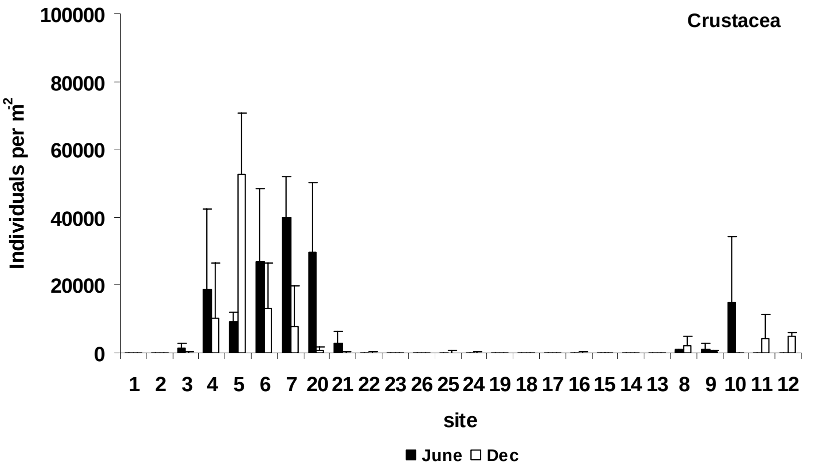


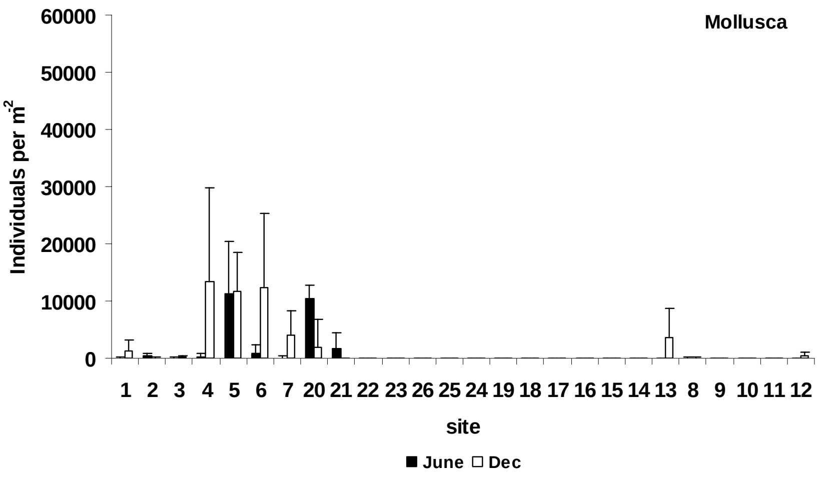
Figure 9: Mean abundances and standard deviations of macrofauna recorded at the various intertidal locations of the sampling sites during the surveys in June and December 2004. HT = near the shoreline, MT = inbetween shoreline and low water line (not sampled in June when water levels were higher), LT = low water line. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong. Lake sites are not included here as no "tidal" locations could be differentiated there. Note the different scales on the y-axis for a) and b).

Abundances of single taxa varied in the study area (Fig. 10) and the overall abundances (Fig. 8) are dominated by certain taxa. Polychaetes were confined to the Murray Mouth and northern end of the North Lagoon, where oligochaetes occurred as well, yet these worms were also found at the freshwater sites around the lake. Amongst the polychaetes, *Capitella* spp. had the highest abundances (see chapter 5.6), followed by nereid polychaetes (*Simplisetia aequisetis* and *Australonereis ehlersi*). In June, polychaete abundances were highest south of the Tauwitchere barrage (sites 20 to 22), whereas by December polychaete abundances were higher towards the Murray Mouth (sites 4 and 20) (Fig. 10). Polychaetes were outnumbered by amphipod crustaceans at these sites in front of the barrages. Some


Polychaeta
Individuals per m-2
140000
120000
100000
80000
60000
40000
20000
0
1 2 3 4 5 6 7 20 21 22 23 26 25 24 19 18 17 16 15 14 13 8 9 10 11 12
site
June Dec


Oligochaeta
Individuals per m-2
25000
20000
15000
10000
5000
0
1 2 3 4 5 6 7 20 21 22 23 26 25 24 19 18 17 16 15 14 13 8 9 10 11 12
site
June Dec


Crustacea
Individuals per m-2
100000
80000
60000
40000
20000
0
1 2 3 4 5 6 7 20 21 22 23 26 25 24 19 18 17 16 15 14 13 8 9 10 11 12
site
June Dec



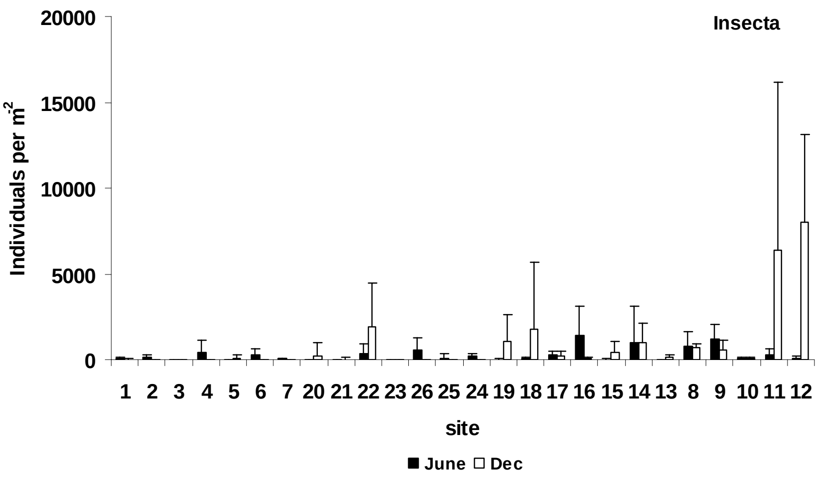


Figure 10: Mean abundances and standard deviation of macrofaunal taxa recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina. Note variations in scale of the y-axis.

amphipods were also encountered at the lake sites. Despite for amphipods, crustacean were rare in the study area. Molluscs were confined to the Murray Mouth region and the northern end of the North Lagoon, yet their numbers were low compared to other taxa. At the saltpan of site 13, two snail species (*Coxiella striata* and *Hydrobia* sp. 1) occurred in low numbers. Insects accounted for almost all of the macrofaunal abundances throughout the Coorong and at the lake sites, yet the numbers were so low that they are negligible for the overall abundance pattern (Fig. 8 and 10). Seasonal differences for most taxa are hard to detect given the high variability at single sites in each survey in June and December.

5.4 Distribution patterns of selected species

Macrobenthic organisms may be suitable to indicate estuarine health. An overview on the ecological requirements of selected species, based on a literature review and the records of this survey, is presented in Appendix 4. Distribution patterns for these species are given in Fig. 11–14. The species selected were the most abundant of their respective phylum and their abundances and spatial distributions tightly follow the patterns described in the previous chapter.

Amongst the polychaetes, the *Capitella capitata* species complex is known to occur in anoxic, sulphide-rich sediments (Appendix 4), which was encountered at the study sites where this species was found (Fig. 11). However, similar sediment conditions prevailed throughout most of the Coorong, where capitellids were rarely recorded during this survey. This species is adapted to estuarine salinity ranges and single specimens have been found under hypersaline conditions. Thus, no match was found between the tolerance range and adaptations of *Capitella* spp. and the distribution pattern in the study area.

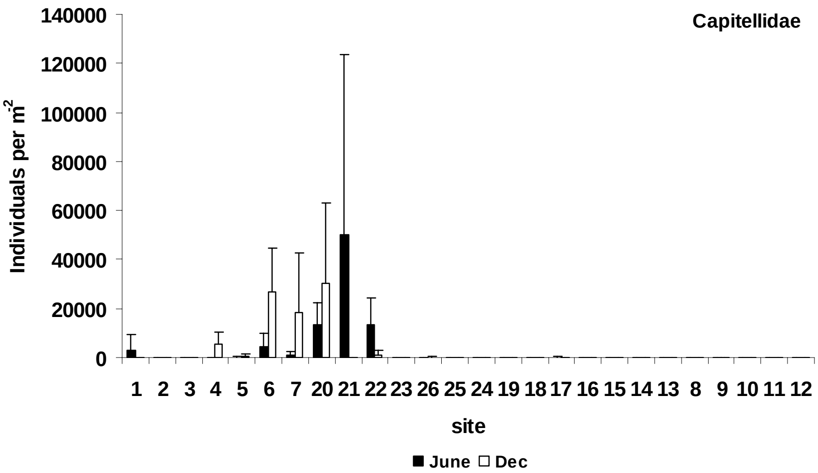


Figure 11: Mean abundances and standard deviation of *Capitella* spp., recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

A further polychaete, the nereid *Simplisetia aequisetis* (formerly *Ceratonereis pseudoerythraeensis*) was abundant in the study area (Fig. 12). This species is a known food item for migratory shorebirds (Kalejta 1993). Similarly to *Capitella* spp., it is adapted to estuarine conditions (Appendix 4) and was found in similar substrates, yet higher abundances were recorded at sites closer to the Murray Mouth and Goolwa Channel (Fig. 12) and it was absent throughout the Coorong.

The second species of the family Nereididae which occurred in the study area, *Australonereis ehlersi*, had a similar distribution patterns as *Simplisetia aequisetis*, but was not as abundant. Both species were encountered from juveniles to mature specimens of several cm lengths.

The predatory polychaete *Nephtys australiensis* was locally abundant and more confined to sandier mudflats in the Murray Mouth region (Appendix 3). It is adapted to estuarine salinities, yet cannot sustain hypoxia as the capitellids and nereids (Appendix 4). This species was also found in several size ranges. The scavenging polychaete *Phyllodoce novaehollandiae* occurred with larger specimens at sandier sites near the Murray Mouth and was most frequently observed at site 3. The occurrence of the reef building serpulid polychaete *Ficopomastus enigmaticus* was noted in the field, yet this species was not assessed with the field methods used in this survey.

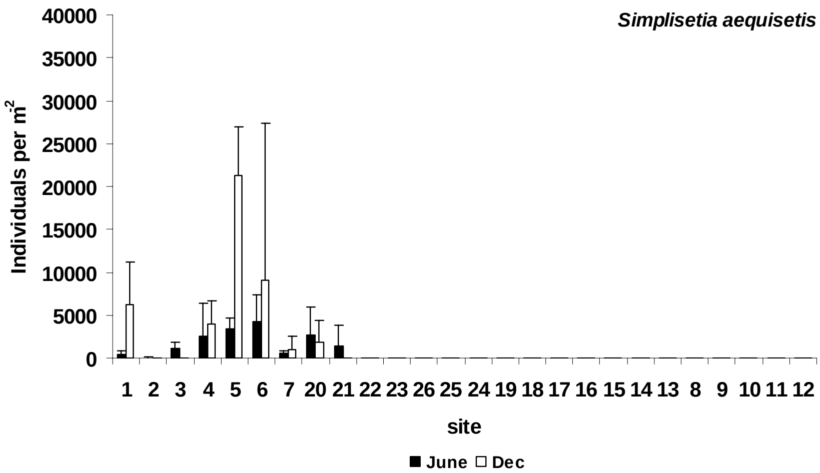


Figure 12: Mean abundances and standard deviation of *Simplisetia aequisetis* (Polychaeta, Nereididae), recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

Of the few molluscs which occurred in the study area, the small estuarine bivalve *Arthritica helmsi* was abundant (Fig. 13). It was confined to sites near the barrages and almost absent throughout the Coorong (Fig. 13). This species is also a known food source for waders (Appendix 4).

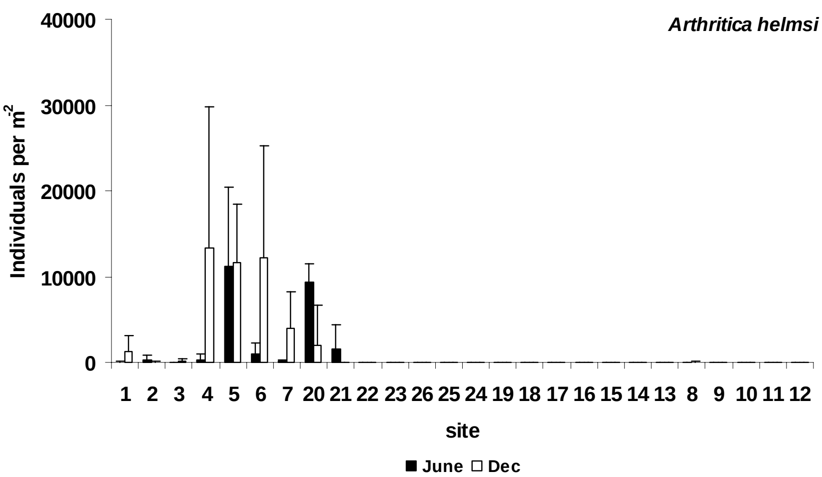


Figure 13: Mean abundances and standard deviation of the micromollusc *Arthritica helmsi* (Bivalvia, Galeommatidae), recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

Insect larvae are common in aquatic environments and chironomid larvae were abundant at several sites along the Coorong and Lower Lakes (Fig. 14). The occurrence of these larvae varies seasonally and higher numbers were found in December than June. These larvae are often tolerant towards a wide range of environmental conditions (Appendix 4), which is reflected in their distribution pattern in the study area (Fig. 14).

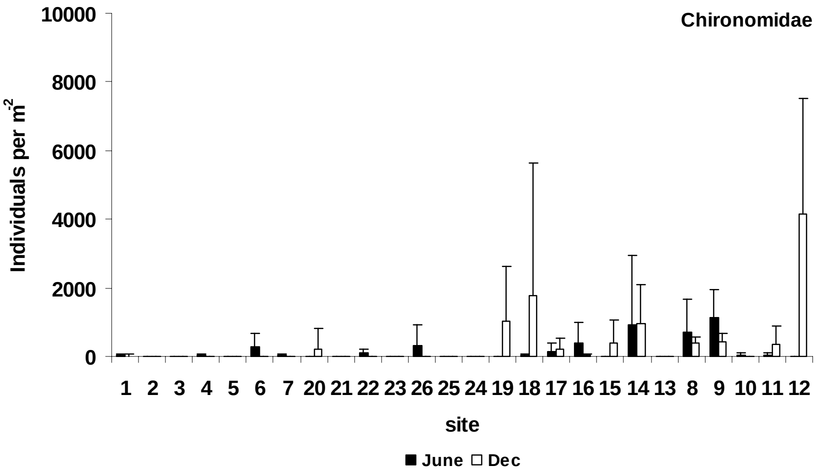


Figure 14: Mean abundances and standard deviation of Chironomid larvae (Insecta, Chironomidae) recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

5.5 Benthic biomass

As abundance data are irrespective of the size of the organisms, biomass data provide further information on food available for higher trophic levels. Biomass values were low in the study area, with a mean biomass in the Murray Mouth region of 2.58 g afdw m^{-2} and 0.97 g afdw m^{-2} in the North Lagoon. In the South Lagoon (0.40 g afdw m^{-2}) and at the lake sites (0.29 g afdw m^{-2}), biomass was negligible. The distribution pattern of biomass follows closely the one for abundances (Fig. 8 and Fig. 15), with some exceptions. For example, the few specimens of snails found at the salt pan of site 13 account for a relatively high biomass value there.

Polychaetes and crustaceans contribute most to the overall biomass (Fig. 15 and 16). The biomass of molluscs and insects was lower and highly variable between sites and season. The overall biomass distribution, however, changed little between winter and summer, or is obscured by the high variation within sites. Seasonal variations reflecting recruitment may account for the higher biomass of polychaetes and molluscs recorded in December.

While most of the amphipods remain small-sized as adults, polychaetes can increase in size with growth from less than a centimetre as juveniles to over 10 cm in length. The higher biomass of polychaetes recorded in the Murray Mouth region in summer results from the occurrence of more large sized nereids than in June (Fig. 12 and Fig. 16). The molluscs occurring in the study area, especially the bivalve *Arthritica helmsi*, were largely small-sized species, which did not account for much of the biomass, except for some snails.

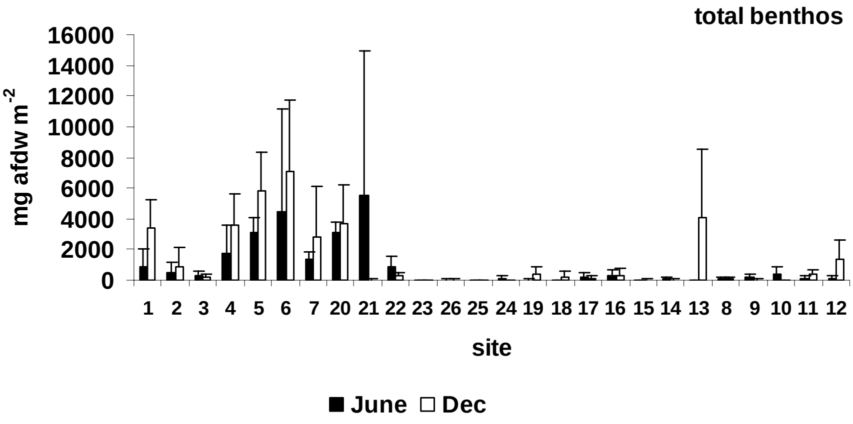


Figure 15: Mean biomass (ash-free dry weight afdw) values and standard deviation of macrofauna recorded at the sampling sites during the surveys in June and December 2004. Sites 1 to 7 are in the Murray Mouth region, sites 20 to 13 from north to south in the Coorong, and sites 8 to 12 around Lake Alexandrina.

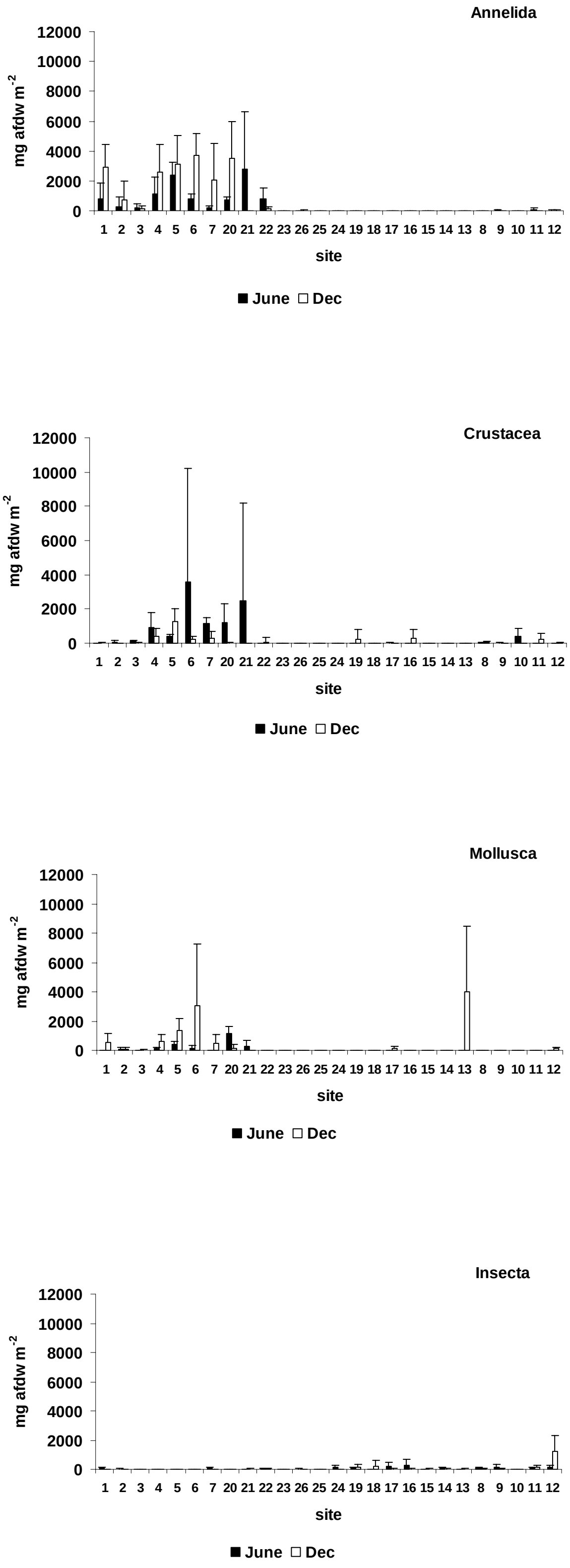


Figure 16: Mean biomass values and standard deviation of major macrofaunal taxa recorded at the sampling sites during the surveys in June and December 2004. See Fig. 15 for details.

5.6 Benthic communities

Based on the species and abundance data, multivariate statistics can find and test for similarities between assemblages at study sites. These analyses revealed significant differences between all regions. The benthos found in the mudflats in front of the barrages forms one community, which is distinct from the benthos found in the lake and South Lagoon, while some similarity exists with the North Lagoon. This pattern was more pronounced in December than in June. The hydrodynamically based demarcation between the Murray Mouth and North Lagoon at the southern end of the Tauwitchere barrage is not reflected in the benthic communities, as sites 20 and 21 (in June only) formed part of the benthic community in the Murray Mouth. Ecologically, site 20 (Pelican Point) should be classified as part of the Murray Mouth region.

In June, benthic assemblages at the study sites in the Murray Mouth region and North Lagoon revealed higher similarities to each other and formed a distinct cluster, with one lake site (LL10) mixed in (Fig. 17). The highest similarity was found between sites 4, 6 and 7 in front of the barrages. Most of the sites from the lake and South Lagoon were similar to each other, yet at a lower level, as several sites in the lagoons deviated from other sites. ANOSIM test results gave significant differences between assemblages in the four regions (R=0. 364, p=0.001). This was even clearer when sites 20 and 21 were grouped to the Murray Mouth (R=0.578, p=0.001). In pairwise comparisons, benthic assemblages found at the Murray Mouth were well separated from the Lower Lakes (R=0.776, p=0.002), the South Lagoon (R=0.791, p=0.002), and the North Lagoon (R=0.699, p=0.001), whereas the other groups were not as well separated.

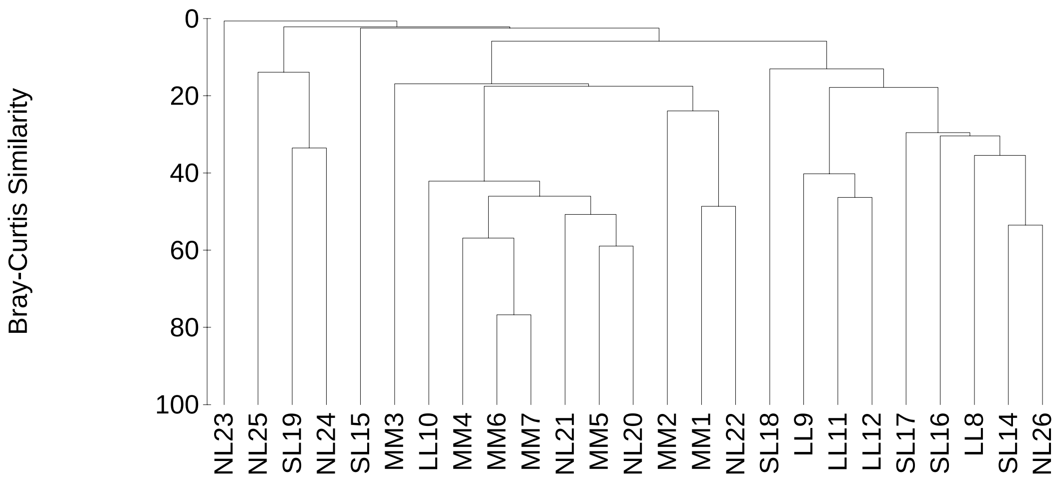


Figure 17: Dendrogram of macrofaunal assemblages in June 2004, based on mean values per site. Site 13 was deleted from the analysis as no organisms were found there. Square root transformation. Site codes with MM=Murray Mouth region, NL=North Lagoon, SL=South Lagoon, LL=Lower Lakes

To analyse similarity in the benthos in the saltwater regions of the study area only, multidimensional scalings (MDS) were carried out without the lake sites. This showed a well defined benthic assemblage at all sites between Boundary Creek (site 4) and the northern end of the North Lagoon (site 21) (Fig. 18).

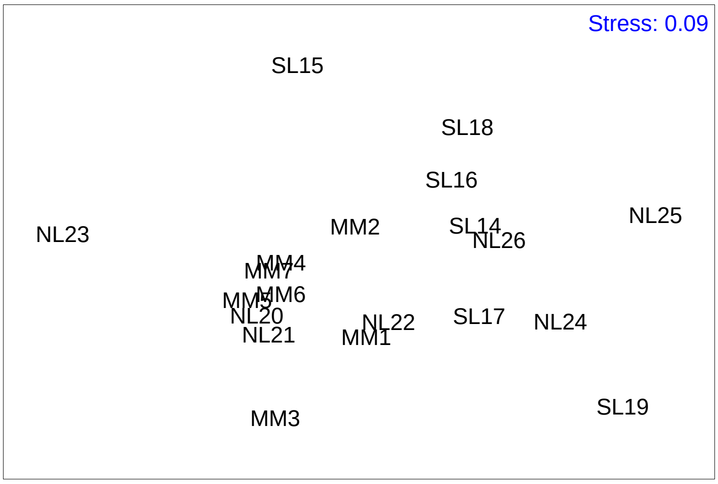


Figure 18: MDS plot (Multidimensional scaling) of macrofaunal assemblages in the Murray Mouth and Coorong in June 2004, based on mean values per site. Site 13 was deleted from the analysis as no organisms were found there. Square root transformation. Site codes with MM=Murray Mouth region, NL=North Lagoon, SL=South Lagoon

In December, the pattern was generally the same, with clearly distinct benthic communities in the Murray Mouth region and South Lagoon (Fig. 19). Some sites of the North Lagoon fell into the same cluster with the Murray Mouth region, yet at a low similarity. Only site 20 was again very similar to the benthic assemblages found along the barrages. Lake sites were more similar to the South Lagoon, and some outliers occurred. Differences between assemblages in the four regions were significant (R=0.487, p=0.001, ANOSIM). This was even clearer when site 20 (Pelican Point) was grouped to the Murray Mouth (R=0.568, p=0.001). In pairwise comparisons, benthic assemblages found at the Murray Mouth were well separated from the South Lagoon (R=0.852, p=0.001) and clearly different from the Lower Lakes (R=0.614, p=0.001) and North Lagoon (R=0.566, p=0.003). Benthic communities in the North and South Lagoon were also different from each other (R=0.539, p=0.003).

The MDS analysis without the lake sites revealed the similarity of benthic assemblages in the Murray Mouth region and South Lagoon further (Fig. 20). Several North Lagoon sites are unrelated to either community. The southernmost sampling site (site 13, Cantara) and the sites opposite to the Murray Mouth (sites 2 and 3) are also distinct and furthest apart from each other.

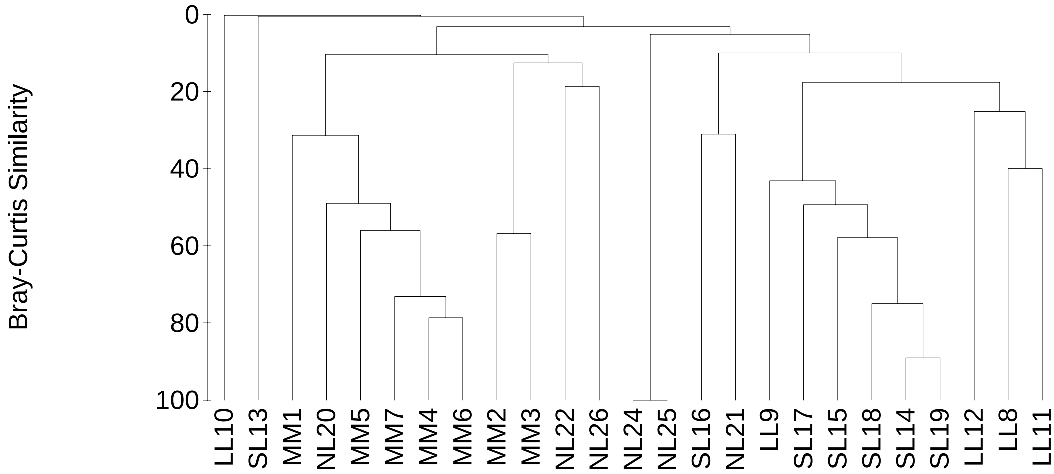


Figure 19: Dendrogram of macrofaunal assemblages in December 2004, based on mean values per site. Site 23 was deleted from the analysis as no organisms were found there. Square root transformation. Site codes with MM=Murray Mouth region, NL=North Lagoon, SL=South Lagoon, LL=Lower Lakes

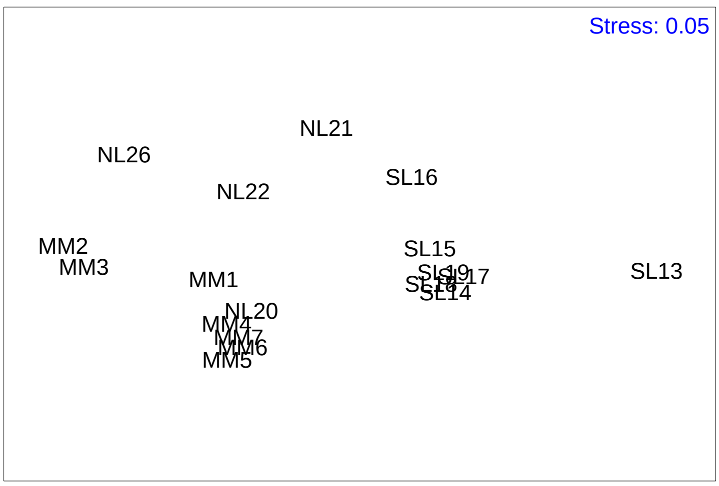


Figure 20: MDS plot (Multidimensional scaling) of macrofaunal assemblages in the Murray Mouth and Coorong in December 2004, based on mean values per site. Site 23 was deleted from the analysis as no organisms were found there, and sites 24 and 25, were outliers and omitted. Square root transformation. Site codes with MM=Murray Mouth region, NL=North Lagoon, SL=South Lagoon

The analysis of similarity (SIMPER) reveals species typical for a benthic assemblages or discriminating between groups. The most typical species for the Murray Mouth were *Simplisetia aequisetis* and in December *Arthritica helmsi* as well. *Capitella*, and the insect *Cafius* sp. were most typical for the North Lagoon. Chironomid larvae, and in December also insects (Corixidae), were typical for the South Lagoon. Typical for the lake were oligochaeta and in December chironomid larvae. Species discriminating benthic assemblages between the Murray Mouth and the South Lagoon and Lake were *S. aequisetis*, *Capitella*, and the amphipod species 1 and 10. In December, *A. helmsi* contributed to the distinctions of these communities as well. Thus, the same species that were typical for certain assemblages also discriminated between the different benthic communities.

5.7 Shorebird phenology and distribution pattern

Out of 65 bird species listed in the aquatic bird counts, 22 species of shorebirds (waders) were recorded in the study area between 2001 and 2004. Ten species thereof were resident to Australia and New Zealand, and 12 migrate between breeding grounds in the northern hemisphere and over-wintering sites in Australia. For each of 2002 and 2004, the total number of migratory shorebirds was higher than of resident shorebirds. The three most abundant migratory wader species are red necked stints, Sharp-tailed sandpiper and curlew sandpiper. The three most abundant resident shorebirds were banded stilts, red necked avocet and black-winged stilts.

The migratory pattern is evident in the phenology of shorebirds (Fig. 21). Shorebirds arrive in the Coorong and Murray Mouth in October/November and depart again to their breeding sites on the northern hemisphere by April/May. Slight variation as to the arrival and departure of the shorebirds occurred between years, but the overall number of waders visiting the study

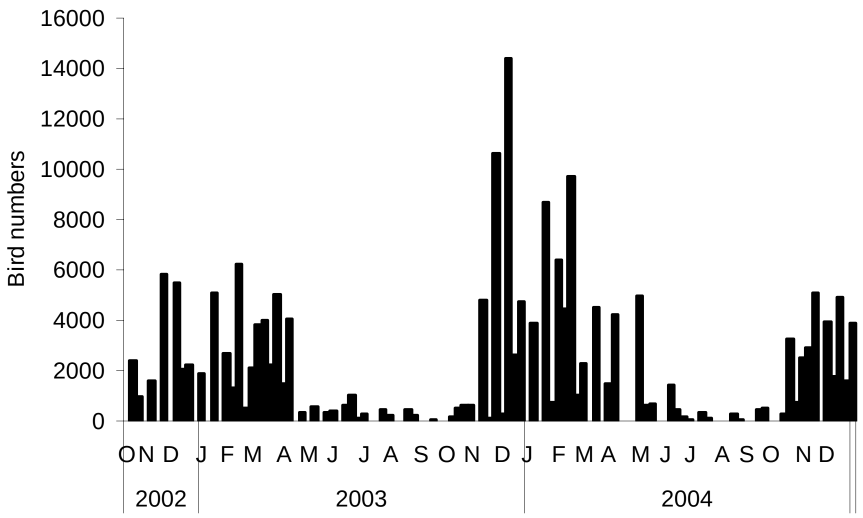


Figure 21: Phenology of waders at all bird survey sites in the study area, from October 2002 to December 2004. The figure is based on an incomplete data set.

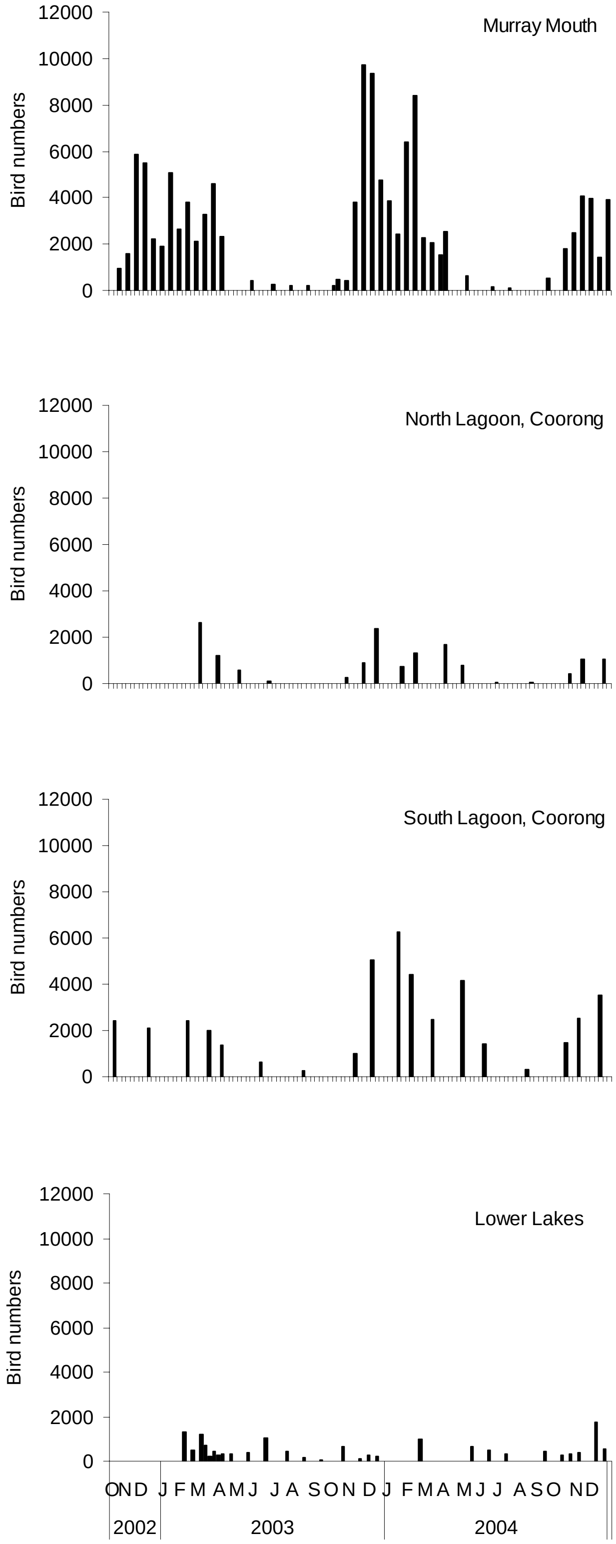


Figure 22: Phenology of waders at all bird survey sites in the four major regions of the study area, from October 2002 to December 2004. The figure is based on an incomplete data set.

area also varies between years (Fig. 21). Shorebird numbers were higher during the summer season 2003/2004 than in the previous and following year, especially at the onset of the over-wintering time.

The sampling dates for the winter and summer campaign of the benthic survey fell into the end of over-wintering season 2003/2004 with low shorebird numbers in June. The summer survey in December occurred about two months into the new over-wintering season (Fig. 21).

The number of waders and the phenology varies between regions and years. The migratory pattern is most pronounced in the Murray Mouth region of the study area, and to a small degree in the North and South Lagoon of the Coorong (Fig. 22), whereas no seasonal variations were apparent at the lake sites, where shorebird numbers were low. Shorebird numbers were also low in the North Lagoon. The phenology in the South Lagoon and shorebird numbers recorded there were closer to those found in the Murray Mouth.

The spatial distribution of waders in the study area in 2004 showed concentrations in the Murray Mouth region and around Parnka Point, which is separating the North and South Lagoon (Fig 23). The bird data for that year were split into numbers recorded between January - June and July - December, as the mid year period separates the over-wintering seasons (Fig. 21). At most sites shorebird numbers varied little between the first and second half of the year, yet near the Goolwa Channel and south of Parnka Point numbers were lower in the second half of the year. Sites with high shorebird numbers throughout the year were the Ewe Is. Barrage, Tauwitchere Island, Pelican Point, and Villa del Yumpa.

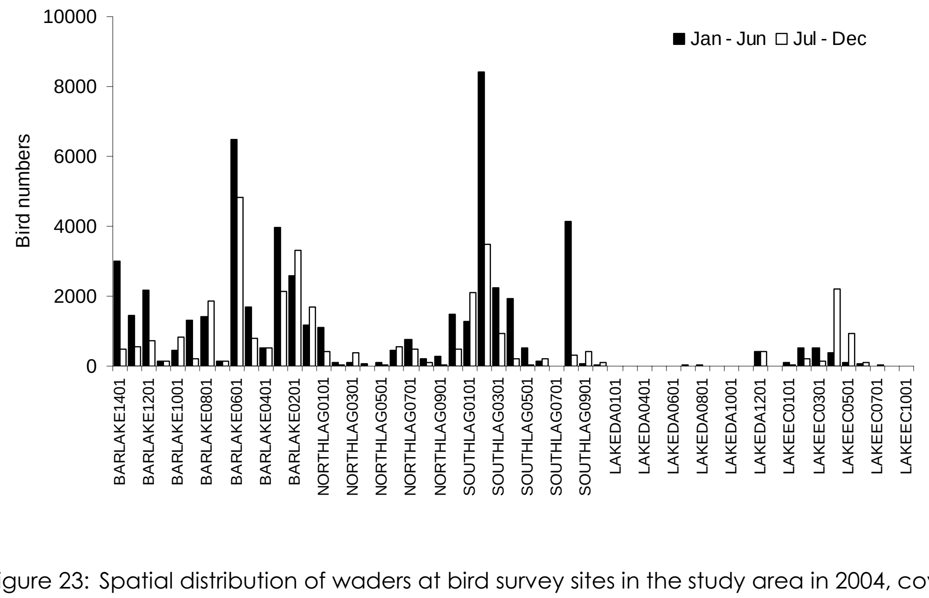


Figure 23: Spatial distribution of waders at bird survey sites in the study area in 2004, covering the two separate over-wintering seasons separately. The figure is based on an incomplete data set.

The sites for the benthic survey adequately covered the spatial distribution patters of the shorebirds, with an overlap of 21 sites (Fig. 24). Five sites along the Coorong which were surveyed for benthos were not included in the regular bird monitoring.

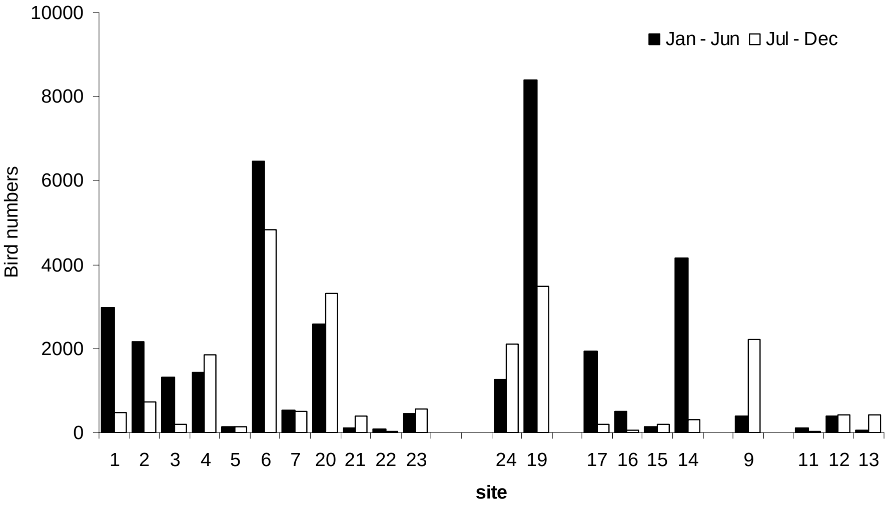


Figure 24: Spatial distribution of waders at benthic survey sites area in 2004. The figure is based on an incomplete data set. No bird data were recorded at the missing sites.

The distribution pattern of the shorebirds did not follow the distribution of macrofaunal abundances and biomass in the area (Figures 8, 15 and 24), as the sites along the Coorong where larger numbers of waders were recorded, provided no benthic food in the mudflats there.

As the harvestable food fraction is linked to the burial depth of benthic prey and the bill length of the birds, we classified waders by their bill length into three groups and correlated their abundance and distribution pattern to the distribution of benthic prey. Curlews, godwits and oystercatchers with a longer bill were low in numbers and confined to the Murray Mouth region, where deeper burying larger polychaetes occurred (Fig. 25). Plovers, red-necked stints and avocets who are feeding in the top sediment layer, occurred mainly in this region, too, where amphipods were available as prey items (Fig. 10). The majority of the sandpipers, stints, stilts, turnstones, knots and greenshanks with a medium bill length were found in the Coorong near Parnka Point. This pattern was especially due to banded stilts.

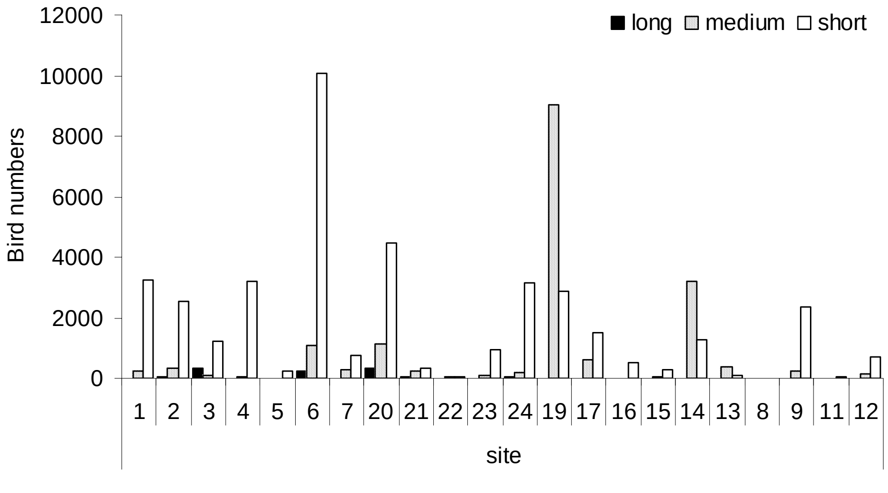


Figure 25: Spatial distribution of waders classified by bill length at benthic survey sites area in 2004. The figure is based on an incomplete data set. No bird data were recorded at the missing sites.

6. Discussion

6.1 The state of benthic communities in the Murray Mouth, Coorong and Lower Lakes

Diversity, abundance and biomass of benthic communities in estuaries

Diversities are generally lower in estuaries than in open coastal environments, while abundances and productivity can be high (Costanza et al. 1993, Attrill 2002, Ysebaert et al. 2003). Benthic macrofauna in estuaries is mainly composed of polychaetes, amphipods and molluscs (Hutchings 1999, Vivier & Cyrus 1999, Ysebaert et al. 2003, Dye & Barros 2005). Oligochaetes, insect larvae and molluscs are becoming more typical with a higher freshwater component (Vivier & Cyrus 1999, Ysebaert et al. 2003). Our findings agree with those patterns.

No organisms were recorded at several sampling sites in our study, especially in the Coorong. While high variations are known for benthos, and samples containing no species have been reported from other estuaries (Ysebaert et al. 2003), the diversity of macrofauna in the Murray Mouth and Coorong found in this study and by Geddes (1987, 2005b, a) is low. Yet, the diversity is comparable to low diversities found in other estuaries, such as seasonally closed estuaries or lagoons in Tasmania (Edgar et al. 1999) or Western Australia (Kanandjembo et al. 2001) (Table 5). Barrages have been reported to reduce diversities in estuaries (Vivier & Cyrus 1999) and are likely to have contributed to the low benthic species richness in the Murray Mouth and Coorong.

Several macrobenthic species have been described as common in estuaries of southeast Australia and Tasmania (Edgar et al. 1999, Hirst 2004). This includes the polychaetes *Australonereis ehlersi* and *Nephtys australiensis*, which were both frequently encountered in the Murray Mouth during this study. The bivalve *Arthritica helmsi* (syn. *A. semen*) is common in estuaries along the entire south Australian coast (Edgar et al. 1999, Cresswell et al. 2000, Kanandjembo et al. 2001) and occurred in the Murray Mouth as well. Thus, the polychaete and mollusc species recorded in the area (this study and Geddes 1987, 2005a) are common inhabitants of temperate Australian estuaries. A similar taxonomic composition (on the genus level) occurs in estuaries in South Africa (Kalejta & Hockey 1991). For amphipods, further taxonomic studies are needed here as in other estuaries to ensure identifications and allow comparisons of distribution ranges. Chironomids and larvae of coleopteran are commonly recorded in estuaries and were the only macrofauna found at several sites in the Coorong (Geddes 1987, Edgar et al. 1999). Isopods have been recorded near the high tide level in Tasmanian estuaries, reflecting their more terrestrial affinities (Edgar et al. 1999). Correspondingly, they were found in the drier parts of the exposed sandflats in the Coorong in the December survey of this study.

Our sampling design reached across the estuarine salinity gradient and vertically from the high tide line towards the low water level (if mudflats were exposed). Faunal differences along the salinity gradient were pronounced. Variations were high along the vertical gradient, seen in the high standard deviations of all figures, yet no consistent pattern as to higher diversity, abundance or biomass at the high, mid or low 'tide' level was apparent. In an estuary in the Netherlands, Ysebaert et al. (2003) carried out a large-scale survey extending their vertical gradient into the subtidal. They found highest diversity, abundance and biomass in the intertidal, with highest diversity and biomass in the polyhaline (salinity > 18 ppt) lower reaches of the estuary. In our study, diversity, abundance and biomass were also higher in the polyhaline area near the Murray Mouth.

Mean abundances of macrobenthos in the Murray Mouth and northern Coorong fall within the size range of densities recorded from other estuarine mudflats in temperate and subtropical latitudes (Table 5). Our biomass values are, however, much lower than most values reported in the literature, which could reflect the poor health of the system. Different methodologies are used to determine biomass (wet weight, dry weight, or ash-free dry weight AFDW). Biomass determinations can also be affected by the preservation method used, although it has been debated whether the type of fixation causes significant variations in biomass values (Brey 1986, Gaston et al. 1996). We did not pre-fix specimens in formalin to avoid contact with this carcinogenic substance. To test the correctness of our values, biomass measurements should be carried out on specimens from the various taxa found using different fixation methods. This exercise could also be used to set up correlation curves between various biomass calculations to develop conversion factors from dry and wet weight to AFDW, which could avoid time consuming AFDW determinations.

The annual migration takes shorebirds across several biogeographic zones. Latitudinal changes in diversity, abundance and biomass are documented (Ricciardi & Bourget 1999, Attrill et al. 2001, Cusson & Bourget 2005). However, as Table 5 shows, abundances and biomass are also highly variable at single sites.

Benthic communities in estuaries are transitional (Attrill & Rundle 2002) and their composition and distribution can be explained by salinity and sediment characteristics (Ysebaert et al. 2003). Correspondingly, our study showed a defined community in the Murray Mouth region and another well defined community in the South Lagoon, while the benthos of the North Lagoon was more transitional.

Table 5: Comparison of macrofaunal characteristics in intertidal mudflats of estuaries and open coasts around Australia and the West Pacific flyway. Further examples of estuaries from South Africa and northern Europe are included. Biomass values are AFDW unless indicated otherwise (DW). Some values are derived from figures in the respective reference and those values are indicated by ~. ICOLL = Intermittently Open and Closed Lake or Lagoon

Location	Habitat type	Species number	Abundance (ind. m^{-2})	Biomass (g m^{-2})	Other characteristics	Reference
Tasmania	Estuaries	~20 - ~60		42.5 1.7 on west coast	Species richness highest in coastal inlets, lowest in coastal lagoons & seasonally closed bar estuaries	(Edgar et al. 1999)
Coorong	Lagoon	21				(Geddes 1987, 2005b)
Coorong & Murray Mouth	Estuary and lagoon	40 (total) 0-14 per site	440 – 19365 (mean values per region)	0.4 – 2.6 (mean values per region)	Values lowest in the Coorong South Lagoon & highest near the Murray Mouth	This study
Perth	Estuary	37	~10000			(Kanandjembo et al. 2001)
Roebuck Bay	Mudflat	161	1287, range 40 – 16280	12.5, range 0.07 - 167	High patchiness of benthos	(Pepping et al. 1999)
Malaysia	Tidal flat			6.7 – 69.4	Biomass dominated by one bivalve species	(Sasekumar & Chong 1986)
Java	Bay		463	1.5	Inter- & subtidal sites	(Warwick & Ruswahyuni 1987)
Korea	Estuarine tidal flat	40		3.1 – 51.9	Biomass dominated by molluscs	(Doornbos & Groenendijk 1986)
Korea	Tidal bay	3 – 24, 87 in total	550 (mean), 40 (min) -1730 (max)		Inter- & subtidal sites, higher diversity & density in intertidal	(Shin et al. 1989)
West Africa	Tidal flats	111	1401 (mean), 152 (min) – 5635 (max)	17		(Wolff et al. 1993a, Wolff et al. 1993b, Wijnsma et al. 1999)
South Africa	ICOLL with barrage	24	18567			(Vivier & Cyrus 1999)
South Africa	Estuaries			4.7 – 20.35	Variations in relation to freshwater inflow	(Scharler & Baird 2005)
South Africa	Estuary	25	17332 (min)– 197000 (max)	19.4 (DW)	Densities varied with seasons & sites	(Kalejta & Hockey 1991)
Netherlands	Estuary	0-25	~13000	~25	Values are for polyhaline zone, biomass lower in mesohaline zone	(Ysebaert et al. 2003)
Germany	Tidal flats			50		(Scheiffarth & Nehls 1997)

Faunal gradients in estuaries

The fauna in estuaries is following the strong environmental gradients in these systems (Attrill & Rundle 2002). Salinity is the most important environmental factor in estuaries, and together with temperature and accompanying physico-chemical properties, it determines species distribution and abundances (Kinne 1966, Mackay & Cyrus 2001, Ysebaert et al. 2003). The faunal distribution in the various regions of our study agrees with this. The sharp salinity gradients enforced by the barrages and the hypersaline conditions prevailing throughout most of the Coorong (Geddes 2005a) are, however, extreme in comparison to most other estuaries and coastal lagoons. Earlier studies have already demonstrated effects following varying episodes of environmental conditions on marine biota in the Coorong (Geddes & Butler 1984, Geddes 1987). The data from the survey presented here corroborate these earlier findings and substantiate concerns about the environmental health of the study area.

Some polychaete species recorded in this study have been reported from other estuarine locations under a variety of salinity values. The nereid polychaete *Simplisetia aequisetis* (synonymous with *Ceratonereis pseudoerythraeensis*) was reported to occur in salinities from 10 – 35 ppt (Hutchings & Glasby 1985), yet its distribution was negatively correlated with salinity in southeast Australian estuaries (Hirst 2004), which can be corroborated by our study. Geddes (1987) also observed a decline in abundance of this species and several other polychaetes as salinities fell below 5 ppt, but has later reported their occurrence in subtidal sediment of the Coorong up to salinities of about 70 ppt (Geddes 2003). Further polychaetes in the study area *Australonereis ehlersi* and *Nephtys australiensis* have been collected from salinities of 5 – 39 ppt (Hutchings & Murray 1984). Other polychaetes, like *Phyllodoce novaehollandiae* are reported from marine habitats (33.8 ppt), which corresponds to its occurrence near the Murray Mouth. In spite of such tolerances to lower salinities, the distribution patterns found in our study clearly indicate preferences of the mudflat fauna to more marine conditions.

We measured salinity in the water overlying the sampling locations near the water edge. While this gives a good reflection of the overall and large scale salinity gradients in the study area, the porewater salinities in the mudflats could have been different. Hirst (2004) reports less variation in sediment porewater than water salinity between several estuaries along the southeast coast. Porewater salinity can also be more characteristic of the environmental conditions at the scale of the benthic organisms and should be included in future studies, especially as mudflats in the Coorong are exposed for prolonged durations and salinities in the sediment could increase.

In the hypersaline South Lagoon, oxygen concentrations in the water were below the detection limit. Very high salinities are accompanied by low levels of dissolved oxygen, critical for respiration of most aquatic invertebrates (Williams 1998). Hypoxic conditions (< 2 mg l^{-1} O_2) were shown to cause low diversity and biomass of macrobenthos in Chesapeake Bay (Dauer et al. 1992). Our oxygen measurements in the Coorong and Lake in December gave values slightly above hypoxia and could have already contributed to the lack of macrofauna at most sites. The lake sites in our study were characterised by more limnic fauna, although brackish conditions occurred at some sites. Distributions of these organisms in the system would also be determined by their salinity tolerances (Kefford et al. 2003, Kefford et al. 2005).

Sediment compositions are a further determinant of benthic communities in estuaries (Ysebaert et al. 2003). In ICOLLs (Intermittently closed or open lakes and lagoons) in NSW, the sediment was getting finer and more variable into the lagoon and lakes and the organic content of the sediment increased correspondingly with this increase in silt content towards the inner reaches (Dye & Barros 2005). Such a clear pattern was not apparent in our study area, where most of the sediments were fine to medium fine sands, with coarser sediment found in the South Lagoon in June, probably due to sampling sites closer to the high tide level when water levels were higher. The contents of organic matter were three- to fourfold higher in the Lake site sediments than the estuary and lagoon, and slightly higher in the South Lagoon. Similarly, Vivier & Cyrus (1999) report very high organic matter contents at their lake sites which were characterised by detrital mud.

While high abundances of macrobenthos were recorded at sampling sites around the Murray Mouth and the northern end of the Coorong lagoon, most other sites were almost devoid of fauna. Paton et al. (2000) and Geddes (2005a) describe a similar distribution for macrofauna in the area. The dominance of polychaetes and amphipods in the estuarine part of the study area corresponds with investigations in other estuaries (for example Vivier & Cyprus 1999). Links between environmental conditions and macrobenthos are, however, not always straightforward. Dye & Barros (2005) could not find clear relationships in ICOLLs in New South Wales. Statistical tools like multiple logistic regression and other numerical modelling techniques have been used to predict macrobenthic distributions in estuaries and lagoons with strong coupling of benthic, sedimentary and physicochemical processes (Millet & Guelorget 1994, Ysebaert et al. 2002, Thrush et al. 2005). Based on an extensive data set stretching over several decades and hundreds of sampling sites, Ysebaert et al. (2002) present response surfaces which may be useful for evaluating effects of different management, although they cannot explain controlling processes. The literature survey presented in this study (see appendix) and the records from the field survey are stepping stones for such future models for the Coorong.

Spatial and temporal distribution patterns of benthic fauna in estuaries

Abundances are known to vary spatially within estuaries, reflecting the changing environmental conditions described above. In the study area, highest abundances were recorded in the estuarine section, with abundances decreasing with increasing distances from the mouth. Although this was extreme and the hypersaline conditions in the South Lagoon are unparalleled, a similar decrease in abundance with distance from the mouth has been found by Dye & Barros (2005).

Patchy distributions in relation to salinities were observed for molluscs in an estuarine inlet in Western Australia (Cresswell et al. 2000, Semeniuk & Wurm 2000). The micromollusc *Arthritica semen* (syn. *A. helmsi*) was the most abundant mollusc in their study and found throughout the study area, yet highly variable in space and time. Geddes (2005b) reports this bivalve as widespread in the Coorong and Murray Mouth, yet we found it confined to the more marine conditions, and highly variable between sites, especially in winter.

Spatial patterns in the distribution of benthic fauna can vary with season and between years, which was found to be further complicated as these changes were site specific in an estuary in South Africa (Kalejta & Hockey 1991). Spatial and temporal patterns of macrofauna can be tightly linked and vary on several scales, which needs to be considered for the data interpretation and future sampling designs (Hewitt et al. 1998).

Temporal variations in estuarine habitats and biota result from seasonal changes in rainfall and freshwater discharge rates or drought periods (Attrill et al. 1996, Attrill & Power 2000, Kanandjembo et al. 2001, Rozas et al. 2005). The amount of rainfall affects salinity, stratification, and turbidity in estuaries, and can regulate the opening or closure of the mouth in ICOLLs. In addition, barrages can cause closure of the mouth, as in the case of the Murray (Vivier & Cyrus 1999). Low salinities after winter flooding have been shown to cause mass mortalities of a bivalve in estuaries in Victoria (Matthews & Fairweather 2004, Matthews 2005). In a long-term study of a sub-tropical estuary on Australia's east coast, freshwater flows also proved critical for estuarine production (Currie & Small 2005). Although floods triggered the initial decline, a series of drought years was characterised by low benthic abundances and diversity. Currie & Small (2005) observed a recovery after the onset of rains, yet the structure of the benthic assemblage had changed. The reduced water discharge across the barrages resembles such a period of prolonged drought for the Murray estuary and the poor conditions of the benthic communities reported in this study and by Geddes (2003, 2005b, a) and Paton (2003) indicate the necessity to increase flows. Following the long periods of barrage closure in the past decade, small water releases in 2003 and 2004 did not cause an increase in macrobenthos (Geddes 2005b).

Discharge from the rivers also regulates the seasonal input of sediments and nutrients into the estuary and nearby sea (Lillebo et al. 2005, Rozas et al. 2005). In the Coorong, the barrages prevent the natural flow of river Murray water. In the year this study was carried out, no water release had occurred prior to the winter sampling in June nor the summer sampling in December. The observed variations between those two sampling occasions are therefore largely due to temperature and the larger extent of the mudflats in summer due to evaporation, as well as to life cycles and recruitment patterns of the benthic fauna. Infaunal records by Geddes (2005b) also indicate some seasonal variation. Yet, whether these variations in benthic abundances are truly seasonal, or follow other temporal fluctuations, or result from predation pressure, has not yet been investigated in this area. In December ,the sediment at most of the mudflats in the Coorong was dry and solid, unsuitable both for benthic life and foraging by waders.

Species interactions and animal-sediment relationships of benthic fauna in estuaries

Distribution patterns of benthic fauna are not only determined by environmental conditions, such as sediment properties, but by modifications of the sediment caused by organisms themselves, as well as by interactions between species (Olafsson et al. 1994, Reise 2002, Ysebaert et al. 2003). Such interactions include sediment disturbance by burrowing activity, predation or competition. Amphipods and nereid polychaetes can secrete mucous that binds sediment particles together and raises the erosion threshold, while reducing the sedimentation of previously resuspended particles (Meadows et al. 1990). On the other hand, their burrowing activity can increase sediment reworking and biogeochemical fluxes (Sayama & Kurihara 1983, Mermillod-Blondin et al. 2005) and polychaetes of the families Nereidae and Capitellidae affect the flux of O_2 and CO_2 across the sediment-water interface (Kikuchi 1986, 1987). Related species were abundant in the mudflats near the Murray Mouth and could have similar effects on sediment properties and biogeochemistry here.

Most capitellids are deposit feeders while nereid polychaetes display flexibility in their feeding modes (Fauchald & Jumars 1979, Riisgard & Kamermans 2001). Members of the other polychaete families encountered are scavengers (Phyllodocidae) and predators (Nephtyidae). Nephtyidae are important endobenthic predators in mudflats (Schubert & Reise 1986) and amphipods are among their prey items (Redmond & Scott 1989). Yet, in the Murray Mouth, the low numbers of *Nephtys australiensis* (Redmond & Scott 1989) in relation to the high abundance of amphipods does not indicate to a strong predation pressure by this endobenthic predator.

Amphipods are important food items for fish and birds in marine and freshwater systems (Raffaelli et al. 1991, Wooster 1998) and subject to episodic predation by migratory shorebirds (Wilson 1991), which can influence their life history strategy (Hilton et al. 2002). Macroalgal mats, which were observed at several sites in the Murray Mouth, can reduce amphipod numbers, as has been shown in an estuary in Scotland (Raffaelli et al. 1991, Raffaelli 1999), which could affect higher trophic levels.

Shorebirds preying on the polychaete *Simplisetia aequisetis* (syn. *Ceratonereis pseudoerythraeensis*) affected the population structure of their prey (Kent & Day 1983). In a series of experiments these authors could show that the density-dependant adult - juvenile interaction of the polychaetes was reduced, as birds preyed on the larger worms, which thus affected the recruitment success of the worms. This should, however, be studied further, as *S. aequisetis* in the Murray Mouth is brooding its young (own observations).

Although the Coorong and Murray Mouth are characterised by few species and strong environmental gradients, no simplistic approach can be taken to understand ecological processes and the effects of different management scenarios in this system.

Estuarine benthos in relation to estuarine geomorphology and mouth opening/closure

Recent comparisons of benthic fauna in estuaries around Tasmania (Edgar et al. 1999) and the southeast of Australia (Hirst 2004, Dye & Barros 2005, Dye 2005) have shown geographic variations with the prevailing type of estuary. The geomorphological characteristic most important for explaining difference in the biota was the presence of a bar. Macrofaunal assemblages differed between closed and open ICOLLs, with higher diversities found in open situations (Dye & Barros 2005). The macrofauna in open estuaries along the southeast coast of Australia were also characterised by having more 'singletons', species that were confined to single sites (Hirst 2004). For the Coorong and Murray Mouth, diversities are low in comparison to other estuaries in Australia and elsewhere (Table 5). With the lack of historical records on benthic fauna it cannot be explained whether the more recent man-induced closure of the mouth has contributed to this depauperated state.

The conditions of an open or closed estuary have several implications for benthic fauna. Changes in the water stratification, salinity, tidal range and oxygen availability affect the benthos (Edgar et al. 1999, Dye & Barros 2005). The presence of a bar can also restrict the movement of the more mobile species and inhibit their recruitment (Teske & Wooldride 2001). Few bivalve species were found in coastal lagoons and seasonally closed estuaries in Tasmania (Edgar et al. 1999), which might reflect the reliance of this taxon on a pelagic larval stage, subject to exchange with the nearby ocean. Comparisons of the fauna in Danish estuaries and coastal areas have shown that the estuarine macrofauna relies on colonization from the adjacent sea and are not self-reproducing systems (Josefson & Hansen 2004). The importance of uninhibited exchange between the Murray estuary and the open ocean cannot be underestimated.

In the Oosterschelde (Netherlands), a storm surge barrier installed in the 1980´s remains open unless storm events occur. The closure of the barrier lead to hydrodynamic changes and prolonged emersion of the intertidal habitats. In a series of experiments, the tolerance of benthic macrofauna was tested towards various scenarios of submergence and emergence, showing mortality following several days of continuous emersion (Hummel et al. 1986, Hummel et al. 1988). In the Coorong, the low water levels following the closure of the Murray Mouth and low flow across the barrages causes extended periods of emergence, especially in the summer months. This would have contributed to the scarcity of macrobenthos recorded in this region during our survey in December.

6.2 Recommendations on the monitoring of benthic communities and indicator species

Indicators

Based on the tolerance and life history characteristics, attributes of certain species may be useful indicators for specific environmental conditions, and their presence, absence or a certain reference range of abundance can indicate changes in ecosystems (Grizzle 1984, Pocklington & Wells 1992, Ward 2000, Bustos-Baez & Frid 2003, Hiscock et al. 2003). In estuaries, characterised by high natural variations, species are tolerant towards a wide range of environmental conditions (Wilson 1994), which complicates the search for bioindicators. Wilson (1994) also points out that no single indicator should be used and that it is necessary to specify which conditions an indicator is supposed to indicate. Selection criteria and identifiers have to be carefully chosen by managers and scientists together (Hiscock et al. 2003). Depending on the required level of distinction, different taxonomic levels may be sufficient as indicators (Chessman et al. 2002)

The *Capitella capitata* species complex has been widely used to indicate eutrophication and pollution effects (Bustos-Baez & Frid 2003). *Capitella* spp. were among the most abundant benthic organisms in this study, esp. in the Murray Mouth region. However, we could not find a link between *Capitella* spp. and organic matter in sediments.

A more suitable indicator for sedimentary conditions and food availability for shorebirds might be the nereid polychaete *Simplisetia aequisetis*, which has to be explored further. A high sensitivity of nereid polychaetes to marine pollution has been shown before (Reish 1970). This species completes its life cycle within the estuary, as juveniles were found in the burrows of adults. Such adaptations in the reproductive mode of Nereididae in brackish waters have been documented before (Sato 1999).

Practical aspects have to be considered for the choice of indicators as well. Amphipod species distributions for example, can be indicative of certain sedimentary conditions (Grant

1981). They were richest in abundance at several sites near the Murray Mouth and at lake sites, yet at present, detailed knowledge on these species is not available in Australia. Furthermore, the distinction of amphipod species is taxonomically very difficult. Ten morphospecies were distinguished (Appendix 3) and every specimen requires a detailed identification under the microscope. This excludes their potential usefulness as indicators. *Arthritica helmsi* is a micromollusc that was abundant at certain sites and is known from estuaries in all of southern Australia. Its use as an indicator demands life sorting, to separate life from dead shells. This poses constraints on the number of samples that can be processed.

It has also been suggested that abiotic variables can be used to indicate the health or stress of benthic systems (Maher et al. 1999, Caeiro et al. 2005, Hyland et al. 2005), although the usefulness is critically discussed by these authors. We measured the content of organic matter in the sediments and found little variation between the estuarine and hypersaline regions with values only slightly higher than those reported for an estuary in South Africa (Vivier & Cyrus 1999). High organic contents were found at some of our lake sites and eutrophication cannot be excluded as a cause. As discussed above, benthic distribution patterns are not determined by environmental conditions alone and abiotic variables as indicators cannot establish causality of responses.

Site selection and sampling frequency

In this study, the sites were selected by the DEH on the basis of covering representative areas and coinciding with sites of bird surveys. Community analyses have shown that little variation exists between benthic communities in the Murray Mouth region and South Lagoon. This has already allowed to reduce the number of sites in each region for further surveys. In a similar approach using multivariate statistics to analyse their biomass data, Durell et al. (2005) mapped habitat patches in an estuary in northwest Europe and could reduce sampling effort to monitor food supplies for overwintering shorebirds. A reduction of the number of sites while increasing the number of replicates taken per site is recommendable to increase the accuracy and precision. The growing data set available for macrobenthos in the Coorong and Murray Mouth can be used to determine optimal sample sizes and power (Bros & Cowell 1987).

In our study, variation was high at single sites, largely due to the spread of samples between the high tide level and water line. As the mudflats were exposed further in December than in June, the "high tide" samples shifted a bit further into the actual mudflats, whereas in June these samples were partly obtained from supratidal locations. With a low tidal range and irregular tidal rhythm in the Coorong and Murray Mouth region, the distinction of sites by tidal level has to be questioned.

Spatial and temporal fluctuations are intrinsic to estuarine and coastal ecosystems, which poses methodological challenges (Morrisey et al. 1992a, b, Kendall & Widdicombe 1999, Warwick et al. 2002). Thrush et al. (1994) found that species and site specific spatial patterns can vary more than temporal patterns and pose the question as to what density estimates are needed for a site to prevent spatial variations confounding the temporal sequence. Most of the variability in macrobenthic species in a long-term data set from an estuary in the Netherlands could be explained by variations at the scale of stations and local environmental variables (Ysebaert & Herman 2002). These studies indicate that sufficient pilot data over a wider spatial and temporal scale are required to develop a monitoring design able to detect changes resulting from disturbance events or impacts.

Careful consideration has to be given to the chosen variables and the spatial and temporal scale of monitoring coastal ecosystems to address the objectives (Comin et al. 2004). Based on this report and ongoing studies, a monitoring scheme for the Coorong and Murray Mouth can be discussed with the DEH in relation to their management needs.

6.3 The value of the Coorong and Murray Mouth as a feeding ground for overwintering waders

The Coorong and Murray Mouth are an overwintering site for shorebirds, which frequent the area between November and April. The phenologies showed slight variations in the beginning and end of the overwintering period between years. The records also indicated variations in shorebird numbers within and between migration periods of 2002/2003, 2003/2004 and the beginning of 2005. While this could partly be due to the bird survey method and incompleteness of the data set at this stage, it cannot be ruled out that it hints to bird movements during their overwintering time in South Australia. The phenology was most pronounced in the Murray Mouth region, where overall shorebird numbers were also highest. A continuation of bird and benthos surveys in this area is therefore warranted, as it is of highest ecological value albeit needing careful management.

Food availability

Migratory shorebirds are exposed to differences in prey availability and prey risks along their flyways (Zwarts et al. 1990, Wolff 1991, Piersma et al. 1993a, Elner & Seaman 2003). Worldwide, total biomass in intertidal sand- and mudflats is about 24 g AFDW m^{-2} on average (range 5 – 80 g AFDW m^{-2}), with no apparent latitudinal trend (Piersma et al. 1993a). Compared to that, biomass in the Coorong is substantially lower (Table 5). Even in the Murray Mouth region, which had the highest biomass values within the study area, the biomass was 10 times lower than the average from other mudflats. The low biomass values recorded in this study give rise to concern whether the Coorong and Murray Mouth can provide enough food for the fattening of the waders overwintering here.

The composition of taxa contributing to benthic biomass varies between tidal flats worldwide, with bivalves, gastropods, polychaetes and crustaceans accounting for most of the biomass (Piersma et al. 1993a). Molluscs and polychaetes are the preferred prey item for several shorebirds and the birds often prefer certain size classes of prey (Kalejta 1993, Piersma et al. 1993b, Stillman et al. 2005). In the Murray estuary, it is mainly polychaetes and amphipods which make up the biomass, while molluscs were underrepresented. As discussed above, a scarcity of molluscs has been found in other semi-closed estuaries. Geddes (2003, 2005b) recorded several specimens of the bivalve *Notospisula trigonella*. However, we only found shell remains in the flotsam, indicating their higher abundance in past times. A continuous opening of the Murray Mouth may facilitate the re-establishment of their populations and thus increase the food supply for shorebirds.

Shorebirds are flexible in their diet (Skagen & Oman 1996) and in the study area, they had to switch from marine to limnic food items between the Murray Mouth, Coorong and Lake. Chironomid and other insect larvae were abundant in the South Lagoon and the Lake sites, where they constituted the main food source for the shorebirds. Insect larvae abounded in an inland mudflat in Hungary, where waders caused an 87 % reduction in prey densities (Szekely & Bamberger 1992).

Shorebirds can deplete their invertebrate prey in their overwintering grounds, depending on the available foraging area and seasonal population dynamics of their preferred prey (Kalejta 1993, Mercier & McNeill 1994). If intense predation coincides with the time of reproduction of the prey, possible prey depletion cannot be detected (Kalejta 1993). In the tidal flats of the northern Wadden Sea, birds consume 15-25 % of the mean annual biomass of macrozoobenthos (Scheiffarth & Nehls 1997). It has been debated whether shorebirds are food limited (Petersen & Exo 1999, Morris & Keough 2003). For the Coorong and Murray Mouth, studies on foraging behaviour and uptake rates are needed to evaluate whether food limitation exists.

Foraging

Shorebird feeding in mudflats is also subject to variations in sediment properties (Gerritsen & van Heezik 1985). The foraging efficiency of shorebirds feeding on polychaetes and oligochaetes can be higher in muddy than sandy sediments, as sand grains can interfere with the detection and or capture of prey (Quammen 1982, 1984). Most of the sites with high densities of polychaetes and oligochaetes were fine sand and well sorted. At several sites in the Coorong, however, the sorting coefficients indicated poor sorting and this mix of particles of various grain sizes could have implications to the foraging ability of birds.

The mud- and sandflats in the Coorong are exposed for long periods of time following reduced water level in the area and evaporation in summer. The surfaces were very solid and signs of activity of benthic organisms were absent (own observations). The water content of the sediment can affect the habitat selection and foraging success of shorebirds, as peck depth and prey detection depend on the penetrability of the sediment (Myers et al. 1980, Mouritsen & Jensen 1992). In the Coorong, only the moister sediments near the water line are suitable for foraging by shorebirds, yet even here the foraging effort is paired with low prey densities.

The quality of a feeding habitat for shorebirds is determined by the attainable intake rate, which depends on the burial depth and size of prey items in relation to the reach of the bill (Piersma et al. 1993a, Zwarts & Wanink 1993, Dann 1999, Elner & Seaman 2003). A suitable feeding habitat for shorebirds is not only characterised by sufficient harvestable food, but as well by low risk of predation, low density of competitors and low costs of thermoregulation (Piersma et al. 1993a, Piersma et al. 1993b). While nothing is known on the latter factors in the study area, some indication on harvestable food fraction was obtained by classifying the shorebirds into three categories of different bill length. Shorebirds with long bills were confined to sites near the Murray Mouth were larger polychaetes, which live deeper in the sediment, were more abundant. Shorebirds with medium length bill, especially banded stilts, were common south of Parnka Point. Those shorebirds having short bills occurred throughout the study area and would have preyed on amphipods, smaller polychaetes like capitellids, and insect larvae, which live in the top 2-3 cm of the sediment. A study in Port Phillip Bay has shown that red-necked stints, curlew and sharp-tailed sandpiper preferred different prey sizes each and that larger worms (*S. aequisetis*) were more accessible for the curlew sandpipers (Kent & Day 1983). Preferences of birds preying on specific sizes of these worms can vary with site and season (Kalejta 1993). Further studies in the Murray Mouth and Coorong are taking the vertical distribution of benthic fauna into account to allow a detailed differentiation of bird distributions with harvestable prey fractions.

Spatial and temporal distribution of shorebirds

The spatial distribution pattern for waders in the first and second half of 2004 did not match the distribution pattern of benthic macrofauna. Although benthic abundances were highest in the Murray Mouth region, where most shorebirds were counted, high shorebird counts around Parnka Point were unrelated to benthic food available in the area. The shorebirds there must either use different food items, like remaining turions of *Ruppia* spp. (Paton 2001, 2002, 2003) or use the area mainly as resting places. More detailed observations and studies are needed to explain the spatial pattern of shorebird distribution in the Coorong. Yet several possible explanations can be discussed.

Predator-prey relationships between shorebirds and benthos are very site-specific, depending on the type of prey available. Cummings et al. (1997) observed no response by shorebirds to experimental modifications of prey density, yet discuss whether their patches were on a scale too small for the birds to detect and respond to in relation to a mobile prey. Prey mobility could have also caused that predator exclusion did not affect invertebrate numbers in a mudflat in Scotland, although size-selective predation was observed on the amphipod *Corophium* (Raffaelli & Milne 1987). Ribeiro et al. (2004) could show that shorebirds foraging on certain prey (polychaetes, crabs) made specific use of mudflat habitats to follow the spatial distribution of their prey, and certain areas of the mudflat were frequented by a greater diversity of shorebirds than others. These finding asks for much finer scaled observations of birds and benthos at selected sites in the Coorong and Murray Mouth in order to understand causal links between their spatial distributions.

We surveyed benthic food availability two times in 2004 and found little variation in the large-scale pattern of abundances and biomass, although variations were significantly different at single sites. The species composition of the benthic assemblages was also different between June and December as was the share of the major taxa on the biomass. Could such differences affect the value of the Coorong and Murray Mouth as a feeding ground for shorebirds? Seasonal changes in food choice have been reported for dunlins, who also changed their habitat preferences for foraging sites with season (Nehls & Tiedemann 1993). Zwarts & Wanink (1993) found differences in burying depth with season, which were larger for some species than others and affected the accessibility and profitability of benthic prey to shorebirds. In the Coorong, the prolonged exposure of mudflats with low water levels can affect the depth distribution and hence the prey availability for shorebirds, especially over summer (see above). Fluctuations in benthic food availability within and between years have been shown in the Wadden Sea (North Sea) (Zwarts & Wanink 1993). Differences in food availability between years will affect the shorebirds, yet whether this has occurred in the Coorong and Murray Mouth cannot be evaluated as no long-term data on benthic biomass are available.

Eutrophication and disturbances

An increase in benthic abundances following experimental nutrient additions did not result in increased bird predation rates in Port Phillip Bay, Victoria (Morris & Keough 2003). Nutrient additions can also cause defaunation following the development of anoxic conditions in the sediment, often enhanced by macroalgal growth smothering the sediment (Heip 1995). Fresh macroalgal cover can increase prey availability for shorebirds, as benthic fauna moves to the surface to avoid the developing anoxic conditions. Metzmacher & Reise (1994) found that birds were attracted to experimental macroalgal additions, whereas they avoided the established algal mats where all benthic food was depleted. Anoxic sediment reaching to the surface was common at most study sites and near the barrages, decaying macroalgal mats and cow pads covered areas near the high tide line. The high numbers of capitellids found in this region is an indication to such eutrophication, as these polychaetes can tolerate anoxic conditions with high concentrations of hydrogen sulphides (Grassle & Grassle 1976). Although their abundance was a sign for the poor ecological health of the area, they did provide food for foraging waders.

Disturbances from human activities can reduce the suitability of a feeding site for shorebirds (Pfister et al. 1992, Thomas et al. 2003), although effects of human disturbances are not always easily detected (Gill et al. 2001). Shorebirds use mudflats for feeding, yet rely on the availability of suitable undisturbed sites for resting and other behavioural activities (Burger et al. 1997). Shorebirds have also been shown to switch habitats if food supplies cannot be met in their preferred foraging area (Smart & Gill 2003). Thus further site requirements or alternative feeding areas in addition to intertidal foraging grounds could affect the distribution patterns of shorebirds in the Coorong and Murray Mouth.

Barrage effects

Changes to the hydrodynamics in an estuary can further affect benthos and birds (Smaal & Nienhuis 1992, Ravenscroft & Beardall 2003). The Oosterschelde in the Netherlands was converted from an estuary to a tidal bay following the construction of storm surge barrier (Smaal & Nienhuis 1992). Although the main barrier stays open unless severe storm conditions occur, substantial changes to the ecosystem have been documented. Benthic communities changed in composition and prevailing trophic groups, but abundances and biomass varied little to pre-barrier conditions (Meire et al. 1994b, Seys et al. 1994). Bird numbers declined, however, which was largely attributed to a decline in the area available for foraging (Smaal & Nienhuis 1992, Meire et al. 1994a).

In our study area, the challenge exists to provide more freshwater to the Coorong Lagoon to reduce the hypersaline conditions there, while at the same time maintaining marine conditions at the mouth of the estuary. Water release over the barrages should be a continuous rather than pulse release that could cause a sudden salinity drop and reduce macrofauna, which would directly affect the shorebirds, as the Murray Mouth region was their richest feeding ground in the entire area.

Dredging operations as those carried out in the Murray Mouth cause further disturbances to benthic fauna (Newell et al. 1998). While this is currently vital to keep the mouth open, the implications for macrobenthos and birds should be evaluated. Our sampling sites 2 and 3, which were closest to the mouth, had the lowest abundances and biomass for this region. A study on a recreated mudflat in England indicates that it can take several years until benthic abundances and the value of the habitat as a feeding ground for shorebirds are restored (Evans et al. 1998). The Murray estuary and Coorong may have a long way to go to return to their natural conditions.

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APPENDIX 1: Site characteristics of survey stations

Table A1a: Geographic coordinates of the mudflat sampling sites during the surveys in June and = December 2004 =

Table A1b: Details of sampling dates and survey times during the macrobenthic mudflat surveys in = June and December 2004. =

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APPENDIX 2: Environmental parameter

Table A2a: Characteristics of the water body at the sampling sites for the benthic survey in the Murray = Mouth (sites 1 – 7), Northern Coorong Lagoon (sites 20-26), Southern Coorong Lagoon (sites 13-19) = and Lower Lakes (sites 8-12) in June and December 2004. Measurements were taken in about 30 cm = water depths at near the low tide sampling sites, using a YSI 85 multiprobe. Salinity values and = oxygen concentrations exceeded the detection limit of the electrode at several sites and no readings = were taken at site 13 in December, which was a saltpan without any water. Calculated salinities are = based on conductivity with temperature correction. =

Table A2b. Sediment characteristics of the sampling sites in the Murray Mouth (sites 1-7), Northern = Coorong Lagoon (sites 20-26), Southern Coorong Lagoon (sites 13-19) and Lower Lakes (sites 8-12) = in June 2004. HT=High tide location, MT=Mid tide location, LT=Low tide location (MT and LT not = sampled at every site). Grain size distributions are given as the percentages of the single fractions (as = particle diameter in µm or according to the Wentworth scale (phi) with sorting coefficients. Dominant = grain size fractions are highlighted in bold. =

Table A2c. Sediment characteristics of the sampling sites in the Murray Mouth (sites 1-7), Northern = Coorong Lagoon (sites 20-26), Southern Coorong Lagoon (sites 13-19) and Lower Lakes (sites 8-12) = in December 2004. HT=High tide location, MT=Mid tide location, LT=Low tide location (MT and LT not = sampled at every site). Grain size distributions are given as the percentages of the single fractions (as = particle diameter in µm or according to the Wentworth scale (phi) with sorting coefficients. Dominant = grain size fractions are highlighted in bold. =

Table A2d. Sediment organic matter (% AFDW) of the sampling sites in the Murray Mouth (sites 1-7), = Northern Coorong Lagoon (sites 20-26), Southern Coorong Lagoons (sites 13-19) and Lower Lakes = (sites 8-12) in June and December 2004. HT=High tide location, MT=Mid tide location and LT=Low = tide location (MT and LT not sampled at every site). SE (in brackets) was only calculated for = December, when three replicate samples were taken for each tidal level. =

=

APPENDIX 3: Benthic data

A) Species Records

Table A3A: Macrofaunal species presence at each site within each region, based on samples and = observations from surveys conducted in June (J) and December (D) 2004. Ref./Fig. refers to species = morphological characteristics, photos and sketches given in Appendix A3B. Reference specimens (x) = for the amphipods were collected and are held in the Biological Department of Flinders University. =

=

B) Species Identifications

Appendix A3B: Key morphological characteristics of the macrofaunal species found during surveys = conducted at the Murray Mouth, Coorong and Lower Lakes regions in June and December 2004. = Photos and/or sketches, as well as key features are given to distinguish species or morphospecies. = Additional information on habitat and feeding is included where available. Literature references for = further taxonomic or ecological information are included. =

Section 1: Annelida

Section 2: Crustacea

Section 3: Mollusca

Section 4: Insecta

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C) Individual abundances **The Excel tables Table A3Ca to A3Cd are available upon request**

Table A3Ca. Macrofaunal abundances of each taxon as well as totals for higher taxonomic levels and = total macrobenthos, for each replicate at each site, for the Murray Mouth (sites 1-7), Northern Lagoon = (sites 20-26), Southern Lagoon (sites 13-19) and Lower Lakes (sites 8-12), recorded in June 2004 = (see Appendix 1 for individual site sampling dates and site coordinates). Samples were collected using = a corer of 84 cm^2 surface area, then sieved through 500 µm mesh and stored in alcohol for later = identification. H=high tide station, L=low tide station; a, b, c = replicate numbers. =

Table A3Cb. Macrofaunal abundances of each taxon as well as totals for higher taxonomic levels and = total macrobenthos, for each replicate at each site, for the Murray Mouth (sites 1-7), Northern Lagoon = (sites 20-26), Southern Lagoon (sites 13-19) and Lower Lakes (sites 8-12) recorded in December = 2004 (see Appendix 1 for individual site sampling dates and site coordinates). Samples were collected = using either a large corer of surface area 83.32 cm^2 at sites 1-3, 8-19, 24-26, with n=3 for each tidal = level; or a small corer of surface area 19.63 cm^2 at sites 4-7 and 20-23, with n=6 for each tidal level, to = account for the higher abundances expected at theses sites. Samples were sieved through 500 µm = mesh and either sorted alive or stored in alcohol for later sorting and identification. H=high tide station, = M=mid tide station, L=low tide station; a - f = replicate numbers. =

Table A3Cc. Macrofaunal abundances (Individuals m^{-2}) for June 2004, given as mean (AVE) and = standard deviations (SD) for 3 respectively 6 replicates per site (see Table A3Ca for further details). = Abundances are given for each taxon as well as higher taxonomic levels and total macrobenthos. = Sampling sites in the study area are in the Murray Mouth (sites 1-7), Northern Lagoon (sites 20-26), = Southern Lagoon (sites 13-19) and Lower Lakes (sites 8-12). =

Table A3Cd. Macrofaunal abundances (Individuals m^{-2}) for December 2004, given as mean (AVE) = and standard deviations (SD) for between 3 to 18 replicates per site (see Table A3Cb for further = details). Abundances are given for each taxon as well as higher taxonomic levels and total = macrobenthos. Sampling sites in the study area are in the Murray Mouth (sites 1-7), Northern Lagoon = (sites 20-26), Southern Lagoon (sites 13-19) and Lower Lakes (sites 8-12). =

Table A3Ce: Macrofaunal abundances (individuals m^{-2}) and standard deviation (SD) for total = macrobenthos recorded at the various sampling locations per site in June and December 2004. = HT=High tide, near shoreline, or if one location sampled only as at the lake; MT=mid tidal level, interim = between the shoreline and the water line, differentiated only in December, when mudflats were further = exposed; LT=low tide level near the water line, samples partly taken up to 30 cm water depth. = Sampling sites 1-7: Murray Mouth, 20-26: North Lagoon, 19-13: South Lagoon, 8-12: Lake = Alexandrina. =

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D) Biomass **These Excel tables are available upon request**

Table A3Da. Macrofaunal biomass (ash-free dry weight, in mg afdw 84 cm^{-2}) of higher taxonomic = levels and total macrobenthos, for each replicate at each site, for the Murray Mouth (sites 1-7), = Northern Lagoon (sites 20-26), Southern Lagoon (sites 13-19) and Lower Lakes (sites 8-12), recorded = in June 2004 (see Appendix A3Ca fordetails). Annelida are comprised of Polychaeta and Oligochaeta. = Samples were collected using a corer of surface area 84 cm^2 surface area. H = high tide station, L = = low tide station; a, b, c = replicate numbers. =

Table A3Db: Macrofaunal biomass (ash-free dry weight) in mg per corer. Surface areas of corers = were 83.32 cm^2 at sites 1-3, 8-19, 24-26; and 19.63 cm^2 at sites 4-7 and 20-23 (see Appendix Table = A3Cb for further detail). Biomass is given for higher taxonomic levels and total macrobenthos, for each = replicate at each site, for the Murray Mouth (sites 1-7), Northern Lagoon (sites 20-26), Southern = Lagoon (sites 13-19) and Lower Lakes (sites 8-12), recorded in December 2004. Annelida are = comprised of Polychaeta and Oligochaeta. H=high tide station, M=mid tide station, L=low tide station; = a - f = replicate numbers. =

Table A3Dc. Biomass of macrofauna (mg afdw m^{-2}) for June 2004, given as mean and standard = deviations (SD) for 3 respectively 6 replicates per site (see Table A3Ca for further details). Biomass = was determined for higher taxonomic levels. Annelida includes polychaetes and oligochaetes. = Sampling sites in the study area are in the Murray Mouth (sites 1-7), Northern Lagoon (sites 20-26), = Southern Lagoon (sites 13-19) and Lower Lakes (sites 8-12). =

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Table A3Dd. Biomass of macrofauna (mg afdw m^{-2}) for December 2004, given as mean and standard = deviations (SD) per site. The number of replicates differed between sites to accommodate for = variations in abundance, see Table A3Cb for details. Biomass was determined for higher taxonomic = levels. Annelida includes polychaetes and oligochaetes. Sampling sites in the study area are in the = Murray Mouth (sites 1-7), Northern Lagoon (sites 20-26), Southern Lagoon (sites 13-19) and Lower = Lakes (sites 8-12). =

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APPENDIX 4: Literature review of selected species

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APPENDIX 1: Site characteristics of survey stations

Table A1a: Geographic coordinates of the mudflat sampling sites during the surveys in June and December 2004.

		June		December	
	Site #	Easting	Northing	Easting	Northing
Murray Mouth	1	303120	6066509	303150	6066520
	2	305494	6065430	305498	6065443
	3	308435	6063708	308441	6063716
	4	309754	6065310	309749	6065312
	5	313958	6063542	313959	6063546
	6	314973	6062980	314928	6063011
	7	318007	6061089	317930	6061094
Lower Lakes	8	312160	6070081	312162	6070083
	9	331315	6084156	331323	6084162
	10	335433	6090909	335417	6090894
	11	347255	6086488	347315	6086530
	12	343355	6071625	343299	6071579
Southern Coorong Lagoon	13	387821	5978942	387822	5978937
	14	378737	5996705	378651	5996560
	15	377534	6000516	377533	600507
	16	371168	6011641	371158	6011653
	17	367781	6015271	367727	6015151
	18	362459	6023436	362363	6023454
	19	360577	6024954	360572	6024791
Northern Coorong Lagoon	20	320676	6059359	320739	6059238
	21	326188	6055342	326191	6055339
	22	331780	6051162	331730	6051193
	23	333877	6048422	333967	6048453
	24	355577	6026464	355345	6027334
	25	354875	6029562	354713	6029489
	26	342965	6041532	342768	6041498

Table A1b: Details of sampling dates and survey times during the macrobenthic mudflat surveys in June and December 2004.

		June		December	
	Site #	Date	Time	Date	Time
Murray Mouth	1	7/6/2004	11:45	13/12/2004	12:20
	2	7/6/2004	12:30	13/12/2004	13:50
	3	7/6/2004	13:30	13/12/2004	15:00
	4	7/6/2004	15:00	15/12/2004	13:45
	5	7/6/2004	16:00	15/12/2004	13:15
	6	7/6/2004	16:30	15/12/2004	12:15
	7	8/6/2004	9:30	15/12/2004	11:15
Lower Lakes	8	8/6/2004	10:45	14/12/2004	18:30
	9	8/6/2004	12:30	14/12/2004	17:30
	10	8/6/2004	14:30	14/12/2004	16:50
	11	8/6/2004	15:00	14/12/2004	15:50
	12	8/6/2004	16:25	14/12/2004	14:20
Southern Coorong Lagoon	13	9/6/2004	7:25	17/12/2004	12:30
	14	9/6/2004	9:00	17/12/2004	12:00
	15	9/6/2004	10:00	17/12/2004	10:45
	16	9/6/2004	10:30	17/12/2004	9:00
	17	9/6/2004	11:00	17/12/2004	8:30
	18	9/6/2004	12:00	16/12/2004	17:00
	19	9/6/2004	12:30	16/12/2004	15:50
Northern Coorong Lagoon	20	9/6/2004	14:45	15/12/2004	10:00
	21	9/6/2004	15:45	14/12/2004	12:15
	22	9/6/2004	16:30	14/12/2004	11:00
	23	9/6/2004	17:00	14/12/2004	10:30
	24	10/6/2004	7:45	16/12/2004	13:30
	25	10/6/2004	8:30	16/12/2004	13:00
	26	10/6/2004	9:30	16/12/2004	12:00

APPENDIX 2: Environmental parameter

Table A2a: Characteristics of the water body at the sampling sites for the benthic survey in the Murray Mouth (sites 1 – 7), Northern Coorong Lagoon (sites = 20-26), Southern Coorong Lagoon (sites 13-19) and Lower Lakes (sites 8-12) in June and December 2004. Measurements were taken in about 30 cm water = depths at near the low tide sampling sites, using a YSI 85 multiprobe. Salinity values and oxygen concentrations exceeded the detection limit of the electrode = at several sites and no readings were taken at site 13 in December, which was a saltpan without any water. Calculated salinities are based on conductivity = with temperature correction. =

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Site =		Water Temperature = [°C] =		Salinity = [ppt] =		Calculated salinity = [ppt] =		Conductivity [mS/cm] =		% O_2 =		O_2 [mg/l] =	
		June	**December**	**June**	**December**	**June**	**December**	**June**	**December**	**June**	**December**	**June**	**December**
Murray Mouth	**1**	14.90 =	22.80 =	30.20 =	25.30 =	30.24 =	25.75 =	37.57 =	33.63 =	112.30 =	44.00 =	10.64 =	33.00 =
	2	14.50 =	24.20 =	29.90 =	21.10 =	29.79 =	21.52 =	36.78 =	49.60 =	101.20 =	53.80 =	8.60 =	3.11 =
	3	14.80 =	23.60 =	29.50 =	33.50 =	32.23 =	33.67 =	39.70 =	44.80 =	88.00 =	36.90 =	7.27 =	2.52 =
	4	17.10 =	27.20 =	29.70 =	27.70 =	29.93 =	27.29 =	38.86 =	50.40 =	118.50 =	81.00 =	10.08 =	5.48 =
	5	15.30 =	24.60 =	32.50 =	33.10 =	32.61 =	33.40 =	40.51 =	45.01 =	96.10 =	82.50 =	7.84 =	6.02 =
	6	17.20 =	25.30 =	31.90 =	28.80 =	32.12 =	28.89 =	41.48 =	45.01 =	79.90 =	105.40 =	6.72 =	7.35 =
	7	13.30 =	22.20 =	26.50 =	34.50 =	34.47 =	34.88 =	41.00 =	49.60 =	71.70 =	70.60 =	6.11 =	4.72 =
North Coorong Lagoon	**20**	15.30 =	20.60 =	28.40 =	26.50 =	28.40 =	26.85 =	35.78 =	37.89 =	92.00 =	58.90 =	7.60 =	4.38 =
	21	14.80 =	21.00 =	32.30 =	36.70 =	32.23 =	40.61 =	39.70 =	55.30 =	88.60 =	35.60 =	7.39 =	2.66 =
	22	15.70 =	19.60 =	26.70 =	44.20 =	24.48 =	44.94 =	31.53 =	58.70 =	73.00 =	41.70 =	6.00 =	2.92 =
	23	14.60 =	20.20 =	33.80 =	48.70 =	33.75 =	49.16 =	41.22 =	64.30 =	74.10 =	39.80 =	5.85 =	2.68 =
	24	11.30 =	33.00 =	54.10 =	=	75.32 =	96.77 =	78.30 =	155.60 =	70.00 =	73.00 =	5.30 =	=
	25	11.20 =	30.10 =	46.00 =	=	44.96 =	98.83 =	50.00 =	146.10 =	41.80 =	70.00 =	3.64 =	=
	26	12.40 =	28.60 =	39.80 =	75.20 =	39.36 =	73.69 =	45.40 =	110.40 =	63.50 =	91.00 =	5.32 =	4.66 =
South Coorong Lagoon	**13**	12.40 =	=	27.30 =	=	27.43 =	=	32.83 =	=	60.30 =	=	5.30 =	=
	14	14.10 =	31.20 =	=	=	106.18 =	97.38 =	109.20 =	148.70 =	71.00 =	66.00 =	=	=
	15	15.80 =	25.60 =	=	28.50 =	104.23 =	28.65 =	111.00 =	45.00 =	101.00 =	73.00 =	=	4.85 =
	16	16.00 =	20.40 =	=	=	94.60 =	101.84 =	103.00 =	119.30 =	82.00 =	75.00 =	=	=
	17	15.60 =	20.50 =	=	=	124.86 =	104.66 =	127.60 =	122.20 =	80.50 =	43.30 =	=	=
	18	15.40 =	31.00 =	=	=	124.44 =	93.41 =	126.80 =	143.00 =	84.60 =	85.40 =	=	=
	19	16.60 =	34.00 =	=	=	92.18 =	93.12 =	102.00 =	155.30 =	80.00 =	157.00 =	=	=
Lower Lakes	**8**	14.50 =	21.70 =	0.80 =	0.70 =	0.81 =	0.74 =	1.285 =	1.374 =	86.00 =	40.00 =	7.23 =	3.48 =
	9	22.00 =	24.40 =	7.90 =	3.50 =	7.92 =	5.80 =	12.8 =	10.14 =	150.00 =	44.60 =	12.00 =	3.58 =
	10	13.60 =	22.40 =	0.70 =	1.00 =	0.70 =	0.99 =	1.085 =	1.826 =	87.70 =	38.00 =	8.97 =	3.21 =
	11	19.30 =	21.90 =	2.30 =	1.20 =	2.61 =	1.55 =	4.277 =	2.77 =	79.40 =	44.20 =	7.14 =	3.61 =
	12	18.00 =	27.00 =	6.70 =	4.50 =	7.89 =	4.27 =	11.69 =	8.12 =	111.80 =	37.50 =	10.14 =	2.89 =

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Table A2b. Sediment characteristics of the sampling sites in the Murray Mouth (sites 1-7), Northern Coorong Lagoon (sites 20-26), Southern Coorong Lagoon = (sites 13-19) and Lower Lakes (sites 8-12) in June 2004. HT=High tide location, MT=Mid tide location, LT=Low tide location (MT and LT not sampled at every = site). Grain size distributions are given as the percentages of the single fractions (as particle diameter in µm or according to the Wentworth scale (phi) with = sorting coefficients. Dominant grain size fractions are highlighted in bold. =

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site	µm phi	<63 >4	63 4	125 3	250 2	500 1	710 0.5	1000 0	2000 -1	median	sorting	Verbal Description
1 =	HT =	0.56 =	1.95 =	**75.29**	20.53 =	0.97 =	0.31 =	0.23 =	0.16 =	2.35 =	0.33 =	Fine sand, very well sorted =
=	LT =	3.14 =	1.49 =	**88.33**	6.59 =	0.24 =	0.20 =	=	=	2.47 =	0.28 =	Fine sand, very well sorted =
=	mean =	1.85 =	1.72 =	**81.81**	13.56 =	0.60 =	0.26 =	0.12 =	0.08 =	2.42 =	0.3 =	Fine sand, very well sorted =
2 =	HT =	0.46 =	0.74 =	31.27 =	**64.28**	3.07 =	0.10 =	0.07 =	0.01 =	1.72 =	0.44 =	Medium sand, well sorted =
=	LT =	1.39 =	0.79 =	25.32 =	**71.89**	0.40 =	=	0.21 =	=	1.66 =	0.38 =	Medium sand, well sorted =
=	mean =	0.93 =	0.77 =	28.29 =	**68.09**	1.73 =	0.05 =	0.14 =	=	1.69 =	0.42 =	medium sand, well sorted =
3 =	HT =	3.25 =	1.01 =	**45.20**	**48.22**	1.60 =	0.46 =	0.25 =	=	2 =	0.54 =	Fine -medium sand, moderately well sorted =
=	LT =	0.29 =	0.52 =	11.22 =	**87.16**	0.63 =	0.09 =	0.06 =	0.04 =	1.54 =	0.28 =	Medium sand, very well sorted =
=	mean =	1.77 =	0.77 =	28.21 =	**67.69**	1.11 =	0.28 =	0.16 =	0.02 =	1.69 =	0.42 =	Medium sand, well sorted =
4 =	HT =	2.02 =	2.55 =	**45.81**	**42.53**	2.28 =	0.63 =	1.39 =	2.79 =	2 =	0.56 =	Fine - medium sand, moderately well sorted =
=	LT =	2.17 =	1.85 =	32.67 =	**60.10**	1.42 =	0.41 =	0.61 =	0.76 =	1.75 =	0.49 =	Medium sand, well sorted =
=	mean =	2.10 =	2.20 =	39.24 =	**51.31**	1.85 =	0.52 =	1.00 =	1.78 =	1.86 =	0.53 =	Medium sand, moderately well sorted =
5 =	LT =	3.38 =	0.88 =	37.98 =	**56.58**	0.60 =	0.24 =	0.34 =	=	1.84 =	0.52 =	Medium sand, moderately well sorted =
6 =	HT =	1.53 =	1.46 =	**46.26**	**40.70**	5.47 =	=	4.59 =	=	2 =	0.58 =	Fine - medium sand, moderately well sorted =
7 =	HT =	6.67 =	3.31 =	25.80 =	**63.34**	0.59 =	0.14 =	0.07 =	0.07 =	1.75 =	0.51 =	Medium sand, moderately well sorted =
=	LT =	5.68 =	2.46 =	**50.10**	39.35 =	1.91 =	0.35 =	0.10 =	0.05 =	2.15 =	0.55 =	Fine sand, moderately well sorted =
=	mean =	6.18 =	2.89 =	37.95 =	**51.35**	1.25 =	0.24 =	0.09 =	0.06 =	1.92 =	0.56 =	Medium sand, moderately well sorted =
20 =	HT =	1.42 =	2.08 =	36.03 =	**37.99**	20.57 =	=	1.91 =	=	1.71 =	0.66 =	Medium sand, moderately well sorted =
21 =	HT =	19.01 =	3.49 =	**21.47**	15.63 =	**25.52**	=	14.89 =	=	1.6 =	1.25 =	Medium sand (fine - coarse), poorly sorted =
=	LT =	5.06 =	1.63 =	**39.14**	**42.97**	6.26 =	=	4.95 =	=	1.87 =	0.62 =	Medium sand, moderately well sorted =
=	mean =	12.03 =	2.56 =	**30.30**	**29.30**	15.89 =	=	9.92 =	=	1.77 =	0.85 =	(Fine-) Medium sand, moderately sorted =
22 =	HT =	9.16 =	1.05 =	3.46 =	5.09 =	**75.09**	=	6.14 =	=	0.57 =	0.33 =	Coarse sand, very well sorted =
=	LT =	0.24 =	1.98 =	**66.75**	23.65 =	4.07 =	=	3.30 =	=	2.27 =	0.45 =	Fine sand, well sorted =
=	mean =	4.70 =	1.51 =	**35.11**	14.37 =	**39.58**	=	4.72 =	=	1.4 =	0.98 =	Medium sand (fine - coarse), moderately sorted =
23 =	HT =	9.38 =	2.23 =	**47.15**	**29.86**	3.29 =	=	8.10 =	=	2.17 =	0.63 =	Fine sand, moderately well sorted =
=	LT =	0.54 =	1.83 =	**31.05**	**30.69**	22.56 =	=	13.32 =	=	1.47 =	0.86 =	Medium sand, moderately sorted =
=	mean =	4.96 =	2.03 =	**39.10**	**30.28**	12.92 =	=	10.71 =	=	1.85 =	0.77 =	(Fine-) Medium sand, moderately sorted =
24 =	HT =	1.01 =	1.06 =	10.35 =	**77.11**	2.92 =	=	7.55 =	=	1.51 =	0.33 =	Medium sand, very well sorted =

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=	LT =	0.05 =	0.12 =	12.06 =	**81.53**	1.62 =	=	4.62 =	=	1.51 =	0.3 =	Medium sand, very well sorted =
=	mean =	0.53 =	0.59 =	11.20 =	**79.32**	2.27 =	=	6.08 =	=	1.51 =	0.32 =	Medium sand, very well sorted =
25 =	HT =	0.12 =	1.12 =	16.77 =	**79.73**	1.36 =	=	0.90 =	=	1.59 =	0.3 =	Medium sand, very well sorted =
=	LT =	0.56 =	1.16 =	18.17 =	**76.78**	1.96 =	=	1.37 =	=	1.59 =	0.32 =	Medium sand, very well sorted =
=	mean =	0.34 =	1.14 =	17.47 =	**78.25**	1.66 =	=	1.14 =	=	1.59 =	0.31 =	Medium sand, very well sorted =
26 =	HT =	1.03 =	1.51 =	30.71 =	**52.24**	3.74 =	=	10.76 =	=	1.66 =	0.53 =	Medium sand, moderately well sorted =
=	LT =	0.97 =	1.87 =	**68.30**	17.06 =	2.16 =	1.06 =	8.59 =	=	2.3 =	0.45 =	Fine sand, well sorted =
=	mean =	1.00 =	1.69 =	**49.50**	**34.65**	2.95 =	0.53 =	9.68 =	=	2.05 =	0.61 =	Fine sand, moderately well sorted =
13 =	HT =	2.70 =	3.86 =	**93.44**	=	=	=	=	=	2.51 =	0.26 =	Fine sand, very well sorted =
14 =	HT =	0.62 =	1.50 =	24.14 =	**56.74**	3.83 =	=	13.18 =	=	1.57 =	0.89 =	Medium sand, moderately sorted =
=	LT =	1.10 =	6.46 =	**48.54**	**36.78**	2.47 =	0.57 =	1.79 =	2.31 =	2.12 =	0.57 =	Fine sand, moderately well sorted =
=	mean =	0.86 =	3.98 =	**36.34**	**46.76**	3.15 =	0.28 =	7.48 =	1.15 =	1.65 =	0.58 =	Medium sand, moderately well sorted =
15 =	HT =	6.16 =	3.97 =	**60.18**	14.80 =	1.64 =	0.74 =	3.55 =	8.98 =	2.32 =	0.54 =	Fine sand, moderately well sorted =
=	LT =	1.02 =	4.34 =	**66.90**	17.57 =	2.84 =	=	7.34 =	=	2.32 =	0.42 =	Fine sand, well sorted =
=	mean =	3.59 =	4.15 =	**63.54**	16.18 =	2.24 =	0.37 =	5.44 =	4.49 =	2.32 =	0.48 =	Fine sand, well sorted =
16 =	HT =	0.02 =	0.03 =	0.88 =	18.32 =	**78.89**	=	1.86 =	=	0.6 =	0.3 =	Coarse sand, very well sorted =
=	LT =	0.44 =	1.34 =	10.66 =	**29.16**	**43.39**	=	15.01 =	=	0.8 =	0.67 =	Coarse sand, moderately well sorted =
=	mean =	0.23 =	0.69 =	5.77 =	23.74 =	**61.14**	=	8.43 =	=	0.67 =	0.49 =	Coarse sand, well sorted =
17 =	HT =	0.46 =	1.34 =	31.10 =	**53.38**	6.95 =	=	6.76 =	=	1.66 =	0.51 =	Medium sand, moderately well sorted =
=	LT =	1.83 =	1.35 =	21.13 =	**56.79**	8.83 =	2.51 =	3.26 =	4.29 =	1.52 =	0.43 =	Medium sand, well sorted =
=	mean =	1.15 =	1.34 =	26.11 =	**55.09**	7.89 =	1.26 =	5.01 =	2.15 =	1.6 =	0.49 =	Medium sand, well sorted =
18 =	HT =	0.11 =	0.05 =	0.90 =	9.86 =	28.52 =	=	**60.56**	=	-0.2 =	0.55 =	Very coarse, moderately well sorted =
=	LT =	0.29 =	2.16 =	**31.24**	14.26 =	4.74 =	3.89 =	5.03 =	**38.38**	0.75 =	=	Coarse sand =
=	mean =	0.20 =	1.11 =	16.07 =	12.06 =	16.63 =	1.94 =	**32.80**	**19.19**	-0.05 =	=	Very coarse =
19 =	HT =	3.47 =	5.92 =	**57.35**	15.43 =	8.20 =	=	9.62 =	=	2.29 =	0.63 =	Fine sand, moderately well sorted =
=	LT =	2.35 =	0.40 =	**75.86**	14.36 =	3.18 =	=	3.85 =	=	2.36 =	0.32 =	Fine sand, very well sorted =
=	mean =	2.91 =	3.16 =	**66.61**	14.89 =	5.69 =	=	6.74 =	=	2.33 =	0.52 =	Fine sand, moderately well sorted =
8 =	HT =	20.17 =	7.48 =	**40.65**	**25.31**	3.14 =	=	3.25 =	=	2.42 =	0.80 =	Fine sand, moderately sorted =
9 =	HT =	4.23 =	16.79 =	**58.55**	20.44 =	=	=	=	=	2.4 =	0.42 =	Fine sand, well sorted =
10 =	HT =	8.51 =	**19.98**	**23.26**	13.25 =	15.95 =	=	19.05 =	=	2.07 =	1.4 =	Fine sand, poorly sorted =
11 =	HT =	20.35 =	16.99 =	**35.24**	19.63 =	5.60 =	=	2.19 =	=	2.63 =	0.93 =	Fine sand, moderately sorted =
12 =	HT =	**32.77**	11.28 =	**37.80**	15.92 =	2.24 =	=	=	=	2.81 =	1.03 =	Fine sand, poorly sorted =

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Table A2c. Sediment characteristics of the sampling sites in the Murray Mouth (sites 1-7), Northern Coorong Lagoon (sites 20-26), Southern Coorong Lagoon = (sites 13-19) and Lower Lakes (sites 8-12) in December 2004. HT=High tide location, MT=Mid tide location, LT=Low tide location (MT and LT not sampled at = every site). Grain size distributions are given as the percentages of the single fractions (as particle diameter in µm or according to the Wentworth scale (phi) = with sorting coefficients. Dominant grain size fractions are highlighted in bold. =

=

site	**µm**	**<63**	**63**	**125**	**250**	**500**	**710**	**1000**	**2000**	**median**	**sorting**	**Verbal description**
	phi	**>4**	**4**	**3**	**2**	**1**	**0.5**	**0**	**-1**			
1 =	HT =	0.89 =	6.98 =	**82.54**	8.37 =	0.78 =	0.19 =	0.24 =	0.00 =	2.68 =	0.42 =	Fine sand, well sorted =
=	MT =	1.31 =	2.82 =	**90.24**	5.32 =	0.23 =	0.08 =	0.00 =	0.00 =	2.68 =	0.38 =	Fine sand, well sorted =
=	LT =	1.39 =	0.00 =	**96.11**	1.91 =	0.14 =	0.14 =	0 =	0 =	2.68 =	0.33 =	Fine sand, very well sorted =
=	mean =	1.20 =	3.27 =	**89.63**	5.20 =	0.38 =	0.13 =	0.12 =	0.06 =	2.68 =	0.38 =	Fine sand, well sorted =
2 =	HT =	0.85 =	4.52 =	**82.50**	11.54 =	0.31 =	0.05 =	0.12 =	0.10 =	2.63 =	0.41 =	Fine sand, well sorted =
=	MT =	1.00 =	0.00 =	**83.09**	15.48 =	0.23 =	0.09 =	0.09 =	0.03 =	2.56 =	0.39 =	Fine sand, well sorted =
=	LT =	1.40 =	4.91 =	**81.63**	11.67 =	0.23 =	0.10 =	0.06 =	0 =	2.63 =	0.41 =	Fine sand, well sorted =
=	mean =	1.08 =	3.15 =	**82.41**	12.90 =	0.25 =	0.08 =	0.09 =	0 =	2.59 =	0.40 =	Fine sand, well sorted =
3 =	HT =	1.22 =	0.01 =	**53.51**	44.87 =	0.24 =	0.06 =	0.03 =	0 =	2.11 =	0.50 =	Fine sand, well sorted =
=	MT =	0.22 =	1.51 =	**87.39**	10.57 =	0.23 =	0.04 =	0.04 =	0 =	2.59 =	0.39 =	Fine sand, well sorted =
=	LT =	0.50 =	2.27 =	**64.15**	32.82 =	0.19 =	0.04 =	0.03 =	0.01 =	2.35 =	0.42 =	Fine sand, well sorted =
=	mean =	0.65 =	1.26 =	**68.35**	29.42 =	0.22 =	0.05 =	0.03 =	0.03 =	2.41 =	0.37 =	Fine sand, well sorted =
4 =	HT =	1.77 =	4.99 =	**59.37**	31.76 =	1.36 =	0.27 =	0.22 =	0.26 =	2.35 =	0.47 =	Fine sand, well sorted =
=	MT =	1.09 =	5.34 =	**66.25**	25.85 =	1.19 =	0.22 =	0.07 =	0.00 =	2.46 =	0.36 =	Fine sand, well sorted =
=	LT =	3.01 =	10.22 =	**57.13**	25.58 =	3.15 =	0.62 =	0.28 =	0.00 =	2.50 =	0.49 =	Fine sand, well sorted =
=	mean =	1.96 =	6.85 =	**60.92**	27.73 =	1.90 =	0.37 =	0.19 =	0.09 =	2.43 =	0.46 =	Fine sand, well sorted =
5 =	LT =	3.25 =	4.61 =	**77.04**	13.90 =	0.95 =	0.18 =	0.06 =	0.02 =	2.56 =	0.44 =	Fine sand, well sorted =
6 =	HT =	1.55 =	3.20 =	**84.16**	10.71 =	0.30 =	0.08 =	0.00 =	0.00 =	2.43 =	0.40 =	Fine sand, well sorted =
=	LT =	4.82 =	2.89 =	**84.12**	7.40 =	0.53 =	0.12 =	0.09 =	0.03 =	2.68 =	0.42 =	Fine sand, well sorted =
=	mean =	3.18 =	3.05 =	**84.14**	9.05 =	0.41 =	0.10 =	0.05 =	0.01 =	2.67 =	0.39 =	Fine sand, well sorted =
7 =	HT =	8.91 =	5.97 =	**78.53**	5.38 =	0.69 =	0.26 =	0.17 =	0.09 =	2.37 =	0.47 =	Fine sand, well sorted =
=	LT =	4.25 =	2.30 =	**82.48**	9.91 =	0.62 =	0.25 =	0.19 =	0.00 =	2.48 =	0.48 =	Fine sand, well sorted =
=	mean =	6.58 =	4.14 =	**80.50**	7.64 =	0.65 =	0.26 =	0.18 =	0.04 =	2.43 =	0.44 =	Fine sand, well sorted =
20 =	HT =	5.21 =	0.01 =	35.53 =	**46.55**	7.87 =	2.86 =	0.70 =	1.28 =	2.11 =	0.61 =	Fine sand, moderately well sorted =
=	MT =	3.12 =	0.65 =	13.79 =	**64.73**	12.67 =	3.95 =	1.08 =	0.00 =	1.70 =	0.39 =	Medium sand, well sorted =
=	LT =	1.47 =	0.80 =	15.73 =	**62.56**	14.61 =	3.95 =	0.81 =	0.08 =	1.70 =	0.56 =	Medium sand, moderately well sorted =
=	Mean =	3.27 =	0.48 =	21.68 =	**57.95**	11.72 =	3.59 =	0.86 =	0.45 =	1.80 =	0.41 =	Medium sand, well sorted =

=

21 =	HT =	8.91 =	6.05 =	**53.62**	12.54 =	10.23 =	3.55 =	2.46 =	2.65 =	2.48 =	0.71 =	Fine sand, moderately well sorted =
=	MT =	5.17 =	3.68 =	**63.27**	13.70 =	9.10 =	3.41 =	1.52 =	0.15 =	2.48 =	0.46 =	Fine sand, well sorted =
=	LT =	2.72 =	3.37 =	**83.40**	8.16 =	1.34 =	0.55 =	0.22 =	0.23 =	2.63 =	0.43 =	Fine sand, well sorted =
=	mean =	5.60 =	4.37 =	**66.76**	11.47 =	6.89 =	2.50 =	1.40 =	1.01 =	2.56 =	0.51 =	Fine sand, moderately well sorted =
22 =	HT =	0.77 =	1.89 =	**41.33**	10.92 =	10.08 =	16.83 =	11.66 =	6.51 =	1.65 =	1.16 =	Medium sand, poorly sorted =
=	LT =	2.58 =	0.00 =	**38.01**	23.48 =	16.47 =	9.73 =	7.22 =	2.50 =	1.81 =	0.89 =	Medium sand, moderately well sorted =
=	mean =	1.67 =	0.95 =	**39.67**	17.20 =	13.28 =	13.28 =	9.44 =	4.51 =	1.74 =	1.02 =	Medium sand, poorly sorted =
23 =	HT =	1.91 =	0.00 =	**82.60**	8.93 =	3.56 =	1.98 =	0.81 =	0.20 =	2.56 =	0.40 =	Fine sand, well sorted =
=	MT =	1.56 =	0.00 =	**82.68**	8.25 =	3.62 =	2.24 =	1.04 =	0.61 =	2.56 =	0.40 =	Fine sand, well sorted =
=	LT =	0.98 =	6.37 =	**76.91**	8.47 =	3.95 =	2.12 =	0.78 =	0.42 =	2.59 =	0.46 =	Fine sand, well sorted =
=	mean =	1.48 =	2.13 =	**80.73**	8.55 =	3.71 =	2.11 =	0.88 =	0.41 =	2.56 =	0.42 =	Fine sand, well sorted =
24 =	HT =	1.03 =	4.93 =	**77.76**	13.66 =	1.37 =	0.42 =	0.54 =	0.30 =	2.59 =	0.44 =	Fine sand, well sorted =
=	LT =	1.06 =	5.75 =	**77.88**	12.64 =	1.46 =	0.50 =	0.48 =	0.22 =	2.59 =	0.44 =	Fine sand, well sorted =
=	mean =	1.05 =	5.34 =	**77.82**	13.15 =	1.41 =	0.46 =	0.51 =	0.26 =	2.59 =	0.44 =	Fine sand, well sorted =
25 =	HT =	0.78 =	2.52 =	**71.28**	21.66 =	2.60 =	0.78 =	0.32 =	0.07 =	2.46 =	0.47 =	Fine sand, well sorted =
=	LT =	2.04 =	1.31 =	**48.03**	45.71 =	2.13 =	0.46 =	0.31 =	0.00 =	2.56 =	0.54 =	Fine sand, moderately well sorted =
=	mean =	1.41 =	1.91 =	**59.66**	33.68 =	2.36 =	0.62 =	0.31 =	0.03 =	2.28 =	0.49 =	Fine sand, well sorted =
26 =	HT =	0.34 =	0.79 =	**59.95**	37.17 =	0.97 =	0.40 =	0.21 =	0.16 =	2.24 =	0.49 =	Fine sand, well sorted =
=	LT =	0.21 =	1.88 =	**52.43**	40.35 =	3.43 =	1.21 =	0.42 =	0.07 =	2.11 =	0.53 =	Fine sand, moderately well sorted =
=	mean =	0.28 =	1.33 =	**56.19**	38.76 =	2.20 =	0.81 =	0.31 =	0.11 =	2.19 =	0.52 =	Fine sand, moderately well sorted =
13 =	HT =	**50.08**	20.39 =	19.22 =	6.54 =	1.39 =	1.04 =	1.33 =	0.00 =	4.00 =	0.82 =	Very fine sand, moderately sorted =
14 =	HT =	1.04 =	2.86 =	**56.58**	34.63 =	2.59 =	1.06 =	1.06 =	0.19 =	2.24 =	0.19 =	Fine sand, very well sorted =
=	LT =	0.48 =	4.57 =	**59.74**	30.11 =	2.07 =	0.81 =	1.88 =	0.35 =	2.35 =	0.50 =	Fine sand, well sorted =
=	mean =	0.76 =	3.71 =	**58.16**	32.37 =	2.33 =	0.94 =	1.47 =	0.27 =	2.30 =	0.52 =	Fine sand, moderately well sorted =
15 =	HT =	0.43 =	6.24 =	**67.12**	18.69 =	2.94 =	1.16 =	1.96 =	1.47 =	2.48 =	0.35 =	Fine sand, very well sorted =
=	LT =	0.20 =	0.91 =	2.75 =	5.49 =	11.94 =	9.25 =	24.59 =	**44.87**	-0.26 =	0.39 =	Very coarse sand, well sorted =
=	mean =	0.32 =	3.57 =	**34.93**	12.09 =	7.44 =	5.21 =	13.27 =	23.17 =	1.09 =	1.36 =	Medium sand, poorly sorted =
16 =	HT =	0.27 =	0.83 =	9.36 =	**61.19**	17.05 =	4.69 =	2.33 =	4.27 =	1.48 =	0.30 =	Medium sand, very well sorted =
=	LT =	0.26 =	7.99 =	**62.95**	21.27 =	4.84 =	1.11 =	0.45 =	1.12 =	2.46 =	0.44 =	Fine sand, well sorted =
=	mean =	0.27 =	4.41 =	36.16 =	**41.23**	10.95 =	2.90 =	1.39 =	2.69 =	2.05 =	0.69 =	Fine sand, moderately well sorted =
17 =	HT =	2.55 =	2.44 =	**53.00**	28.33 =	5.27 =	2.44 =	5.40 =	0.56 =	2.19 =	0.65 =	Fine sand, moderately well sorted =
=	LT =	3.22 =	0.00 =	**39.08**	37.93 =	5.51 =	2.36 =	5.69 =	6.21 =	2.07 =	0.71 =	Fine sand, moderately well sorted =
=	mean =	2.89 =	1.22 =	**46.04**	33.13 =	5.39 =	2.40 =	5.54 =	3.38 =	2.00 =	0.71 =	Fine sand, moderately well sorted =

=

18 =	HT =	9.56 =	15.52 =	**40.86**	15.95 =	6.44 =	6.30 =	5.01 =	0.34 =	2.52 =	0.70 =	Fine sand, moderately well sorted =
=	LT =	1.93 =	3.95 =	**67.36**	20.67 =	3.72 =	2.38 =	0.00 =	0.00 =	2.44 =	0.35 =	Fine sand, very well sorted =
=	mean =	5.75 =	9.73 =	**54.11**	18.31 =	5.08 =	4.34 =	2.51 =	0.17 =	2.48 =	0.57 =	Fine sand, moderately well sorted =
19 =	HT =	3.55 =	1.90 =	**65.77**	18.21 =	3.35 =	1.88 =	5.34 =	0.00 =	2.44 =	0.44 =	Fine sand, well sorted =
=	LT =	3.48 =	1.89 =	**68.18**	21.26 =	3.42 =	1.78 =	0.00 =	0.00 =	2.46 =	0.33 =	Fine sand, very well sorted =
=	mean =	3.52 =	1.89 =	**66.97**	19.74 =	3.38 =	1.83 =	2.67 =	0.00 =	2.44 =	0.38 =	Fine sand, well sorted =
8 =	HT =	17.63 =	20.11 =	**49.34**	12.11 =	0.81 =	0.00 =	0.00 =	0.00 =	3.04 =	0.78 =	Very fine sand, moderately sorted =
9 =	HT =	22.72 =	14.61 =	**40.18**	16.22 =	2.45 =	1.00 =	2.83 =	0.00 =	2.93 =	1.02 =	Fine sand, poorly sorted =
10 =	HT =	2.35 =	0.00 =	13.29 =	34.58 =	**47.97**	1.45 =	0.06 =	0.29 =	1.00 =	1.09 =	Medium sand, poorly sorted =
11 =	HT =	34.19 =	0.01 =	**39.10**	6.82 =	2.72 =	2.79 =	4.88 =	9.50 =	2.80 =	1.17 =	Fine sand, poorly sorted =
12 =	HT =	**64.08**	5.31 =	20.74 =	7.38 =	1.37 =	0.94 =	0.11 =	0.07 =	4.30 =	0.92 =	Silt, moderately sorted =

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Table A2d. Sediment organic matter (% AFDW) of the sampling sites in the Murray Mouth (sites 1-7), = Northern Coorong Lagoon (sites 20-26), Southern Coorong Lagoons (sites 13-19) and Lower Lakes = (sites 8-12) in June and December 2004. HT=High tide location, MT=Mid tide location and LT=Low = tide location (MT and LT not sampled at every site). SE (in brackets) was only calculated for = December, when three replicate samples were taken for each tidal level. =

Site =	=	June =	December =	
1 =	HT =	4.44 =	2.44 =	(0.23) =
=	LT =	3.84 =	2.49 =	(0.45) =
=	LT b =	=	1.67 =	(0.08) =
=	mean=	4.14 =	2.20 =	(0.20) =
2 =	HT =	3.95 =	1.63 =	(0.52) =
=	MT =	=	1.51 =	(0.26) =
=	LT =	2.68 =	2.06 =	(0.23) =
=	mean=	3.32 =	1.73 =	(0.20) =
3 =	HT =	1.55 =	0.76 =	(0.06) =
=	MT =	=	1.64 =	(0.03) =
=	LT =	0.41 =	1.89 =	(0.73) =
=	mean=	0.98 =	1.43 =	(0.27) =
4 =	HT =	1.26 =	0.9 =	(0.04) =
=	MT =	=	0.71 =	(0.05) =
=	LT =	2.37 =	23.04* =	(21.80) =
=	mean=	1.82 =	8.22 =	(7.30) =
5 =	LT =	1.30 =	1.63 =	(0.20) =
6 =	HT =	1.21 =	1.24 =	(0.10) =
=	LT =	2.48 =	2.53 =	(0.37) =
=	mean=	1.85 =	1.88 =	(0.34) =
7 =	HT =	1.48 =	0.65 =	(0.29) =
=	LT =	2.68 =	1.30 =	(0.29) =
=	mean=	2.08 =	0.97 =	(0.23) =
20 =	HT =	1.26 =	4.06 =	(1.54) =
=	MT =	=	1.59 =	(0.44) =
=	LT =	=	0.86 =	(0.10) =
=	mean=	=	2.17 =	(0.67) =
21 =	HT =	=	1 =	(0.01) =
=	MT =	=	1.87 =	(0.19) =
=	LT =	2.65 =	1.35 =	(0.15) =
=	mean=	=	1.41 =	(0.14) =
22 =	HT =	0.43 =	0.33 =	(0.05) =
=	LT =	5.70 =	0.97 =	(0.14) =
=	mean=	3.06 =	0.65 =	(0.16) =
23 =	HT =	2.45 =	0.6 =	(0.15) =
=	MT =	=	1.2 =	(0.14) =
=	LT =	6.41 =	0.97 =	(0.13) =
=	mean=	4.43 =	0.92 =	(0.11) =
24 =	HT =	1.25 =	2.46 =	(0.21) =
=	LT =	=	3.89 =	(0.66) =
=	mean=	=	3.17 =	(0.44) =
25 =	HT =	1.29 =	1.96 =	(0.37) =
=	LT =	0.54 =	3.55 =	(0.71) =
=	mean=	0.92 =	2.75 =	(0.50) =
26 =	HT =	2.15 =	1.52 =	(0.12) =
=	LT =	1.68 =	2.64 =	(0.30) =
=	mean=	1.91 =	2.08 =	(0.29) =
13 =	HT =	6.19 =	9.53 =	(1.19) =
14 =	HT =	4.37 =	2.82 =	(0.05) =
=	LT =	4.66 =	2.76 =	(0.24) =
=	mean=	4.51 =	2.79 =	(0.11) =

15 =	HT =	1.50 =	2.33 =	(0.14) =
=	LT =	0.84 =	1.38 =	(0.25) =
=	mean=	1.17 =	1.85 =	(0.25) =
16 =	HT =	2.77 =	1.02 =	(0.17) =
=	LT =	1.88 =	2.62 =	(0.23) =
=	mean=	2.32 =	1.82 =	(0.38) =
17 =	HT =	0.70 =	1.84 =	(0.24) =
=	LT =	1.09 =	1.92 =	(0.12) =
=	mean=	0.89 =	1.88 =	(0.12) =
18 =	HT =	1.04 =	6.69 =	(1.21) =
=	LT =	3.54 =	4.85 =	(0.44) =
=	mean=	2.29 =	5.77 =	(0.71) =
19 =	HT =	0.61 =	2.55 =	(0.21) =
=	LT =	4.86 =	3.97 =	(0.47) =
=	mean=	2.74 =	3.26 =	(0.39) =
8 =	HT =	2.79 =	7.38 =	(2.25) =
9 =	HT =	55.38 =	15.42 =	(3.02) =
10 =	HT =	0.13 =	0.16 =	(0.05) =
11 =	HT =	2.59 =	13.38 =	(0.29) =
12 =	HT =	1.58 =	13.78 =	(1.51) =

* this high value could result from inefficient burning (oven failure) =

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APPENDIX 3: Benthic data

- D) **Species Records**
- E) **Species Identifications**
- F) **Individual abundances**
- E) **Biomass**

Table A3A: Macrofaunal species presence at each site within each region, based onsamples and observations from surveys conducted in June (J) and December (D) 2004. = Ref./Fig. refers to species morphological characteristics, photos and sketches given in Appendix A3B. Reference specimens (x) for the amphipods were collected and are held in the = Biological Department of Flinders University. =

						Murray Mouth							North Lagoon							South Lagoon							Lower Lakes				
Phyla	Class	Order	Family	Species	Ref./Fig.	1	2	3	4	5	6	7	20	21	22	23	26	25	24	19	18	17	16	15	14	13	8	9	10	11	12
Annelida=	Polychaeta=		Nereididae=	*Australonereis ehlersi*	A2=	JD	JD	JD		D	J	J	D	J	D																
				Simplisetia aequisetis	A3=	JD	J	J	JD	JD	JD	JD	JD	J																	
			Capitellidae=	*Capitella spec.*	A1=	JD			JD	JD	D	JD	JD	J	JD		D					J					D				
			Nephtyidae=	*Nephtys australiensis*	A4=	JD	JD				J	D	D																		
			Phyllodocidae=	*Phyllodoce novaehollandiae*	A5=		JD	JD	D			JD		J																	
	Oligochaeta=			Oligochaeta indet.=	A6=	JD			JD	JD			D		D						D							J	J	JD	JD
Crustacea=	Malacostraca=	Amphipoda=		Amphipod sp. 1=	x/A7=				D	JD	JD	JD	JD	JD	JD	J											J	J	J	J	
				Amphipod sp. 2=	x/A8=				JD	JD	JD	JD	JD	J													D		J		
				Amphipod sp. 3=	x/A9=		JD	JD	JD	D	JD	JD	D	J													D	D			
				Amphipod sp. 4=	x/A10=				D		D	JD															D				
				Amphipod sp. 5=	x/A11=			JD	JD	D	JD	JD	JD	J																D	
				Amphipod sp. 6=	x/A12=				JD	D	JD	J	D	J													D		J	D	J
				Amphipod sp. 7=	x/A13=				D		JD	D															D			D	
				Amphipod sp. 8=	x/A14=					D																				D	
				Amphipod sp. 9=	x/A15=				J	JD	J	D	J														D			D	
				Amphipod sp. 10=	x/A16=				JD	JD	JD	JD	J	J													JD		J		
		Mysidacea=	Nototanaidae=	Mysid indet.=	x/A17=			J					D																		
		Isopoda=		Isopod indet.=	A18=			J												D	D	J	D				J				
		Decapoda=	Grapsidae=	*Paragrapsus gaimardii*	A19=	D								J																	
	Ostracoda=			Ostracod indet.=	A20=													D	D								D	JD			JD
Mollusca=	Gastropoda=	Pulmonata=	Amphibolidae=	*Salinator fragilis*	A21=	JD	J				D		J	J																	
			Glacidorbidae=	Glacidorbid sp.=	A22=							D																			
			Physidae=	*Physa acuta*	A23=																						J				D
			Pomatiosidae=	*Coxiella striata*	A24=																	D				D					
			Hydrobiidae=	Hydrobiid sp. 1=	A25=																					D					
				Hydrobiid sp. 2=	A26=	JD	JD	D	D				J		J																
				Hydrobiid sp. 3=	A27=								J																		
	Bivalvia=	Venerioda=	Galeommatidae=	*Arthritica helmsi*	A28=	JD	JD	D	JD	JD	JD	JD	JD	J			D										D				
		Mytiloidea=	Mytilidae=	*Brachidontes* sp.=	A29=			J																							
Arthropoda=	Insecta=	Collembola=		Collembola indet.=	A30=										JD						D										
		Hemiptera=	Notonectidae=	Notonectidae indet.=	A31=																						D			D	D
			Corixidae=	Corixidae indet.=	A32=																						D	D			D
			Veliidae=	Veliidae indet.=	A33=																										D
		Coleoptera=	Hydrophilidae=	cf. *Berosus* (Larvae)=	A34=																						D			JD	JD
			Dytiscidae=	Dytiscidae indet.=	A35=																						D				
			Elmidae=	Elmidae indet.=	A36=														J	J		J				D					
			Ptiliidae=	Ptiliidae indet.=	A37=																								D	D	
			Staphylinidae=	cf. *Cafius* sp.=	A38=												J	J	J				J								
		Diptera=	Chironomidae=	Chironomidae (Larvae)=	A39=	JD			J		J	J	D		J		J			JD	JD	JD	JD	D	JD		JD	JD	J	JD	D
			Dolichopodidae=	Dolichopodidae (Larvae)=	A40=		J					J	D	D	D								JD	JD				J			J
			Stratiomyidae=	Stratiomyidae (Larvae)=	A41=																J			D							
			Ceratopogonidae=	Ceratopogonidae (Larvae)=	A42=																		J		J					JD	D
			Culicidae=	Culicidae (Larvae)=	A43=																				J						
			Empididae=	Empididae sp. 1 (Larvae)=	A44=		J		J										J				J								
			Empididae=	Empididae sp. 2 (Larvae)=	A45=	J	J		J						J		J								J						
			Tabanidae=	Tabanidae (Larvae)=	A46=										J							J	J								
		Odonata=	cf. Coenagrionidae=	Zygoptera (Larvae)=	A47=																						J				
		Thysanoptera=	Phlaeothripidae=	Phlaeothripidae indet.=	A48=					D																					D

=

Appendix A3B: Key morphological characteristics of the macrofaunal species found during surveys = conducted at the Murray Mouth, Coorong and Lower Lakes regions in June and December 2004. = Photos and/or sketches, as well as key features are given to distinguish species or morphospecies. = Additional information on habitat and feeding is included where available. Literature references for = further taxonomic or ecological information are included. =

Section 1: Annelida =
Key features including photos for the identified annelid species (Polychaeta and Oligochaeta). =
=

Taxa: Polychaeta
Family: Capitellidae
Species: *Capitella sp.*
'

Body cylindrical, resembling an earthworm. ' Prostomium short and without appendages (Fig. ' A1a and b). Capitellids are deposit feeders and live ' in semi-permanent mucus tubes in the mud. High ' haemoglobin content of the blood allows Capitellids ' to live in low oxygen environments and accounts ' for the normally red colouration of the animal when ' alive. '

Hutchings, P. A. (1984). An illustrated guide to the ' estuarine polychaete worms of New South Wales. = Coast and Wetlands Society. '
'

Key features:
Prostomium blunt, eye spots absent. 9 thoracic ' segments. Setae bearing hooks on distal end ' present on each segment. '
'

Figure A1a. *Capitella sp*. '

Figure A1b. *Capitella sp*., anterior end =

=

Taxa: Polychaeta
Family: Nereididae
Species: *Australonereis ehlersi* (Augener 1918)
=

This species is widespread throughout Australian = estuaries and protected shores. Body dorso-= ventrally flattened, sheathed in a limp, sandy tube. = Pharynx without any paragnaths. Lamellae on = ventral side of anterior segments (Fig. A2). =

Hutchings, P. A. (1984). An illustrated guide to the = estuarine polychaete worms of New South Wales. = Coast and Wetlands Society. =
=

Key features:
Cephalic tentacles all short. Prostomium width = narrower than segments. Lamellae on ventral side = of anterior segments. =
=

Figure A2. *Australonereis ehlersi*, ventral = side of anterior body part =

=

Taxa: Polychaeta
Family: Nereididae
Species: *Simplisetia aequisetis (Ceratonereis pseudoerythraeensis)* Augener 1913 '
'

This species is widespread throughout Australian ' estuaries in muddy sand often associated with ' seagrass beds. Body flattened, tapering, robust ' anteriorly. Two pairs of eye spots. Four pairs of ' tentacular cirri (Fig. A3a). Two short pairs, one ' medium, one long. Eversible pharynx with stout, ' curved jaws. Paragnaths arranged around the ' distal end of extended pharynx (Fig. A3b). '

Hutchings, P. A., Turvey, S. P. (1982). The = Nereididae of South Australia. Transactions of the = Royal Society of South Australia. Vol. 106, Pt. 3, = pp. 93-144. =
=

Key features:
Two pairs of eye spots. Four pairs of tentacular ' cirri. Two short pairs, one medium, one long. ' Paragnaths arranged around the distal end of ' extended pharynx. '

Figure A3a. *Simplisetia aequisetis,* anterior = end =

Figure A3b. *Simplisetia aequisetis,* everted = pharynx =

=

Taxa: Polychaeta
Family: Nephtyidae
Species: *Nephtys australiensis* Fauchald 1965
=

This species is widespread throughout estuaries of = South Australia, Tasmania, Victoria, New South = Wales and Southern Queensland. Long slender = worms, quadrangular in cross section (Fig. A4a). = Very short antennae and oral palps. Eversible = pharynx with lateral jaws. Parapodia have defined = upper and lower lobes. =

Hutchings, P. A., Murray, A. (1984). Taxonomy of = polychaetes from the Hawkesbury River and the = southern estuaries of New South Wales, Australia. = Records of the Australian Museum. Vol. 36, supp. = 3. =
=

Key features:
Very small prostomium with short antennae and = palps (Fig. A4b). Parapodia bilobed, upper lobe = similar in size to lower lobe. =

Figure A4a. *Nephtys australiensis,* anterior = end =
=

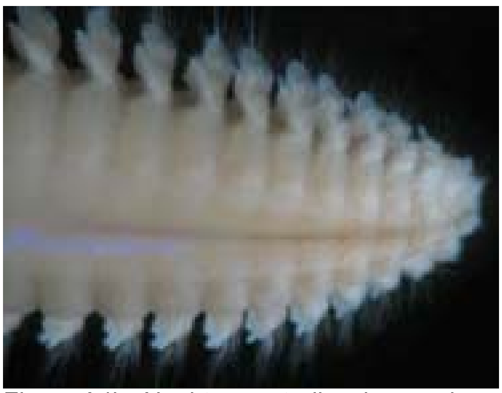


Figure A4b. *Nephtys australiensis,* anterior = end (dorsal view) with small prostomium. =
=

=

=

Taxa: Polychaeta
Family: Phyllodocidae
Species: *Phyllodoce novaehollandiae* Kinberg 1866

Pale to dark brown body with darker intersegmental pigment bands (Fig. A5a). 4 buccal antennae plus four pairs of tentacular cirri (Fig. A5a). Two round eye spots. Pharynx with numerous elongate papillae arranged in longitudinal rows, basally with rugged ridges. Often found in seagrass beds or sand flats.

Hutchings, P. A. (1984). An illustrated guide to the estuarine polychaete worms of New South Wales. Coast and Wetlands Society.

Key features:
Arrow shaped head, 1 pair of eye spots. Pharynx with numerous elongate papillae arranged in longitudinal rows, basally with rugged ridges (Fig. A5b).

Figure A5a. *Phyllodoce novaehollandiae,* anterior end

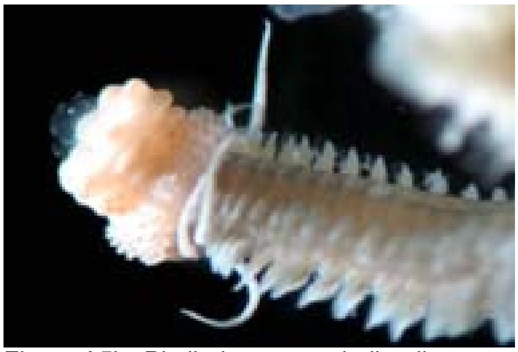


Figure A5b. *Phyllodoce novaehollandiae,* everted pharynx

Taxa: Oligochaeta
Family: Oligochaeta

Oligochaetes include the familiar earthworms, although oligochaetes are proportionally smaller and more slender. The anterior end of oligochaetes usually lacks appendages or obvious sense organs (Fig. A5a and b). Typically each segment after the prostomium bears four bundles of chaetae .

Knight-Jones, E. W., Knight-Jones, P., Nelson-Smith, A. (1995), Chapt. 6, Annelids, In: Hayward, P. J. & Ryland, J. S., Handbook of the Marine Fauna of North-west Europe. Oxford University Press.

Key features:
Anterior end lacks appendages. Small bundles of chaetae on the segments after the prostomium.

Figure A6a. Oligochaeta indet.

Figure A6b. Anterior end of unidentified oligochaete

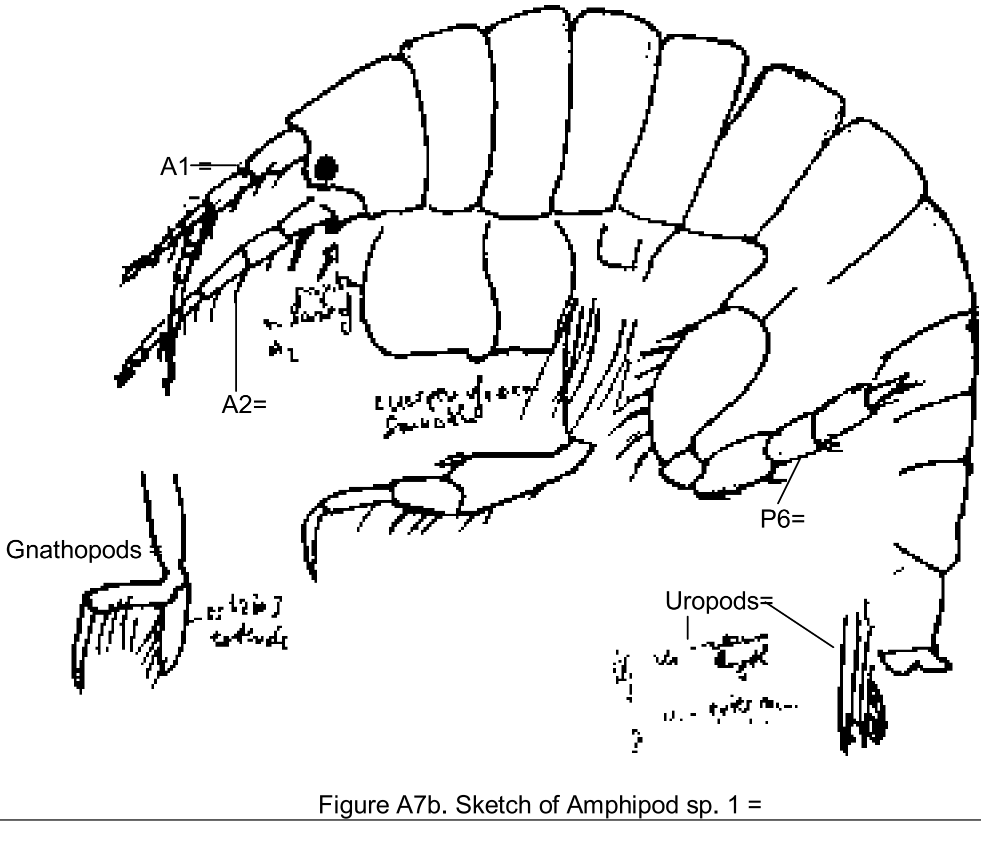
Section 2: Crustacea =
Key features of the identified crustaceans. In the case of amphipods, morphospecies were = distinguished. Photos (where available) and/or sketches are included. =

=

AMPHIPOD SP. 1 =

Head:
Antennae short '
A_1 & A_2 same length. '
Projection at base of A_2 '
Gnathopods:
Gnathopod 2:extension on article 3 '
Subchelate '
Uropods:
all biramous =
Pereopods:
P6 & P7 same length =
Setae:
Few on A_2 and posterior side of P_6 =

Figure A7a. Amphipod sp. 1 =



=

Figure A7b. Sketch of Amphipod sp. 1 =

=

AMPHIPOD SP. 2

Head:
A_1 & A_2 same length

Gnathopods:
Extension on article 3

Uropods:
All biramous

Pereopods:
P6 longer than P7

Setae:
A_2 and posterior side of P6 with many setae (“fluffy”)

Figure A8a. Amphipod sp. 2

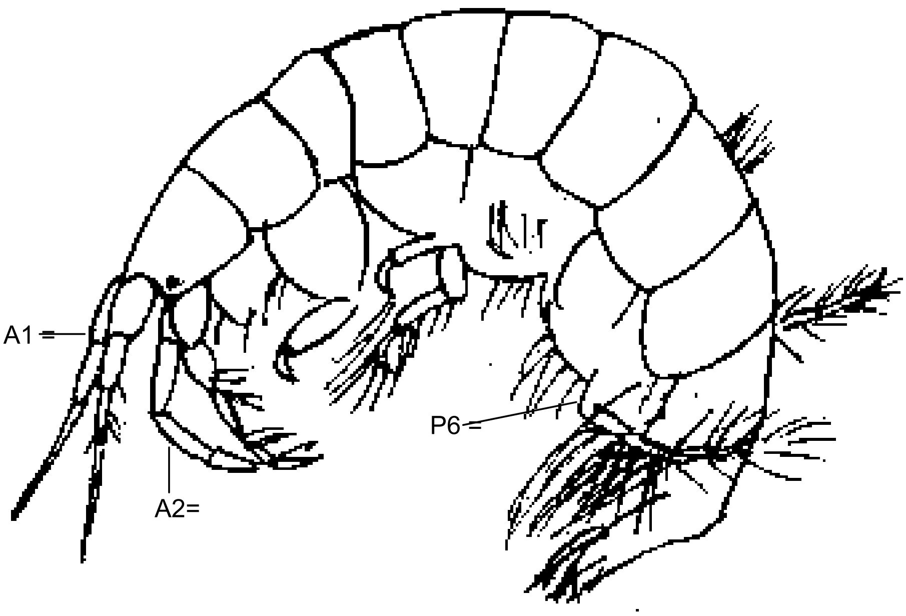


Figure A8b. Sketch of Amphipod sp. 2

AMPHIPOD SP. 3

Head:
A_2 longer than A_1
Head different to sp. 1 & 2
Longer rostrum

Gnathopods:
Subchelate, no extension on article 3

Uropods:
all biramous
same length

Figure A9a: Amphipod sp. 3

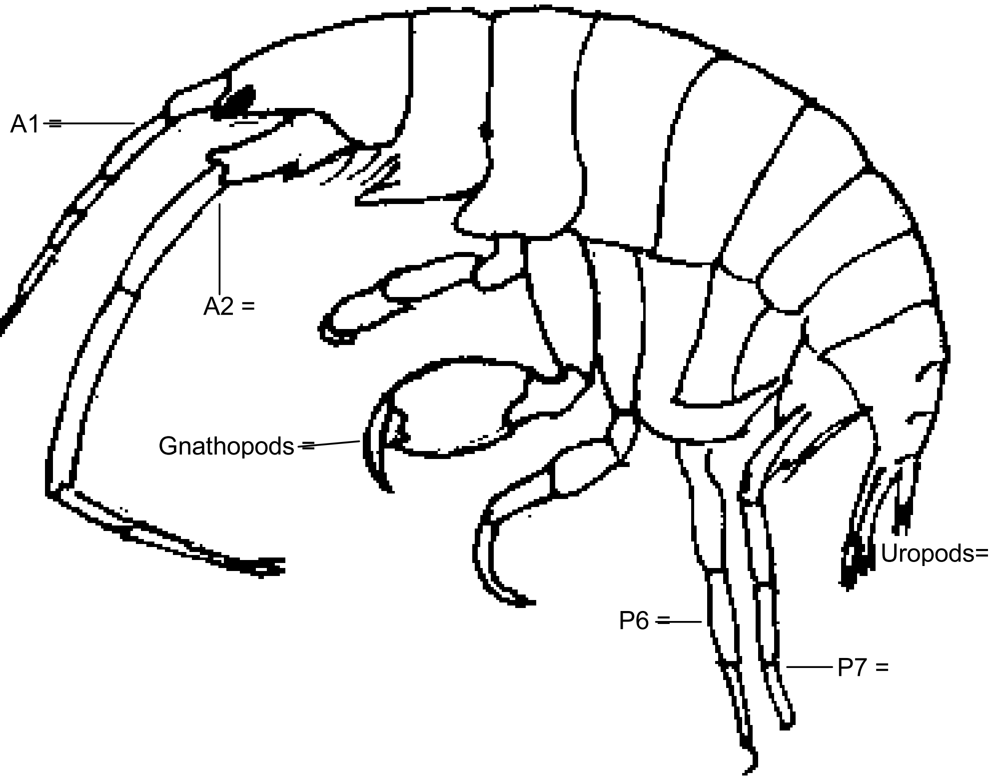


Figure A9b. Sketch of Amphipod sp. 3

=

AMPHIPOD SP. 4 =

Head:
A_2 longer than A_1 =
A_1 shorter and more delicate than in sp. 3 =

Gnathopods:
Gnathopod 2 chelate with enlarged propodus =

Uropods:
All biramous =
Same length =

Photo N/A =

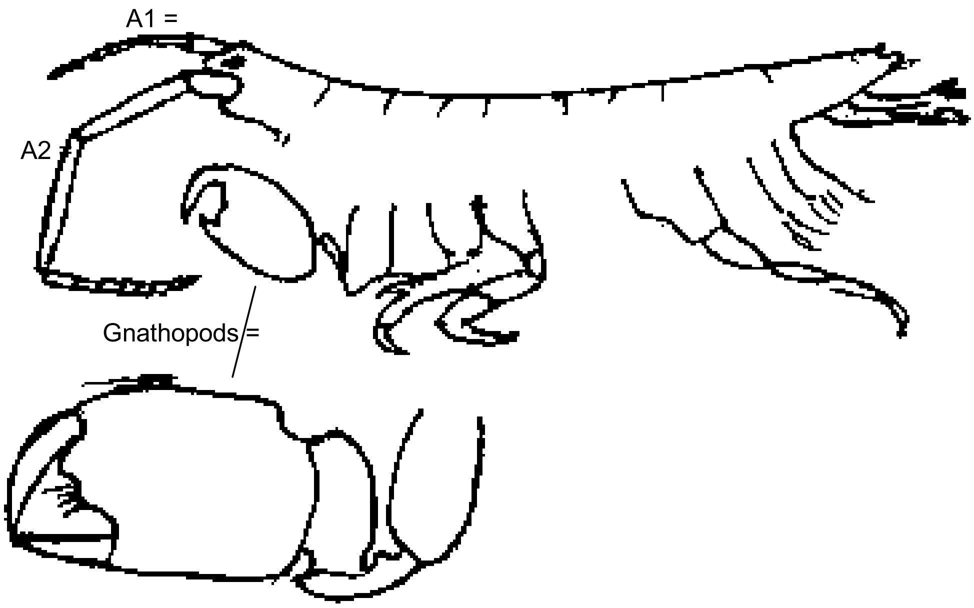


Figure A10: Sketch of Amphipod sp. 4 =

=

AMPHIPOD SP. 5 =

=

Head:

A_2 slightly longer than A_1 =

Both antennae longer than in sp. 1 & 2 =

=

Photo N/A =

Gnathopods:

Subchelate, no extension on article 3 =

=

Uropods:

All biramous =

Same length =

'thorn' at base =

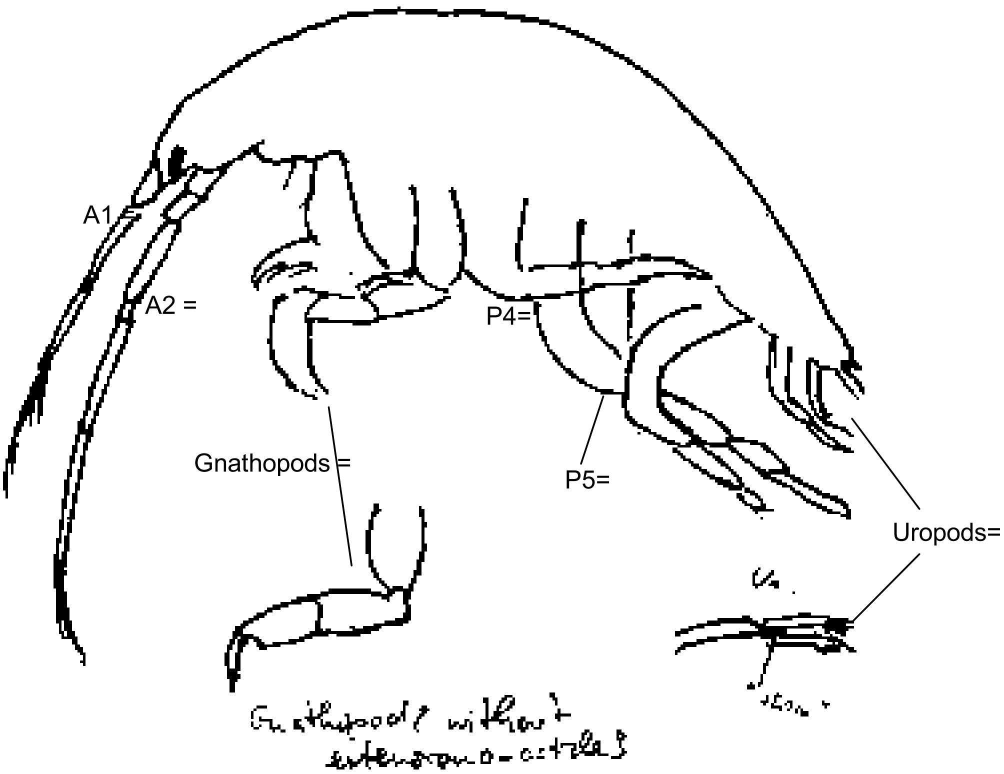
=

Pereopods:

P4 short =

P5 & P6 long =

=



=

Figure A11: Sketch of Amphipod sp. 5 =

=

=

AMPHIPOD SP. 6 =

=

Head:
A_1 longer than A_2 =

=

Gnathopods:
Subchelate =

=

Uropods:
All biramous =

=

Pereopods:
P7 as long as P6 =
Both longer than gnathopods =
Pereopods shorter than sp. 1 =

=

Setae:
Not as many as sp. 1 =

=

Figure A12a. Amphipod sp. 6 =

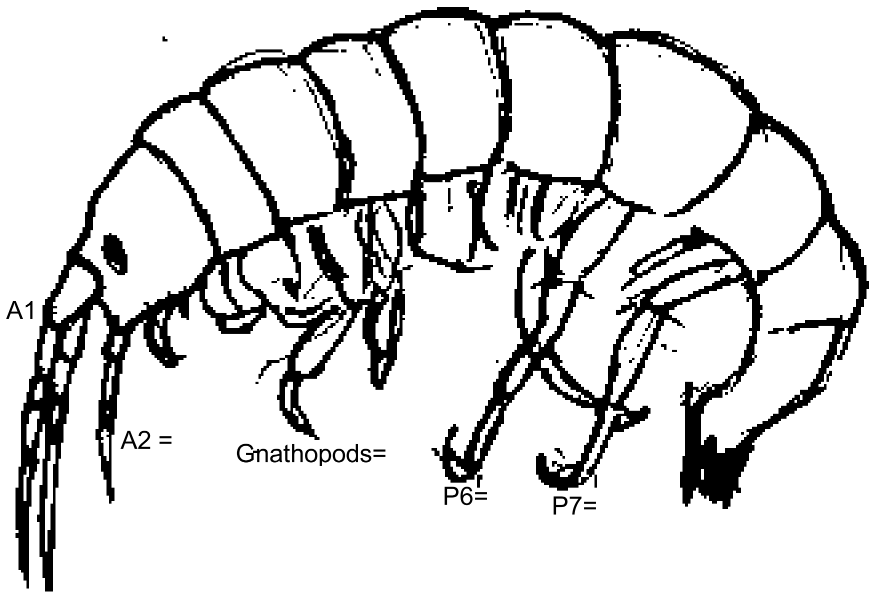


Figure A12b. Sketch of Amphipod sp. 6 =

=

AMPHIPOD SP. 7 =

=

Head:

A_1 slightly longer than A_2 =

=

Gnathopods:

Subchelate =

different shape than sp. 6 – larger =

=

Uropods:

all biramous

=

=

Figure A13a. Amphipod sp. 7 =

=

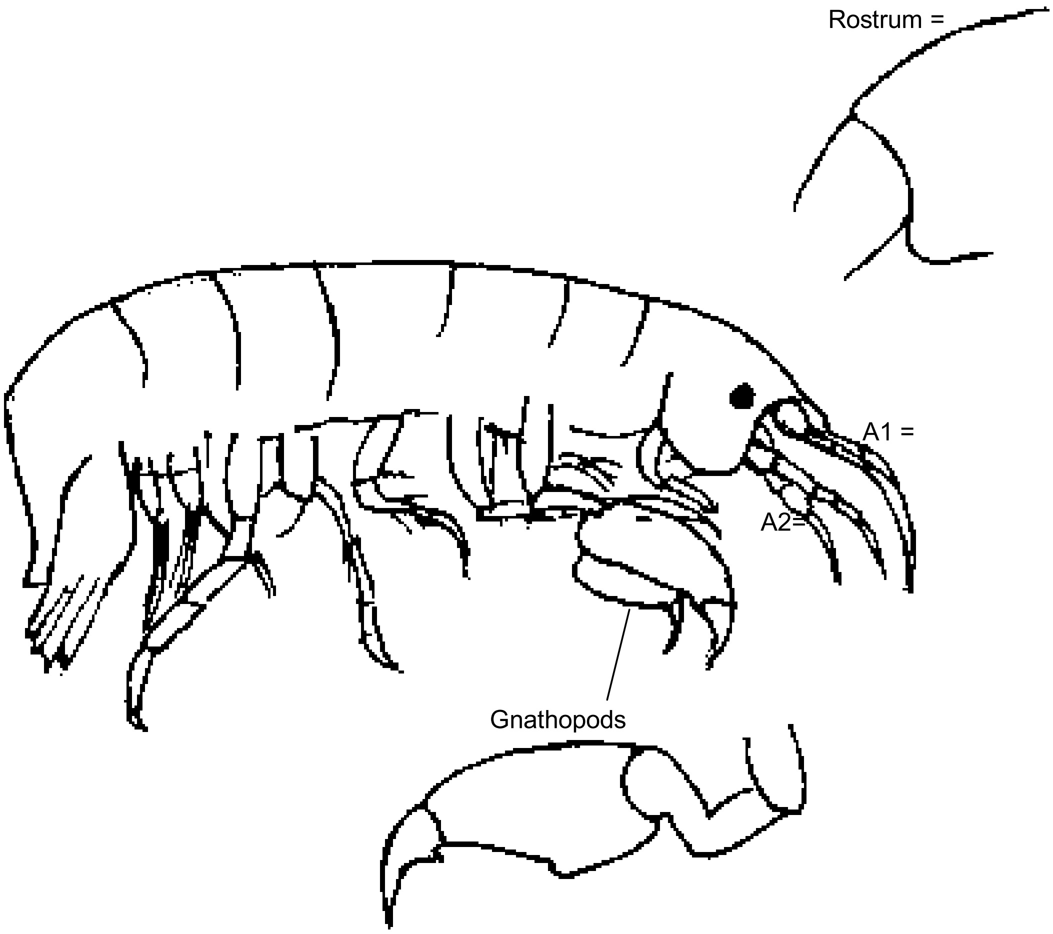


Figure A13b. Sketch of Amphipod sp. 7 =

=

=

AMPHIPOD SP. 8 =

=

Head:
A_2 longer than A_1 =
Extension at base of A_2 =

=

Gnathopods:
Short gnathopods =
Subchelate =

=

Uropods:
All biramous =
U1 slightly longer =

=

Pereopods:
P6 & P7 long =

=

Setae:
Many setae on A2 =

=

=

Photo N/A =

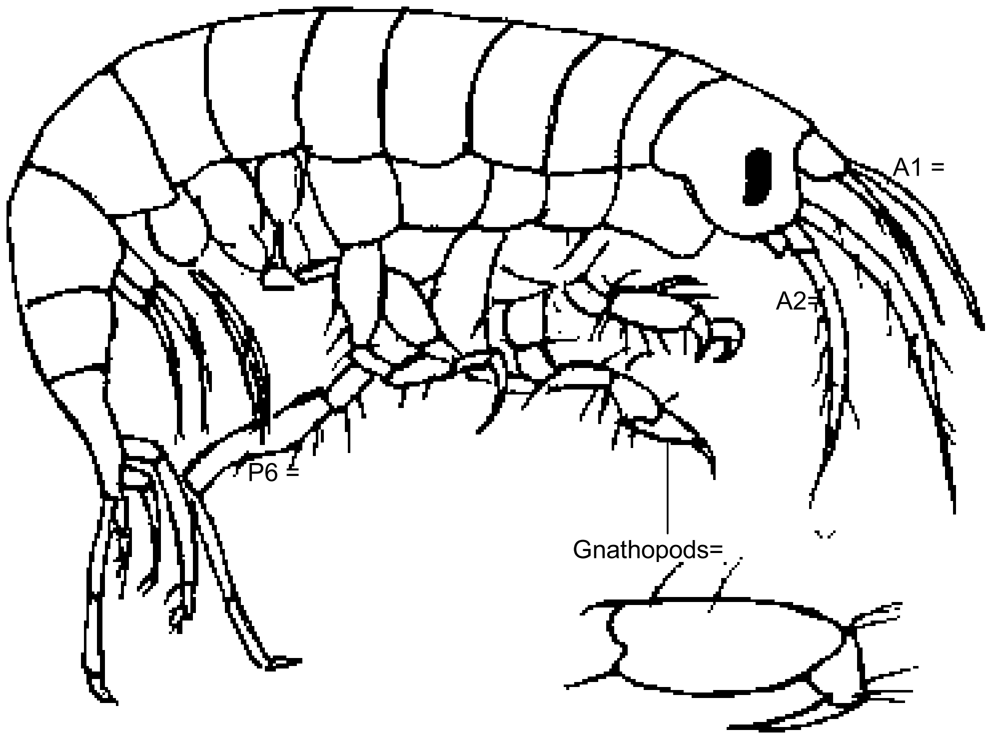


Figure A14: Sketch of Amphipod sp. 8 =

=

=

AMPHIPOD SP. 9 =

Head:
A_1 longer than A_2 =

Gnathopods:
Large gnathopods, subchelate =

Uropods:
All biramous =
U1 longer =

Figure A15a. Amphipod sp. 9 =

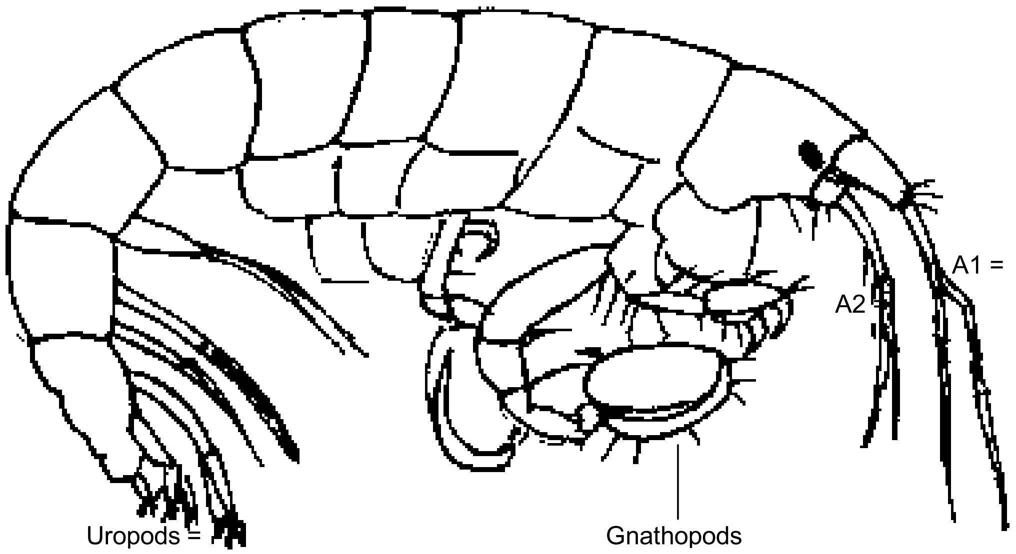


Figure A15b. Sketch of Amphipod sp. 9 =

=

AMPHIPOD SP. 10 =

=

Head:

A_1 & A_2 same length =

Projection at base of A_2 =

Short antennae =

=

Gnathopods:

Subchelate =

No extension on article 3 =

=

Uropods:

All biramous =

Same length =

=

Setae:

many setae present =

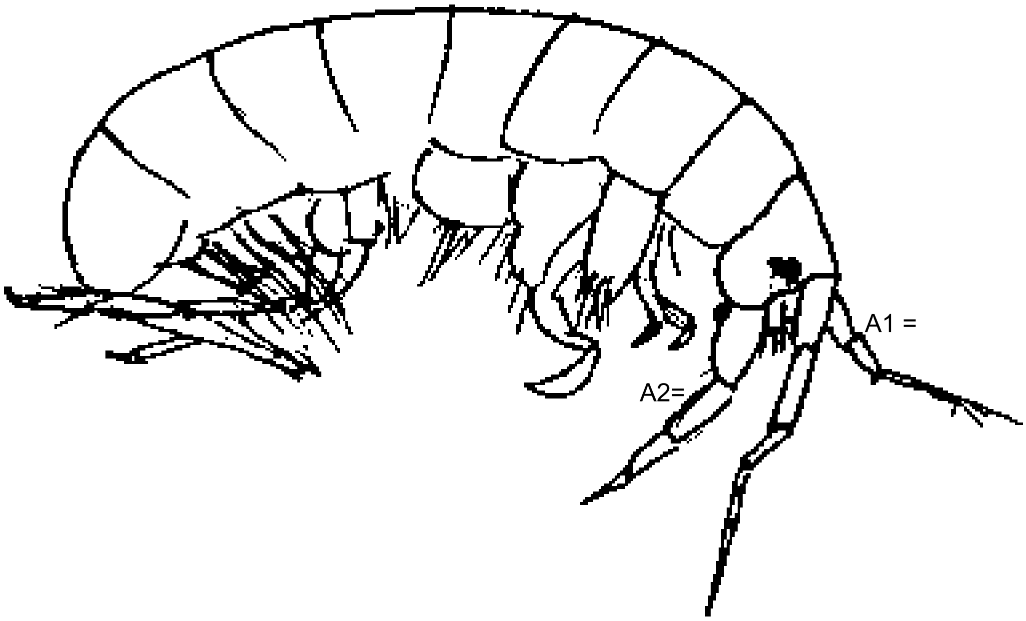
=

=

=

= = = = =

Photo N/A =



=

=

Figure A16: Sketch of Amphipod sp. 10 =

=

=

Taxa: Crustacea
Family: Nototanaidae
Species: Mysid indet. =

=

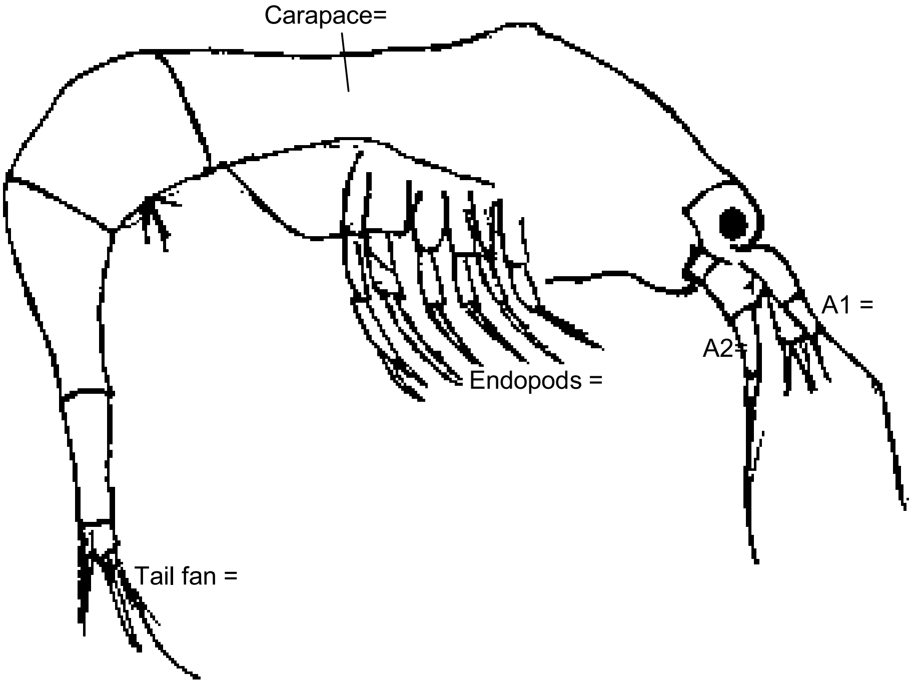
Small, shrimp like crustaceans. =
Carapace extends over most of the = thorax but fuses with only the first three = or four segments. =
First antennae are branched into two, = and second antennae with large leaf-= like projection near the base. =

=

Edgar, G. (2000). Australian Marine = Life (revised edition): The Plants and = Animals of Temperate Waters. Reed = New Holland, Sydney. =

Figure A17a. Mysidacea indet. =

=
=
=



=

Figure A17b. Sketch of an unidentified Mysid =

=

=

Taxa: Crustacea
Species: Isopod indet.

=

Average size 2-20 mm. Body plan adaptable, = enabling them to inhabit large range of habitats. = Numerous species found in freshwater, among leaf = litter on land, as parasites of fishes and = crustaceans, and as borers in wood, as well on sea = floor where they reach their greatest numbers. = In the Coorong, isopods were found in the dry = sands of the upper intertidal. = Most are detritivores, shredders of leaves and other = organic matter. =

Hayward, P.J., Ryland, J.S. (Ed.). (1996). = Handbook of the Marine Fauna of North-West = Europe. Oxford University Press. =

=

Key features:
Dorso-ventrally flattened, lacks carapace. = Comprises of head, thorax of seven segments, and = an abdomen of six segments. = Uniramous pereopods; pleon and telson wholly or = partly fused, forming a pleotelson with five pairs of = biramous pleopods and a pair of uniramous or = biramous uropods. =

Figure A18: Isopod indet. =

=

=

=

Taxa: Crustacea
Family: Grapsidae
Species:*Paragrapsus gaimardii* H. Milne Edwards, 1853

=

Abundant in sheltered bays and estuaries. Usually = found under rocks or in shallow burrows. Large = numbers move around at night in shallow water, = often following the tide. =

Edgar, G. (2000). Australian Marine Life (revised = edition): The Plants and Animals of Temperate = Waters. Reed New Holland, Sydney. =

Poore, G.C.P. (2004). Marine Decapod Crustacea = of Southern Australia. A Guide to Identification. = CSIRO Publ., Collingwood. =

Key features:
Recognised by the two teeth on the side of the = carapace behind the orbital angle. = Body greenish hue with black spots, tips of legs = yellow. =

Figure A19: *Paragrapsus gaimardii* =

=

=

=

Taxa: Crustacea
Species: Ostracod indet.

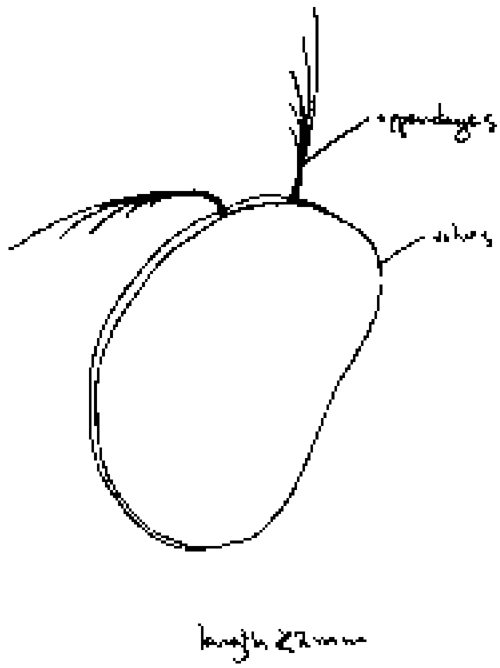
Carapaces are variable, carrying sculpturing such = as pits or ridges and occur in many colours. =
Ostracods propel themselves with an assortment of = legs and antennae. =
Herbivore/detrivore feeders. =
Commonly found on soft sediments at bottom of = ponds and wetlands, some are planktonic or on the = underside of the water surface. =

Davis,J. & Christidis, F. (1999). A Guide to Wetland = Invertebrates of Southwestern Australia. Western = Australian Museum, Perth. =

Gooderham, J.& Tsyrlin, E. (2002). The Waterbug = Book: A Guide to the Freshwater Macro-= invertebrates of Temperate Australia, CSIRO = Publishing, Collingwood. =

Ingram, B. A., Hawking, J. H. & Shiel, R. J. (1997). = Aquatic Life in Freshwater Ponds. A Guide to the = Identification and Ecology of Life in Aquaculture = Ponds and Farm Dams in South Eastern Australia. = Co-operative Research Centre for Freshwater = Ecology, Albury, NSW. =

=



=

Figure A20: Ostracod sp. =

Key Features:
Body covered by two calcareous valves of the = carapace. =
Body is not noticeably segmented and has a = reduced complement of limbs compared with other = crustaceans. =
Shell may bear setae, do not develop growth lines = on shells. Usually about 1 mm in length. =
Majority are pigmented: common colours include = green, blue, brown and purple. =
Can be confused with juvenile bivalves. =

=

=

Section 3: Mollusca
Key features and photos of Mollusc species found in the study area. =
=
=

Class: Gastropoda
Superorder: Pulmonata
Family: Amphibolidae
Species*: Salinator fragilis* (Lamarck, 1982)
'

Amphibolids are pulmonate snails, living in great ' numbers on estuarine mudflats and also samphire ' and mangrove flats. They are sometimes partially ' buried in the substratum and can withstand ' brackish water. '

Stanisic, J. (1998). Order Basommatophora. *In:* ' Beesley, P.L., Ross, G.J.B., Wells, A. (eds) ' Mollusca: The Southern Synthesis. Fauna of ' Australia Vol. 5. CSIRO Publishing, Melbourne, = Part B. pp 1067-1075 =

Shepherd, S.A. & Thomas, I.M. (eds.). (1989). ' Marine Invertebrates of Southern Australia. Part II. ' South Australian Government Printing Division, ' Adelaide. '

Key Features:
Long aperture, whorl taller than spire (Fig. A21a). = Spirally coiled operculum. Fine sculptured shell = with a thin and dextral aperture. Brown band = curves around shell (Fig. A21b). Grey/white = banding on ventral side and spire. Darker orange = on dorsal side =
=
Note: This family is currently under revision by R. = Golding and identifications may need to be revised = as further species of Salinator are described. =
=

Figure A21a: *Salinator fragilis*, apertural ' view =
=

Figure A21b: *Salinator fragilis*, dorsal view =

=
Class: Gastropoda
Superorder: Pulmonata
Family: Glacidorbidae
Species: *Glacidorbid* sp.
=
Glacidorbids are pulmonate snails. Small, flat = coiled shells. They can be confused with = planorbids, yet Planorbidae lack an operculum. = Occur in streams and swamps. Presumably = carnivorous. =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =
=
Key Features:
Spirally coiled operculum (Fig. A22a). Off white = colour, with darker stripes. Spirally radiating ridges = (Fig. A22b). Planispiral (flattened) sinistral shell = with sunken spire (Fig. A22a). =
=

Figure A22a: Glacidorbid sp., apertural = view =

Figure A22b: Glacidorbid sp., dorsal view =
=

=
=

Class: Gastropoda
Superorder: Pulmonata
Family: Physidae
Species: *Physa acuta* Draparnaud, 1805
=

Freshwater snails, not native to Australia. =
Lives on weeds and other substrata in ponds and = fast and slow-moving streams. Also present in = disturbed habitats. Appears to be actively = spreading. =

Stanisic, J. (1998). Order Basommatophora. *In:* = Beesley, P.L., Ross, G.J.B., Wells, A. (eds) = Mollusca: The Southern Synthesis. Fauna of = Australia Vol. 5. CSIRO Publishing, Melbourne, = Part B. pp 1067-1075 =

Davis,J. & Christidis, F. (1999). A Guide to Wetland = Invertebrates of Southwestern Australia. Western = Australian Museum, Perth =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =
=

Key Features:
Thin, sinistral, elongate-conical shell (Fig. A23a). = Translucent, glossy shell. Mottled colouring of = mantle visible through shell (Fig. A23b). Light = brown colour. Sculpture is lacking. No operculum. = Whorl longer than spire. Large aperture (Fig. A23a) =

Figure A23a: *Physa acuta,* apertural view =
=

Figure A23b: *Physa acuta,* dorsal view =
=

=
=

=

Class: Gastropoda
Superfamily: Rissoidea
Family: Pomatiopsidae
Species: *Coxiella striata* (Reeve, 1842)

Coxiella lives in hypersaline habitats, primarily salt lakes, often very abundant, with shells forming large banks. Can survive considerable temperature and salinity ranges. Height 7.5 mm diameter 2.5 mm. Feed mainly on organic detritus.

Ponder, W. & de Keyzer R.G. (1998). Superfamily Rissoidea. *In* Beesley, P.L., Ross, G.J.B., Wells, A. (eds) Mollusca: The Southern Synthesis. Fauna of Australia Vol. 5. CSIRO Publishing, Melbourne, Part B. pp 745-766.

Shepherd, S.A. & Thomas, I.M. (eds.). (1989). Marine Invertebrates of Southern Australia. Part II. South Australian Government Printing Division, Adelaide.

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Key Features:
Dextrally coiled, small shells. Tall spire with blunt tip (Fig. A24a and b). Spirally striate. Oval aperture, orange inside, operculum present (Fig. A24a). Pink/orange/light grey colouring

Figure A24a: *Coxiella striata,* apertural view

Figure A24b: *Coxiella striata,* dorsal view

Class: Gastropoda
Superfamily: Rissoidea
Family: Hydrobiidae
Species: Hydrobiid sp. 1

Hydrobiids are fresh and brackish water snails. Live in a variety of habitats from estuarine to rivers, lakes and springs.

Ponder, W. & de Keyzer R.G. (1998). Superfamily Rissooidea. *In* Beesley, P.L., Ross, G.J.B., Wells, A. (eds) Mollusca: The Southern Synthesis. Fauna of Australia Vol. 5. CSIRO Publishing, Melbourne, Part B. pp 745-766.

Key Features:
Dextrally coiled, small shell. Oval aperture – dark brown inside (Fig. A25a). Short/flattened spire. Dark brown, usually with a light coloured protoconch(Fig. A25a and b).

Figure A25a: Hydrobiid sp. 1, apertural view


Figure A25b: Hydrobiid sp. 1, dorsal view

Class: Gastropoda
Superfamily: Rissoidea
Family: Hydrobiidae
Species: Hydrobiid sp. 2


Figure A26a: Hydrobiid sp. 2, apertural view

Hydrobiids are fresh and brackish water snails. Live in a variety of habitats from estuarine to rivers, lakes and springs.

Ponder, W. & de Keyzer R.G. (1998). Superfamily Rissooidea. *In* Beesley, P.L., Ross, G.J.B., Wells, A. (eds) Mollusca: The Southern Synthesis. Fauna of Australia Vol. 5. CSIRO Publishing, Melbourne, Part B. pp 745-766.

Key Features:
Dextrally coiled, small shell. Orange/yellow colour. Roundish aperture (Fig. A26a). Translucent shell (Fig. A26b). Fist whorl more elongate than in *Hydrobiid* sp. 2 & 3.


Figure A26b: Hydrobiid sp. 2, dorsal view

Class: Gastropoda
Superfamily: Rissoidea
Family: Hydrobiidae
Species: Hydrobiid sp. 3

Hydrobiids are fresh and brackish water snails. Live in a variety of habitats from estuarine to rivers, lakes and springs.

Ponder, W. & de Keyzer R.G. (1998). Superfamily Rissooidea. *In* Beesley, P.L., Ross, G.J.B., Wells, A. (eds) Mollusca: The Southern Synthesis. Fauna of Australia Vol. 5. CSIRO Publishing, Melbourne, Part B. pp 745-766.

Figure A27a: Hydrobiid sp. 3, apertural view

Key Features:
Dextrally coiled, small shell. Distinct angle between 1st and 2nd whorl (Fig. A27a). Aperture more angular compared to *Hydrobiid* sp. 2. Cream/orange colour (Fig. A27b).

Figure A27b: Hydrobiid sp. 3, dorsal view

Class: Bivalvia
Order: Veneroida
Family: Galeommatidae
Species: *Arthritica helmsi* (Hedley, 1915)

Figure A28: *Arthritica helmsi*

Galeommatids live in association with many types of invertebrates. Species is very common in estuarine lagoons. Have ovate shells and mantle edge is not reflected over the shell and is fringed with small tentacles. Filter-feeders.

Lamprell, K., Healy, J. (1998). Bivalves of Australia Vol. 2. Backhuys Publ., Leiden.

Ponder, W. (1998). Superfamily Galeommatoidea. I*n* Beesley, P.L., Ross, G.J.B., Wells, A. (eds) Mollusca: The Southern Synthesis. Fauna of Australia Vol. 5. CSIRO Publishing, Melbourne, Part B viii Pp 316-318

Key Features:
Light apricot/pink colour (Fig. A28). Globular oval shape. Thin, fragile shell. Sculpture postulate with obscure concentric growth lines. Very small, usually <0.5 cm.

Class: Bivalvia
Order: Mytiloidea
Family: Mytilidae
Species: *Brachidontes* sp.

Figure A29: *Brachidontes* sp.

Mytilids are estuarine and marine mussels. Most are suspension feeders and are epifaunal. They live attached by byssal threads to firm substrata, either solitarily or gregariously. Shells with bifurcating sculpture.

Lamprell, K., Healy, J. (1998). Bivalves of Australia Vol. 2. Backhuys Publishers, Leiden

Key Features:
Radiating ribs (Fig. A29). Orange/light brown colour. Irridescent colouring near hinge. Fine concentric striae.

Section 4: Insecta

Key features of the identified insects. Photos and/or sketches are included.

Class: Collembola (Springtails)

The collembola are minute animals, rarely longer than 3mm (Fig. A30). These soft-bodied insects are widely distributed despite their lack of wings. They can move as far as 30cm by releasing tension stored in the forked, spring-like furcula on the underside of the abdomen. They feed on fungi and decomposing organic matter. Prefer moist habitats.

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Davis,J. & Christidis, F. (1999). A Guide to Wetland Invertebrates of Southwestern Australia. Western Australian Museum, Perth

Figure A30. Collembola

Key features:

Small (<3mm), soft-bodied, wingless, furcula (springtail); often found floating in rafts made up of numerous individuals.

Order: Hemiptera

Family: Notonectidae (Backswimmers)

In contrast to the Corixidae, Notonectidae have convex backs and a longer, more pointed rostrum. They swim on their back, trapping a bubble of air in short hairs on the underside of the abdomen. Like the corixids, notonectids are excellent fliers. They are predators, feeding on a variety of invertebrates.

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Davis,J. & Christidis, F. (1999). A Guide to Wetland Invertebrates of Southwestern Australia. Western Australian Museum, Perth

Figure A31. Notonectidae, seen from ventral side.

Key features:

Swim with ventral side up. Convex dorsal surface. Large eyes. First two paris of legs short, third pair long and fringed with hairs (Fig. A31).

Order: Hemiptera
Family: Corixidae (Water boatmen)

The Corixidae have a slightly dorso-ventrally flattened, streamlined body (Fig. A32a). A short, triangular rostrum is in contrast to the long piercing mouthparts of other aquatic insects (Fig. A32b). The front pair of limbs is short and scoop-like. The middle and hind limbs are long and fringed with hairs to aid in swimming. Coroxids occur in still or slow moving water and are excellent fliers capable of moving from one water body to another. They feed on other insect larvae and vegetation.

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Davis,J. & Christidis, F. (1999). A Guide to Wetland Invertebrates of Southwestern Australia. Western Australian Museum, Perth

Key features:
Flattened dorsal surface. Swim with legs under body. Wide head with large eyes. Front limbs reduced to small scoops. Blunt, triangular rostrum.

Figure A32a. Corixidae, cf. *Micronecta* sp.

Figure A32b. Corixidae, detail of ventral side, showing short, blunt, triangular rostrum and short front legs.

Order: Hemiptera
Family: cf. Veliidae

These semi-aquatic insects are found in still and slow moving water. This family is carnivorous and feeds by piercing the body of their prey with the stylet (Fig. A33a & b.) and then sucking out the fluids.

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Ingram, B. A., Hawking, J. H. & Shiel, R. J. (1997). Aquatic Life in Freshwater Ponds. A Guide to the Identification and Ecology of Life in Aquaculture Ponds and Farm Dams in South Eastern Australia. Co-operative Research Centre for Freshwater Ecology, Albury, NSW.

Key features:
Middle and hind legs usually shorter than the length of the body. Long 3 jointed beak. Wings cover the abdomen.

Figure A33a. cf. Veliidae, dorsal view

Figure A33b. cf. Veliidae, ventral view

=

Order: Coleoptera
Family: Hydrophilidae (Water scavenger beetles) '
Larvae
Species: ***cf Berosus***
'

Hydrophilid larvae have large serrated mandibles ' and a wrinkled appearance to their abdomen. ' Occur in wetlands. Often found in slow moving or ' stagnant water, they are predacious and are ' generally poor swimmers. '

Davis,J. & Christidis, F. (1999). A Guide to Wetland ' Invertebrates of Southwestern Australia. Western ' Australian Museum, Perth '

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug ' Book. CSIRO Publ. Collingwood. '

Ingram, B. A., Hawking, J. H. & Shiel, R. J. (1997). ' Aquatic Life in Freshwater Ponds. A Guide to the ' Identification and Ecology of Life in Aquaculture ' Ponds and Farm Dams in South Eastern Australia. ' Co-operative Research Centre for Freshwater ' Ecology, Albury, NSW. '

Figure A34. Hydrophilidae. Larvae of ' *Berosus* sp. '

=

Key features of larvae:
Large fleshy body, with 7 pairs of fleshy filaments ' (Fig. A34). Large serrated mandibles. '
'

=
=

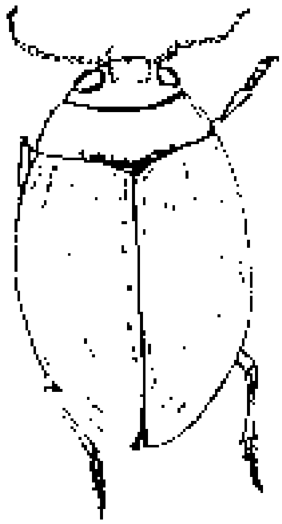
Order: Coleoptera
Family: Dytiscidae (Diving beetles)

Diving beetles are one of the most diverse groups = of aquatic beetles. They have convex dorsal and = ventral surfaces. Adults range from 2-35 mm. They = occur in stagnant or slow moving water and both = larvae and adults are voracious predators. =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =

Davis,J. & Christidis, F. (1999). A Guide to Wetland = Invertebrates of Southwestern Australia. Western = Australian Museum, Perth =
=

Key features:
Streamlined shape. Long, thin antennae. Convex = dorsal and ventral surfaces. Hind legs with fringe of = swimming hairs (Fig. A35). =



=
Figure A35. Sketch of a Dytiscidae. =

=

Order: Coleoptera
Family: Elmidae (Riffle beetles)
=
Small (< 10 mm), darkly coloured beetles with long = legs in relation to their body. Often found in riffles = on rocks or submerged logs. May burrow and live = in slow to swiftly moving waters. =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =
=

Key features:
Long serrated front limbs (Fig. A36). Legs not = adapted for swimming. Long, slender antennae = with segments of equal length. =

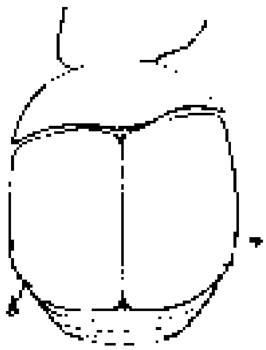
Figure A36. Elmidae, ventral view. =

=
=

Order: Coleoptera
Family: Ptiliidae
=
Very small animals found in stagnant or slowly = moving water. Hard exoskeleton, head completely = covered by pronotum (Fig. A37). =

Davis,J. & Christidis, F. (1999). A Guide to Wetland = Invertebrates of Southwestern Australia. Western = Australian Museum, Perth =
=

Key features:
Minute beetle (<1mm), head completely covered by = pronotum. Filamentous antennae. Elytrae do not = completely cover abdomen. =



=
Figure A37. Sketch of a Ptiliidae. =

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=
=

Order: Coleoptera
Family: Staphylinidae (Rove beetles)
Species: cf. *Cafius sp.* =
=
Elongate beetles with short elytrae, leaving several = abdominal segments exposed (Fig. A38). Holes in = the banks or sand flats of water bodies can indicate = the presence of this species. Mostly predatory, = feeding on larvae or other small insects. =

Matthews, E. G. & Queale, L. F.(1997). Littoral = insects (Phylum Arthropoda: Class Insecta). In: = S.A. Shepherd & M. Davies (Eds), Marine = Invertebrates of Southern Australia. Part III. South = Australian Research and Development Institute = (Aquatic Sciences), Adelaide. pp 1073-1091. =
=

Key features: =
Elongate body, short elytra exposin part of the = abdomen. Paired hooks on the distal end of each = leg. =

Figure A38. Stapylinidae, cf. *Cafius* sp. =

=
=

=

Order: Diptera
Family: Chironomidae (Non-biting midges) =
Larvae

Larvae have elongated, white, fleshy bodies with = sclerotized head capsules (Fig. A39a). A pair of = fleshy pro-legs with small hooks is present on the = 1st= segment after the head (Fig. A39b) and on the = final segment (Fig. A39c). Chironomids move with = a rapid coiling and uncoiling thrashing motion. = Chironomid larvae are detritivorous or herbivorous. = Occur in almost all wetlands. =

Davis,J. & Christidis, F. (1999). A Guide to Wetland = Invertebrates of Southwestern Australia. Western = Australian Museum, Perth =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =

Ingram, B. A., Hawking, J. H. & Shiel, R. J. (1997). = Aquatic Life in Freshwater Ponds. A Guide to the = Identification and Ecology of Life in Aquaculture = Ponds and Farm Dams in South Eastern Australia. = Co-operative Research Centre for Freshwater = Ecology, Albury, NSW. =

=

Key features of larvae:
Elongate, mostly without spines. Fleshy white body. = Sclerotised head capsule, non-retractile. A pair of = pro-legs on the 1st and last segments, equipped = with fine hooks.

Figure A39a. Chironomid larvae. =

Figure A39b. Anterior end of chironomid = larvae, showing sclerotised head and pro-= legs. =

Figure A39c. Posterior end of chironomid = larvae. =

=

=

Order: Diptera
Family: Dolichopodiae (Dollies) **Larvae**

=

Elongate, parallel sided. Head retractable into = thorax (Fig. A40). Welts on all segments. =
A very diverse and widely distributed family. The = larvae are commonly predatory and inhabit the = sediment of slow flowing water bodies. =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =

=

Key features of larvae:
Head capsule sclerotised and retractable. Short = projections on hind ends. =

=

Figure A40. Dolichopodiae larvae. =

=

=

Order: Diptera
Family: Stratiomyidae (soldier flies)
Larvae

Very simple body, no pro-legs. Fully formed, = unretractable head capsule. Hydrophobic hairs = around a spiracle on hind end (Fig. A41). Inhabit = still or slow moving water. Stratiomyids feed on = decaying organic matter and microalgae. =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =
=

Key features of larvae:
Body dorso-ventrally flattened, most segments = sclerotised. Posterior spiracle surrounded by = hydrophobic setae. =
=

Figure A41. Larvae of Stratiomyidae =
=

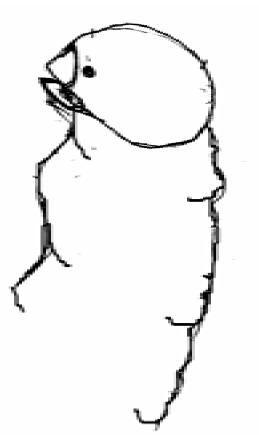
=
=

Order: Diptera
Family: Ceratopogonidae (biting midges, = sandflies) =
Larvae

Sclerotised head capsule, non retractable.. = Ceratopogonids differ from chironomids by lack the = prolegs. Occur in estuaries, streams or = disconnected water bodies. =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =
=

Key features of larvae:
Soft, segmented body, no pro-legs. One pair of eye = spots. Sclerotised head capsule, non retractable. &



= =
Figure A42. Sketch of anterior end of larva = of Ceratopogonidae. =

=

=

Order: Diptera
Family: Culicidae (Mosquitoes), **Larvae**

Mosquito larvae are elongate with the first three segments behind the head slightly wider than the abdomen. Most mosquito larvae are filter-feeding on microalgae, using bristles on the head for sweeping microalgae into the mouth. Some mosquito larvae are predatory, feeding on smaller larvae. All mosquito larvae are restricted to stagnant or slow moving water.

Davis,J. & Christidis, F. (1999). A Guide to Wetland Invertebrates of Southwestern Australia. Western Australian Museum, Perth

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Matthews, E. G., Queale, L. F.(1989). Chapter 22, Littoral insects (Phylum Arthropoda: Class Insecta), in, S.A., Shepherd and M. Davies, (eds), Marine invertebrates of Southern Australia Part III, South Australian Government printing division, Adelaide.

Key features of larvae:
Larvae with stiff erect hair (Fig. A43). Final segment sclerotised. Large bristle covered head. Breathing siphon at the posterior end. Move with a thrashing or wriggling motion and hang from water surface by siphon.

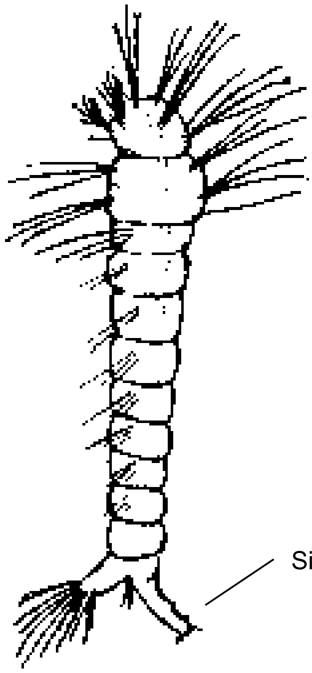


Figure A43. Sketch of Culicidae larvae.

Order: Diptera
Family: Empididae, Larvae
Empididae indet., sp. 1

Head inconspicuous and retractable (Fig. A46a). Larvae with 7-8 pairs of well-developed pro-legs. Posterior end with raised process (Fig. A 44b). Larvae feed by using rectractable sclerotised hook-like mouthparts, predatory. Hook covered prolegs facilitate occurrence in faster flowing waters.

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Ingram, B. A., Hawking, J. H. & Shiel, R. J. (1997). Aquatic Life in Freshwater Ponds. A Guide to the Identification and Ecology of Life in Aquaculture Ponds and Farm Dams in South Eastern Australia. Co-operative Research Centre for Freshwater Ecology, Albury, NSW.

Key features of larvae sp. 1:
Paired pro-legs on segments 1-7 and two pro legs on segment 8, all with hooks. Raise process with spicules on posterior end. Caterpillar like appearance.

Figure A44a. Empididae larvae (sp. 1), head on the right side.

Figure A44b. posterior end of empidid larva (sp. 1) with spicules on raised process

Order: Diptera
Family: Empididae (larvae)
Empididae indet., sp. 2

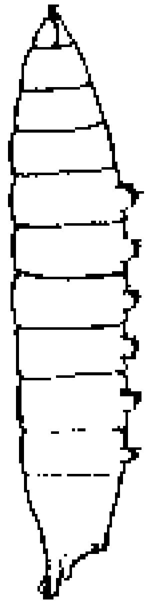
Head inconspicuous and retractable (Fig. A45). = Larvae with 7-8 pairs of well-developed pro-legs. = Posterior end with raised process. Larvae feed by = using rectractable sclerotised hooklike mouthparts, = predatory. Hook covered prolegs facilitate = occurrence in faster flowing waters. =

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =

Ingram, B. A., Hawking, J. H. & Shiel, R. J. (1997). = Aquatic Life in Freshwater Ponds. A Guide to the = Identification and Ecology of Life in Aquaculture = Ponds and Farm Dams in South Eastern Australia. = Co-operative Research Centre for Freshwater = Ecology, Albury, NSW. =

=

Key features of larvae sp. 2:
Paired pro-legs on segments 1-7, but no pro legs = on segment 8. Fleshy body with no lateral = projections. =



= =
Figure A45. Sketch of empidid larva, sp. 2. =

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=

=

Order: Diptera
Family: Tabanidae (March flies)**, Larvae**

Elongate, parallel sided, with tapering or rounded = ends. Larvae without pro-legs. Head retractable = into first segment and bearing two hooks. Welts on = all segments. In shallow, muddy aquatic = environments. =

=

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug = Book. CSIRO Publ. Collingwood. =

Ingram, B. A., Hawking, J. H. & Shiel, R. J. (1997). = Aquatic Life in Freshwater Ponds. A Guide to the = Identification and Ecology of Life in Aquaculture = Ponds and Farm Dams in South Eastern Australia. = Co-operative Research Centre for Freshwater = Ecology, Albury, NSW. =

=

Key features of larvae:
Larvae tapering at both ends. Segments with = welts. Simple hind end. Worm like appearance. =

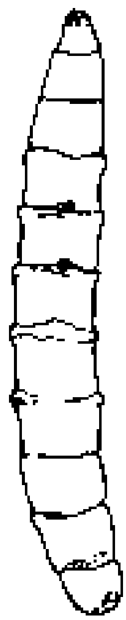

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Figure A46. Sketch of Tabanid larva. =

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=

=

Order: Odonata
Suborder: Zygoptera (Damselflies)
Family: cf. Coenagrionidae

Larvae
Zygoptera larvae are long and slender, with three posterior leaf-like gills (missing in specimen shown in Fig. A47a). All Odonata larvae are predators. The jaws are extensible (Fig. A47b) for catching other aquatic invertebrates. They typically occur in slow moving waters with aquatic vegetation.

Davis,J. & Christidis, F. (1999). A Guide to Wetland Invertebrates of Southwestern Australia. Western Australian Museum, Perth

Gooderham, J. & Tsyrlin, E. (2002). The Waterbug Book. CSIRO Publ. Collingwood.

Key features of larvae:
Long slender body with vertically held gills (missing in specimen shown in Fig. A47a). Extensible mouthparts: Labium kite-shaped. Movable hook of labial palps without setae.


Figure A47a. Zygoptera larvae. Terminal gills missing.


Figure A47b. Detail of extended jaw of Zygoptera larva.

Order: Thysanoptera
Family: Phlaeothripidae

Small (<1mm), slender, dorso-ventrally compressed with asymmetric sucking mouth-parts. Terrestrial, suck on plants. Wings narrow with fringe of long marginal setae or cilia. Adults disperse over long distances via winds.

Mound, L. A., Heming, B. S. (1991). Chapt. 31, Thysanoptera (Thrips), in, The Insects of Australia, pp. 510-515. Melbourne University Press.

Key features:
9 abdominal segments. 2 pairs of legs on 2nd segment. Hairs on marginal fringe of wings and abdomen (Fig. A48). Wings overlap on dorsum at rest.

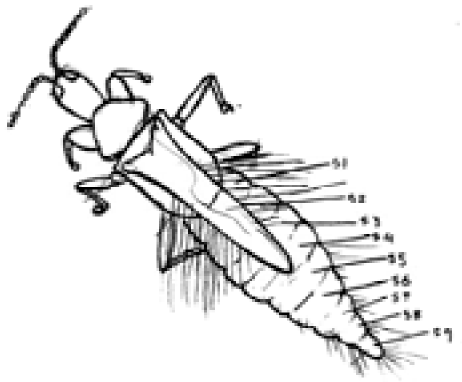
Figure A48. Sketch of Phlaeothripidae.

Table A3Ce: Macrofaunal abundances (individuals m^{-2}) and standard deviation (SD) for total macrobenthos recorded at the various sampling locations per site in June and December 2004. HT=High tide, near shoreline, or if one location sampled only as at the lake; MT=mid tidal level, interim between the shoreline and the water line, differentiated only in December, when mudflats were further exposed; LT=low tide level near the water line, samples partly taken up to 30 cm water depth. Sampling sites 1-7: Murray Mouth, 20-26: North Lagoon, 19-13: South Lagoon, 8-12: Lake Alexandrina.

	June			
	HT		LT	
site	mean	SD	mean	SD
1	873.02	1216.00	7579.37	9023.57
2	238.10	206.20	1309.52	1172.48
3	2658.73	2872.81	3015.87	655.66
4	2579.37	1338.07	51190.48	16373.27
5			24325.40	10142.36
6	51468.25	19867.17	22500.00	17943.84
7	38214.29	14348.57	45793.65	11866.80
20	56388.89	23630.98		
21	238.10	206.20	112182.54	80069.27
22	5238.10	7528.29	22698.41	4589.64
23	0	0	39.68	68.73
26	515.87	893.52	555.56	765.37
25	198.41	343.66	0	0
24	79.37	137.46	277.78	247.82
19	39.68	68.73	0	0
18	79.37	137.46	0	0
17	357.14	357.14	357.14	518.92
16	436.51	655.66	2380.95	2075.67
15	39.68	68.73	0	0
14	1785.71	2990.44	238.10	412.39
13	0	0		
8	1388.89	909.24		
9	2460.32	1192.46		
10	15158.73	19620.24		
11	1111.11	1440.10		
12	476.19	629.94		

	December					
	HT		MT		LT	
site	mean	SD	mean	SD	mean	SD
1	920.15	962.65	14962.39	2782.10	10561.69	5524.80
2	320.05	277.17	160.03	183.33	360.06	317.54
3	200.03	69.29	680.11	762.22	600.10	120.02
4	14263.88	3687.61	34046.53	23751.23	53404.65	44977.78
5					89319.07	21010.69
6	30820.17	22938.24			91696.38	35669.89
7	8914.93	12186.85			53659.36	46877.74
20	19782.65	29587.72	73102.39	31647.92	33791.82	4541.22
21	0	0	339.62	831.89	0	0
22	3396.162	3280.419			3056.55	2695.62
23	0	0	0	0	0	0
26	200.03	249.84			120.02	120.02
25	0	0			320.05	554.34
24	80.01	138.59			240.04	415.76
19	120.02	120.02			2040.33	1816.22
18	0	0			3640.58	5397.31
17	120.02	120.02			360.06	415.76
16	240.04	120.02			40.01	69.29
15	80.01	138.59			800.13	780.89
14	1880.30	868.24			40.01	69.29
13	3880.62	5148.72				
8	3080.49	2644.06				
9	880.14	604.08				
10	40.01	69.29				
11	10681.71	9196.17				
12	13762.20	6124.90				

Appendix 4: Literature Review of selected species

The template with criteria used for these preference curves was provided by the DEH. =

Information was sourced mainly from journal articles, identification manuals and previous studies = around the Coorong regions. Reference details are included in the reference list of the final report. =

Where information is not available either from the literature or from the Coorong area this is identified = by: N/A =

=

Symbols	
*	Data collected during the project around the Murray Mouth, Coorong and Lower Lakes in = June and December 2004. These data are presented as a range from lowest to highest = values from sites where the species was found (site numbers from the survey given in = brackets). The survey period from which the values originate is also indicated. =
**	Data collected from previous studies in same region, mainly Geddes and Buttler (1984). =
^	Water quality data collected by DEH. Not all sites sampled in the 2004 project were = represented in the water sampling surveys. = The range is provided with the site and season in brackets. =

=

=

Species: ***Capitella capitata (Polychaeta, Capitellidae)***

Coorong occurrences: Sites 1, 4-8, 15, 17, 20-22, 26 =

Description/taxonomic features: Resemble earthworms. Have a pointed or rounded head which = lacks appendages and a long cylindrical body. Parapodia are poorly developed. Often reddish in = colour and may be tightly coiled on the sieve (Hutchings 2000). =
Large differences in life history of sibling species (similar adult morphologies but distinct reproductive = modes). Several sibling species are known and each is ecophysiologically diverse in responses to = toxicant and environmental exposure, therefore genetic basis has to be considered when using = species as indicator. =
This species is typically found in disturbed or changeable environments such as estuaries or lagoons = where salinity is subject to sudden changes on a seasonal basis, and also under polluted conditions = where a normally diverse benthic community is absent. =
This species has been regarded as an excellent indicator of organic pollution or environmental = disturbance. =
(see Appendix A3B1 for photos/sketches and further key features) =

Confidence Rating: =

=

= **ABIOTIC REQUIREMENTS**

Parameters	Preference	Reference
Salinity tolerance =	**Coorong:** 0.74 ‰ (site 8-Summer) - 124.86 ‰ (site 17-= Winter) * = Salinities up to 82 ‰ ** = = **Literature:** From areas collected: 10.9 - 29.4 ‰	Henrikson 1969; = Geddes and Butler = 1984 =
Terrestrial/shoreline/ = inundated =	**Coorong:** Shoreline - Inundated * = = **Literature:** Shoreline - Inundated	Hutchings 2000 =
Water depth =	**Coorong:** Intertidal, low to high tide level * = = **Literature:** Estuaries to deep sea.	Grassle and Grassle = 1974; Hutchings 2000=
Turbidity (sunlight) =	**Coorong:** 0.4 (21-Winter) - 150 NTU (20-Winter/Spring) ^ = = **Literature:** Known from parts of estuaries where the = greatest mixing and heavy sedimentation occurs.	Grassle and Grassle = 1974 =
Flow =	**Coorong:** N/A = **Literature:** N/A	=
Temperature =	**Coorong:** 13.3 ºC (site 7-Winter) - 28.6 ºC (site 26-= Summer) * = = **Literature:** Has been cultured at 17 °C and found in the = field at 20-23 ºC.Temperature shown to affect maturity = range.	Mendez *et al.* 1997; = Shull 1997 =
pH =	**Coorong:** 7.0 (site 21-Winter) - 10.1 (site 15-Summer) ^ = = **Literature:** From sediments 7.2 - 8.2	Henrikson 1969 =

=

DO	**Coorong:** 2.66 mg L^{-1} (site 21-Summer) - 33 mg L^{-1} (site 1 Summer) * **Literature:** O_2 uptake shown to decrease with decrease in ambient O_2 tension. Species is known from areas of normal disturbance such as basins following a period of oxygen depletion - well adapted to exploit low O_2 periods. 28-day tolerance limit to decreased dissolved O_2: 1.5 - 3.2 mg L^{-1}. From locations species collected: 10-76 % saturation. When exposed to O_2 concentrations below approximately 9% saturation, they ceased feeding and became quiescent. Higher O_2 concentration caused a decreased growth rate.	Henrikson 1969; Reish 1970; Grassle and Grassle 1974; Forbes *et al.* 1994; Linke-Gamenick *et al.* 2000
Recruitment requirements	**Coorong:** N/A **Literature:** Growth rate related to food quality: diet type influences no. of eggs, no. of spawns, age of sexual maturity and life-time fecundity of planktotrophic larvae. Variation also determined by genetics and environments. Disturbances can negatively affect recruitment and this is more pronounced in muddy environments. Small-scale geochemical processes affect recruitment decisions. Juvenile mortality on mudflats is high. Predicted lifespan between 3.3 and 4.3 months. Sibling species vary in reproductive modes. High growth rates in nitrogen-rich environments. Population size is controlled both by density dependent and density independent causes.	Grassle and Grassle 1974, 1976; Qian and Chia 1992; Mendez *et al.* 1997; Hutchings 2000; Mendez *et al.* 2000; Marinelli and Woodin 2004
Substrate type	**Coorong:** Mean median particle size (Φ) at sites found: 1.09 (site 15-Summer) - 3.04 (site 8-Summer); very fine sand to medium sand, very well sorted to poorly sorted. * Mean organic matter (% AFDW) at sites found: 0.65 (site 22-Summer) - 8.22 (site 4-Summer). * **Literature:** Lives in mucus-lined burrows or tubes comprising detritus and mud in fine sand/mud sediments, often associated with seagrass beds. Builds tubes at or near the surface of the sediment which allows worms to feed in black anoxic muds. Particle size and composition may be important environmental parameters for less opportunistic species. Often associated with organically enriched environments - preference for solute rich muds relative to clean sands.	Grassle and Grassle 1974; Fauchald and Jumars 1979; Hutchings 2000; Linke-Gamenick *et al.* 2000; Marinelli and Woodin 2004

BIOTIC REQUIREMENTS

Parameters	Preference	Reference
Food	**Coorong:** N/A **Literature:** Non-selective motile deposit feeders. Opportunistic species. Feed on algae and dissolved primary amines from surrounding waters. Can be fed on a diet of *Enteromorpha* sp. In laboratory. Feed rapidly at higher food and oxygen levels.	Reish 1970; Fauchald and Jumars 1979; Forbes *et al.* 1994; Hutchings 2000.
Biotic interactions/ competition	**Coorong:** N/A **Literature:** Predation major factor affecting recruitment and population dynamics. Can rapidly colonise new habitats	Mendez *et al.* 1997; Hutchings 2000

Species: ***Simplisetia aequisetis*** **(Polychaeta, Nereididae)**
(formerly *Ceratonereis pseudoerythraeensis)*
=

Coorong occurrences: Sites 1-7, 16, 20-22 =

Description/taxonomic features: Elongate with numerous segments; 5-7 cm in length; 2 pairs of = unequal sized eyes; short stout palps and antennae; no paragnaths on lower ring of eversible = pharynx with one pair of jaws and usually accessory papillae or denticles in a regular pattern = (Hutchings 1984; Wilson 2000).
Common, widespread benthic polychaete; found in wide range of marine habitats. Seagrass beds, = muddy to fine sediments. Wide geographic and ecological distribution. Occurs widely throughout = estuarine and shallow protected coastal waters in Southern Australia. Western Australia, South = Australia, Victoria, New South Wales, Queensland. =
(see Appendix A3B1 for photos/sketches and further key features)

Confidence Rating: =

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ABIOTIC REQUIREMENTS

Parameters	Preference	Reference
Salinity tolerance =	**Coorong:** 21.52 ‰ (site 2-Summer) – 40.61 ‰ (site 21-= Summer) * = Salinites up to 72 ‰ ** = = **Literature:** 9.9 - 35 ‰	Geddes and Butler = 1984; Hutchings and = Murray 1984; = Hutchings and = Glasby 1985 =
Terrestrial/shoreline/ = inundated =	**Coorong:** Intertidal * = = **Literature:** N/A	=
Water depth =	**Coorong:** Intertidal, low to high tidal level* = = **Literature:** Low to deep waters	Hutchings 1984 =
Turbidity (sunlight) =	**Coorong:** 0.4 NTU (site 21-Winter) - 150 NTU (site 20-= Winter/Spring) ^ = = **Literature:** N/A	=
Flow =	**Coorong:** N/A = = **Literature:** N/A	=
Temperature =	**Coorong:** 13.3 ºC (site 7-Winter) - 27.2 ºC (site 4-= Summer)*^= = ***Literature:** N/A	=
pH =	**Coorong:** 7.0 (site 21-Winter) - 8.7 (site 20-Spring) ^ = = **Literature:** N/A	=
DO =	**Coorong:** 3.11 mg L^{-1} (site 2-Summer) - 33 mg L^{-1} (site 1 = Summer)*= = **Literature:** N/A	=
Recruitment = requirements =	**Coorong:** N/A; Juveniles observed in burrow lining of = adult = = **Literature:** Separate sexes, adults die after spawning. = Complete life cycle in 1-1.5 years. Environmental factors = (temperature, lunar cycle, secondarily day length and = salinity) and endogenous factors (neurosecretory = hormones and release of sexual pheremones into the = water) are responsible for the timing and synchrony of = reproduction. Reproductive patterns vary according to = habitat.	Wilson 2000b =

=

Substrate type	**Coorong:** Mean median particle size (Φ) at sites found: 0.67 (site 16-Winter) - 2.68 (site 1-Summer); Fine - coarse sand, poorly sorted - very well sorted. * Mean organic matter (% AFDW) at sites found: 0.97 (site 7-Summer) - 8.22 (site 4-Summer). * **Literature:** Muddy sand often associated with seagrass beds. Changes in organic content may be important for the species as it is a deposit feeder.	Hutchings and Turvey 1982; Kent and Day 1983

BIOTIC REQUIREMENTS

Parameters	Preference	Reference
Food	**Coorong:** N/A **Literature:** Surface deposit-feeder and herbivore. Scavenge on plant matter and other worms. Scavenges on dead microcrustaceans and selective deposit-feeding, avoid ingesting finest mud-silt particles.	Fauchald and Jumars 1979; Kent and Day 1983; Wilson 2000b
Biotic interactions/ competition	**Coorong:** N/A **Literature:** Preferred prey of greenback flounder and wading birds. Predation probably significant influence on size structure of population. Under pressure from bait collectors. Reduced adult density leads to increased recruitment of juveniles.	Kent and Day 1983; Wilson 2000b

Species: ***Nephtys australiensis (Polychaeta, Nephtyidae)***
=
Coorong occurrences: Sites 1-3, 6-7, 20 =

Description/taxonomic features: Long slender bodies, quadrangular in cross-section; one pair of = antennae and one pair of short palps present; eversible pharynx; distinguished by presence of inter-= ramal branchia attached to the ventral notopodial margin (Hutchings 1984; Wilson 2000a).
Most common and endemic estuarine species in south-east Australia. Family taxonomically well = known in Australia. Found in a wide range of environments: intertidal sediments to deep sea, shelf = and inshore depths. In Australia mainly found in muddy and sandy sediments. No studies on biology = of Nephtyidae in Australia (Wilson 2000a). Occurrence is rare with few specimens collected and no = seasonal preference shown (Hutchings and Murray 1984). =
(see Appendix A3B1 for photos/sketches and further key features)

Confidence Rating: =
=
= **ABIOTIC REQUIREMENTS**

Parameters	Preference	Reference
Salinity tolerance =	**Coorong:** 21.52 ‰ (site 2-Summer) - 34.88 ‰ (site 7-= Summer) * = Salinities up to 64‰ ** = = **Literature:** 5-39‰	Geddes and Butler = 1984; Hutchings and = Murray 1984; King *et al*. 2004 =
Terrestrial/shoreline/ = inundated =	**Coorong:** Shoreline - inundated * = = **Literature:** Shoreline - inundated	King *et al*. 2004; = Wilson 2000a =
Water depth =	**Coorong:** Intertidal, low to high tide level = = **Literature:** Shallow water habitats.	Wilson 2000a =
Turbidity (sunlight) =	**Coorong:** 2.0 NTU (site 20-Winter) - 150 NTU (site 20-= Winter/Spring) ^ = = **Literature:** N/A	=
Flow =	**Coorong:** N/A = = **Literature:** N/A	=
Temperature =	**Coorong:** 13.3 ºC (site 7-Winter) - 24.2 ºC (site 2-= Summer) * = = ***Literature:** Laboratory conditions 20 ºC - 21.3 ºC	King *et al*. 2004 =
pH =	**Coorong:** 7.5 (site 20-Summer) - 8.7 (site 20-Spring) ^ = = **Literature:** during water and whole-sediment tests pH = ranged from 7.8-8.20	King *et al.* 2004 =
DO =	**Coorong:** 2.52 mg L^{-1} (site 3-Summer) - 33.00 mg L^{-1} (site = 1-Summer) * = = **Literature:** Mortality severe under hypoxia. = During water and whole-sediment tests survival at >90 % = saturation	Wilson 2000a =
Recruitment = requirements =	**Coorong:** N/A = = **Literature:** Separated sexes, fertilisation of gametes = occurs in water column and larvae are planktonic. = Reproductive success in European species varies = according to seasonal conditions and geography, but no = studies of reproductive biology in Nephtytidae from = Australia.	Wilson 2000a; Olive = and Morgan 1991 =

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Substrate type	**Coorong:** Mean median particle size (Φ) at sites found: 1.69 (site 3-Winter) - 2.68 (site 1-Summer); fine sand to medium sand, very well sorted to moderately well sorted.* Mean organic matter (% AFDW) at sites found: 0.97 (site 7-Summer) - 4.14 (site 1-Winter).* **Literature:** Burrows to depths of ~200 mm, but no permanent tubes. High tolerance to full range of sediment particle sizes (100 % silt to 100 % sand). Nephtyids very common in sandy mud.	Hutchings 1984; Wilson 2000a; King *et al*. 2004
	BIOTIC REQUIREMENTS	
Parameters	**Preference**	**Reference**
Food	**Coorong:** N/A **Literature:** Nephtyids usually considered vagile carnivores, feeding on small molluscs, crustaceans and other polychaetes. Also deposit-feeding in subsurface sediment layer when prey items are scarce.	Fauchald and Jumars 1979; Wilson 2000a; King *et al*. 2004
Biotic interactions/ competition	**Coorong:** N/A **Literature:** Seek other motile invertebrates, molluscs, crustaceans	Wilson 2000a

Species: *Ficopomatus enigmaticus* (Polychaeta, Serpulidae) =

=

Coorong occurrences: Site 1 (species not included in benthic surveys but were observed) =

Description/taxonomic features: Recognised by characteristic tentacular crown and presence of = calcareous tube. Marked thoracic and abdominal regions, have a pair of excretory nephridia with a = single exit (Rouse 2000).
Introduced fan-worm. World-wide distribution in temperate and tropical estuaries; and nearly always = associated with hard substrata, usually rocks. =
Size range 2 mm to >100 mm in length, housed in tube several times longer than the worm.

Confidence Rating: =

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= **ABIOTIC REQUIREMENTS**

Parameters	Preference	Reference
Salinity tolerance =	**Coorong:** 25.75 ‰ (site 1-Summer) - 30.24 ‰ (site 1-= Winter) * = Salinities up to 67‰, newly settled solitary individuals at = higher salinites.** = = **Literature:** Winter/Spring bottom salinites 0-30 ‰; = Summer/Autumn 10-34 ‰. = 1.5 - 50 ‰ = Able to survive in variable salinity and long periods in = freshwater.	Thorp 1987; Geddes = and Butler 1984; = Davies *et al*. 1989; = Thomas and Thorp = 1994 =
Terrestrial/shoreline/ = inundated =	**Coorong:** Shoreline - Inundated * = = **Literature:** Inundated	Davies *et al.* 1989 =
Water depth =	**Coorong:** Intertidal - Subtidal * = = **Literature:** Sublittoral	Davies *et al.* 1989 =
Turbidity (sunlight) =	**Coorong:** N/A = = **Literature:** Preferable habitat brackish waters.	=
Flow =	**Coorong:** N/A = = **Literature:** N/A	=
Temperature =	**Coorong:** 14.9 °C (site 1-Winter)- 22.8 °C (site 1-Summer) = = ***Literature:** Range of bottom waters (England lagoons) = May/October 5.5 - 30 °C; Nov/April 1-20 °C.Range 12-28 = °C	Davies *et al*. 1989; = Thorp 1994 =
pH =	**Coorong:** N/A = = **Literature:** N/A	=
DO =	**Coorong:** 10.64 mg L^{-1} (site 1-Winter) - 33.00 mg L^{-1} (site = 1-Summer) * = = **Literature:** N/A	=

=

Recruitment requirements	**Coorong:** N/A **Literature:** Minimum temperature of 18 ^{o}C for reproduction/spawning. Later stages of gametogenesis require increase in water temperature. Asexual and sexual reproduction. Fertilisation external, either freely in the water or the water of the tube. Larval development planktotrophic or lecithotrophic. Larval settlement require minimum of 11 ^{o}C. Development time 20-25 days. Larval settlement (England) - May; water temperatures >10 ^{o}C initiate spawning by influx of higher salinity water (spring tides). High phytoplankton levels favoured for settlement. Settlement intensity exhibits lunar/tidal periodicity. Settling larvae attracted by old tubes.	Dixon 1981; Thorp 1987; Davies *et al*. 1989; Thorp 1994; Rouse 2000; Kupriyanova *et al*. 2001
Substrate type	**Coorong:** Mean median particle size (Φ) at site observed: 2.42 (site 1-Winter)- 2.68 (site 1-Summer); fine sand, very well to well sorted.* Mean organic matter (% AFDW) at site observed: 2.2 (site 1-Summer) - 4.14 (site 1-Winter). * **Literature:** Preferred particle size range 2-16 µm. Substratum composed of silty muds (median 0.022 mm - 0.047 mm). High levels of organic matter 9 % - 16 %. Clearance and ingestion rates appear to increase with particle concentration.	Davies *et al*. 1989; Thorp 1994; Thomas and Thorp 1994; Rouse 2000

BIOTIC REQUIREMENTS

Parameters	Preference	Reference
Food	**Coorong:** N/A **Literature:** Filter feeder using tentacular crown. Feed on phytoplankton and may also feed on pelagic diatoms, dinoflagellates, and other unicellular lage, as well as small invertebrates including larvae.	Fauchald and Jumars 1979; Thorp 1994; Rouse 2000
Biotic interactions/ competition	**Coorong:** N/A **Literature:** Serpulids are parasitised by copepods and a variety of unicellular organisms. Most common occurring species in south England lagoon, tubicolous amphipods. Fluctuations in associated species related to ability of *F. enigmaticus* to prevent deposition and accumulation of sediment and organic material. Little competition from other serpulids.	Thomas and Thorp 1994; Rouse 2000

Species: ***Salinator fragilis*** **(Gastropoda, Amphiphibolidae)** =

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Coorong occurences: Sites 1, 2, 6, 20, 21 and 25. =

Description/taxonomic features: Thin globose shell with narrow brown band around periphery. = Large aperture on right. Operculum: present, has a nucleus and yellowish colour. Depressed spire = and an inflated last whorl. Shell height usually less than 30 mm, and shell sculpture varies from fine = to coarse. (Stanisic 1998). =
Restricted to estuaries and coastal lagoons. On sand/mud flats amongst mangroves and in salt = marsh, usually in standing water. Little known about life histories of Australian pulmonates and on = longevity. Endemic to Australia. Australian distribution: All states. Often abundant =
(see Appendix A3B3 for photos and further key features)

Confidence Rating: =

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= **ABIOTIC REQUIREMENTS**

Parameters	Preference	Reference
Salinity tolerance =	**Coorong:** 21.52 ‰ (site 2-Summer) – 32.23 ‰ (site 21-= Summer) * = Salinites up to 74 ‰ ** = = **Literature:** 41 ‰ - 44 ‰ = Oyster Harbour (WA) 2-37 ‰ near river mouth, 53 ‰ = further in estuary. At low salinity levels only survive for two = weeks. Annual salinity range of Oyster harbour 35-37 ‰.	Smythe 1975; Wells = & Threlfall 1980; = Geddes and Butler = 1984 =
Terrestrial/shoreline/ = inundated =	**Coorong:** Found on top of substratum on shoreline. * = = **Literature:** Live partially buried in substratum and can = withstand brackish water.	Stanisic 1998 =
Water depth =	**Coorong:** Intertidal, mid to upper tidal levels * = = **Literature:** Upper to mid littoral. = Size structure of *Salinator solida* found to vary with height = on shore, indicative of differences in population = demographics (growth, mortality and age strucuture). = Oyster Harbour (WA) population centered in mid-tide = region	Wells & Threlfall = 1980; Roach & Lim = 2000 =
Turbidity (sunlight) =	**Coorong:** 0.4 NTU (site 21-Winter) - 150 NTU (site 20-= Winter/Spring) ^ = = **Literature:** Preference for sunlight- more active	Smythe 1975 =
Flow =	**Coorong:** N/A = = **Literature:** N/A	=
Temperature =	**Coorong:** 14.5 ºC (site 2-Winter) – 25.3 ºC (site 6-= Summer) * = = **Literature:** Average temperature of 20 ºC lived for 8 = weeks.	Smythe 1975 =
pH =	**Coorong:** 7.0 (site 21-Winter) - 8.7 (site 20-Spring) ^ = = **Literature:** N/A	=
DO =	**Coorong:** 2.66 mg L^{-1} (site 21-Summer) - 33 mg L^{-1} (site 1 = Summer) * = = **Literature:** N/A	=

=

Recruitment requirements	**Coorong:** N/A **Literature:** Hermaphrodites. Lays egg strings on the surface of mud which become covered with fine coating of silt. 14-16 days to hatch. Peaks in egg masses seen in *S. solida* restricted to particular breeding season.	Smyhte 1975; Stanisic 1998; Roach & Lim 2000
Substrate type	**Coorong:** Median particle size: Mean median particle size (Φ) at sites found: 1.59 (site 25-Winter) - 2.68 (site 1-Summer); fine to medium sand; very well sorted - moderately well sorted. * Mean organic matter (% AFDW) at sites found: 1.26 (site 20-Winter) - 4.14 (site 1-Winter). * **Literature:** Mud, appropriate particle size and organic content is essential. Mean particle diameter (Φ) of Oyster Harbour (WA) 1.8 - 2.0	Smythe 1975; Wells and Threlfall 1980
	BIOTIC REQUIREMENTS	
Parameters	**Preference**	**Reference**
Food	**Coorong:** N/A **Literature:** Observed to feed on *Enteromorpha* sp. (algae)	Smythe 1975
Biotic interactions/ competition	**Coorong:** N/A **Literature:** N/A	

Species: ***Arthritica helmsi*** **(Bivalvia, Galeommatidae)**
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Coorong occurrences: Sites 1-8, 16, 20-21, 25 =

Description/Taxonomic features: Micromollusc. Shell: outline oval; or broadly triangular. White = shell with purplish flames and punctuate microscultpture. Opaque; uniform colour, or radial stripes or = rays; or simple flecks or spots; or complex (e.g. zig-zag). (Lamprell and Healy 1998; Ponder 1998). = Endemic to Australia. Australian distribution: NSW and southern Australia to south Western Australia. = Restricted to estuaries and coastal lagoons. Wide dispersal gradient. Shallow burrower, or crawling = on sediment, on mud/sand, seagrass beds and the lower edge of mangroves. Very common, = sometimes abundant. =
(see Appendix A3B3 for photos and further key features) =

Confidence Rating:

= **ABIOTIC REQUIREMENTS**

Parameters	Preference	Reference
Salinity tolerance =	**Coorong:** 0.74 ‰ (site 8-summer) – 73.69 ‰ (site 26-= Summer) * = = **Literature:** Winter 15-40 ‰; Summer 25-55 ‰. = Salinity range of Peel-Harvey estuarine system 2-53 ‰ = with annual salinity range of Oyster harbour 35-37 ‰. = Burrowing activity ceased at 15 ‰ but shown to survive = salinities <10 ‰ = Unstable with large daily or seasonal ranges in salinity; = increased mortality during conditions of increased salinity. = Densities can be high at low salinity levels.	Wells and Threlfall = 1981;Wells and = Threlfall 1982b; Wells = and Threlfall 1982c; = Ponder 1998; = Semeniuk and Wurm = 2000 =
Terrestrial/shoreline/ = inundated =	**Coorong:** Intertidal * = = **Literature:** Intertidal - subtidal	Ponder 1998 =
Water depth =	**Coorong:** Intertidal, low to high tide levels. * = = **Literature:** Densities increase with depth. = Oyster Harbour, WA - maximum density in upper tidal = levels above 0.65 m, decreasing below that level; did not = occur below 0.50 m. = Peel Inlet - does not extend beyond mid-tide region.	Wells and Threlfall = 1980; Ponder 1998 =
Turbidity (sunlight) =	**Coorong:** 0.4 NTU (site 21-Winter) - 150 NTU (site 20-= Winter/Spring) ^ = = **Literature:** N/A	=
Flow =	**Coorong:** N/A = = **Literature:** Grow best in relatively rapid currents, this = renews water masses rapidly and mixes surface waters = into benthic boundary layer thus renewing food sources.	Ponder 1998 =
Temperature =	**Coorong:** 13.3 ºC (site 7-Winter) – 28.6 ºC (site 26-= Summer) * = = **Literature:** most active 18-32 ºC; observed activity down = to 8 ºC. = Range of Peel-Harvey estuarine system 10-27 °C. = Increased mortality during conditions of increased = temperature; median lethal temperature of 37 oC = Substantial loses shown in summer, November 45 491 = ind. m^{-2} dropped to 4893 ind. m^{-2} in January.	Wells and Threlfall = 1981; Wells and = Threlfall 1982b; = Semeniuk and Wurm = 2000 =
pH =	**Coorong:** 7.0 (site 21-Winter) - 8.7 (site 20-Spring) ^ = = **Literature:** N/A	=

=

DO	**Coorong:** 2.52 mg L^{-1} (site 3-Summer) - 33 mg L^{-1} (site 1 Summer)* **Literature:** Leschenault Inlet estuary concentrations were generally >5 mg L^{-1}	Semeniuk and Wurm 2000
Recruitment requirements	**Coorong:** N/A **Literature:** Hermaphroditic; broods young in mantle cavity; young released directly onto substratum as shelled pediveligers; fecundity low but breeding continues throughout most of the year. Short maturation time, rapid growth rates. High population turnover. Able to exploit rapidly favourable periods. Peak during summer months. Maturity in 6 months with largest size reached in nine months, lifespan ~1.1 years	Wells and Threlfall 1981; Wells and Threlfall 1982a; Wells and Threlfall 1982c; Ponder 1998
Substrate type	**Coorong:** Mean median partical size (Φ) at sites found: 1.59 (site 25-Winter) - 3.04 (site 8-Summer);very fine sand to coarse sand, very well sorted - poorly sorted. * Mean organic matter (% AFDW) at sites found: 0.97 (site 7-Summer) - 8.22 (site 4-Summer). * **Literature:** Inhibited from fine sediments. Inhabit muddy sediments, allows to ingest sediments, detritus and associated microbes located on or in substratum. Mean particle diameter (Φ) of Oyster Harbour 1.8 - 2.0 / Peel Inlet 1.1 - 1.4	Wells and Threlfall 1980; Ponder 1998; Semeniuk and Wurm 2000

BIOTIC REQUIREMENTS

Parameters	Preference	Reference
Food	**Coorong:** N/A **Literature:** Plant detritus, bacteria and algal cells. Able to directly absorb dissolved organic matter.	Ponder 1998
Biotic interactions/ competition	**Coorong:** N/A **Literature:** Diet of many predatory organisms. Consumption of settling larvae can decimate new cohorts of soft-sediment molluscs. Lives in association with many species of invertebrates. Major food source for wading birds especially sandpipers, also food source for some fish species.	Wells and Threlfall 1982c; Ponder 1998

Species: ***Tanytarsus barbitarsus (Insecta,*** **Chironomidae*)***
=
Coorong Occurrences: Larvae found at sites 1, 4, 6-12, 14-20, 22, 26 =

Description/taxonomic features: Halobiontic species, medium to large blackish species. Male has = well developed foretarsal beard; mid and hind tibial combs greatly reduced; thorax of female paler = with no fortarsal beard, abdomen blackish to dark brown (Glover 1973).
Worlwide distribution. Occupy a range of habitats; abundant in samphire swamps, mangroves and = saline channels. Large habitat range Western Australia to Victoria; in South Australia: mid-north, = Adelaide plains, Mt Lofty Ranges and Murray River. =
Species can tolerate a wide range of environmental conditions. (See Appendix A3B4 for = photos/sketches and further key features) =

Confidence Rating:

=

ABIOTIC REQUIREMENTS

Parameters	Preference	Reference
Salinity tolerance =	**Coorong:** 0.70 ‰ (site 10-Winter) - 124.86 ‰ (site 17-= Winter) * = = **Literature:** Collected at ranges of 5.1 - 56 g L^{-1} (Red Rock = Lakes, Victoria). Other Australian locations found at = ranges of 2.4 - 177 g L^{-1} to saturated levels. = Adapted to hypersaline conditions, unlike their main = predators (berossus beetles and fish). Seems confined to = saline waters from which potential competitors are = physiologically excluded. = LC_{50} at 89 ± 5 g L^{-1}=	Paterson and Walker = 1974; Kokkin 1986; = Shepherd and Davies = 1997 =
Terrestrial/shoreline/ = inundated =	**Coorong:** Intertidal - inundated * = = **Literature:** Requires extended period of inundation to = build up population to significant levels.	Kokkin 1986 =
Water depth =	**Coorong:** Intertidal, low to high tide level = = **Literature:** Live on or in substrate with majority occupying = the top 5 cm of sediment.	Ingram *et al*. 1997 =
Turbidity (sunlight) =	**Coorong:** 1.0 NTU (site 15-Summer) - 150 NTU (site 20-= Winter/Spring) ^ = = **Literature:** N/A	=
Flow =	**Coorong:** N/A = = **Literature:** N/A	=
Temperature =	**Coorong:** 12.4 ºC (site 26-Winter) - 34 ºC (site 19-= Summer)*= = **Literature:** Many chironomid species complete = development between 0 ºC and 32 ºC. = Requires high summer temperatures to build up = population to significant levels.	Oliver 1971; Kokkin = 1986 =
pH =	**Coorong:** 7.5 (sites 14 and 20 Summer/Autumn) - 10.1 = (site 15-Summer) ^ = = **Literature:** Chironomids 6.0 - 8.0	Oliver 1971 =

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DO	**Coorong:** 2.89 mg L^{-1} (site 12-Summer) - 33 mg L^{-1} (site 1 Summer) * **Literature:** Many chironomid species are able to tolerate very low O_2 conditions. When O_2 concentration in mud-water interface is depleted, some chironomid larvae leave the bottom and are carried about by water current and return to the bottom when O_2 supply is restored.	Oliver 1971
Recruitment requirements	**Coorong:** N/A **Literature:** Female deposits eggs either on water surface or on semi-submerged vegetation. Larvae inhabit all types of aquatic habitats including permanent and temporary, fresh and saline, standing and flowing waters. Larvae recorded in water with dissolved salts in excess of 90 000 mg L^{-1}. Also found in range of 20-170 g L^{-1}. Duration of larval stage dependent on environmental conditions, with water temperature an important factor. Development of chironomids influenced by temperature, photoperiod, amount and quality of food present and competition with other animals. Adult stage lasts several weeks, where reproductive aspects are carried out.	Oliver 1971; Glover 1973; Kokkin 1986; Ingram *et al*. 1997; Davis and Christidis 1999
Substrate type	**Coorong:** Mean median particle size (Φ) at sites found: 0.67 (site 16-Winter) - 4.3 (site 12-Summer); very fine sand to very coarse sand, very well sorted to poorly sorted. * Mean organic matter (% AFDW) at sites found: 0.13 (site 10-Winter) - 55.38 (site 9-Winter). * **Literature:** Many chironomid species live in close association with some type of substrate. Many chironomid species live in silken tubes incorporating fine particles constructed by the larvae,while others are free-living.	Oliver 1971

BIOTIC REQUIREMENTS

Parameters	Preference	Reference
Food	**Coorong:** N/A **Literature:** Newly hatched larvae feed on suspended algae and detritus. Most chironominae are algal or algal-detrital feeders, with the algal feeders mainly feeding on diatoms. Distributed in highly productive waters and reaches great numbers (e.g. 200 000 ind. m^{-2}) in eutrophic systems, indicating a high need for high food levels.	Oliver 1971; Kokkin 1986
Biotic interactions/ competition	**Coorong:** N/A **Literature:** Chironomids are prey for fish, aquatic insects, crustaceans and water birds.	Ingram *et al*. 1997