Benthic Macroinvertebrate survey 2013-14:

Lower Lakes, Coorong and Murray Mouth Icon Site

Report for the
Department of Environment, Water and Natural Resources
and the Murray-Darling Basin Authority

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Cover Image: Amphipods crawling out of the sediment sample at Mulbin Yerrok, North Lagoon, December 2013.

Contents

Appendices provided electronically

The following Word and Excel data files were supplied:

Appendix 1 Sampling sites, dates and coordinates

Appendix 2 Environmental parameters 2013-2014

Appendix 3 Murray Mouth and Coorong Sediment Characteristics 2013-2014

Appendix 4 Murray Mouth and Coorong Species Diversity 2013-2014

Appendix 5 Murray Mouth and Coorong 2013-14 macroinvertebrate abundance

Appendix 6 Murray Mouth and Coorong Biomass_2013-2014

Appendix 7 Lower Lakes Sediment Characteristics_2013-2014

Appendix 8 Lower Lakes Species Diversity_2013-2014

Appendix 9 Lower Lakes Abundance 2013-2014

Appendix 10 Lower Lakes Biomass_2013-2014

Appendix 11 Guide to Mollusca found

1. Executive summary

- The Living Murray (TLM) Condition Monitoring Program provides an annual assessment of key targets for the ecological health of the Lower Lakes, Murray Mouth and Coorong Icon Site. Macroinvertebrates are a key component in this Ramsar listed wetland system, providing the major source of food for migratory shorebirds. This report presents findings from the 10th year of monitoring benthic macroinvertebrates in the Murray Mouth and Coorong, and the six years of more continuous sampling in the Lower Lakes, addressing in particular the condition monitoring target I-1 "*Maintain or improve invertebrate populations in mudflats*".
- As benthic macroinvertebrates respond to environmental changes, a number of sediment and water quality parameters were assessed together with measurements for diversity, abundance and biomass of macroinvertebrates, to identify whether and how these habitat attributes have changed and affected benthic communities. The report is thus addressing the TLM condition monitoring targets M-1 – '*Facilitate frequent changes in exposure and submergence of mudflats*', M-2 – '*Maintain sediment size range in mudflats*', and M-3 – '*Maintain organic content for mudflats*' as well, and also contributes to W-1 – '*Assessment of estuarine conditions between Goolwa Barrage and Pelican Point*'.
- Sampling for macroinvertebrates and mudflats in the summer 2013/14 survey followed procedures from previous years and as described in the LLCMM Condition Monitoring Plan (Maunsell 2009). In the Murray Mouth and Coorong, samples were taken at 11 sites in late November/early December 2013. The Lower Lakes (15 sites) were sampled in January/February 2014 when water levels had dropped slightly for easier access. The Ekman grab had to be used at three lake sites, whereas all other samples were taken with a hand-held PVC corer. The volume of water released over the barrages during this summer 2013/14 monitoring period was less than in the previous three summers.
- Data from this monitoring show that in this fourth year since flow was restored in late 2010, macroinvertebrate populations in the Murray Mouth and northern parts of the North Lagoon of the Coorong are recovering. Species numbers, diversity, abundances and biomass have increased since the drought years, and were more similar to pre-drought monitoring years. For example, the micro-mollusc *Arthritica helmsi*, which was common before the drought, was recorded again from several mudflats. Other macroinvertebrate species had a wider distribution range as well. The vertical distribution of macroinvertebrates had also improved in the Murray Mouth and Coorong, with more species and higher abundances in the deeper sediment layers at several sites, thus providing food for shorebirds with longer bills. Based on abundance and biomass data, food availability for shorebirds was one of the highest since this monitoring began. At the three South Lagoon sites, specimens from several macroinvertebrate species were encountered for the first time in the samples, yet in very low numbers. Overall, the findings showed no uniform recovery, with some species specific response patterns. The community trajectories were also not indicating a return to the initial conditions before the drought, but possibly a development into a new direction.
- In the Lower Lakes, the monitoring target I-1 was not met, as no improvements in macroinvertebrate populations were detected. Amphipods, chironomid larvae and oligochaetes occurred at most sites and accounted for most of the individuals encountered, but abundances were very low and had not increased over previous years. Insect larvae made up most of the species found in the sediments. Apart from Milang, species numbers were low at the sampling sites. Site specific variation in diversity, abundance and biomass occurred with no discernible pattern over the sites, regions or survey years. There were no defined macroinvertebrate communities in the Lower Lakes.
- Assessments of habitat conditions of the mudflats showed that the sediment size ranges and organic matter contents of previous years were maintained in the recent survey for sites in the

Murray Mouth, Coorong and Lower Lakes. Microphytobenthic biomass (Chl-*a*) was low in the Murray Mouth and Coorong. The Murray Mouth, North and South Lagoon provided different habitats for macroinvertebrates, with the Coorong being more saline and sediment having higher organic matter contents. Conditions at Villa de Yumpa were distinct from other sites at the time of sampling in early December 2013. Around the Lower Lakes, environmental variables measured showed very high site specific variation, irrespective of regions. Salinity, sediment organic matter and Chl-*a* explained most of the patterns of macroinvertebrate communities in the Murray Mouth and Coorong, while variation in the macroinvertebrate communities in the Lower Lakes could not be explained by the measured environmental variables.

- Assessing estuarine conditions showed that salinities continued to be low in the Murray Mouth and Mulbin Yerrok in the North Lagoon, similar to previous records since flow resumed. The conditions in the Murray Mouth can be described as oligo- or mesohaline (<18 ppt), increasing to hypersaline (>40 ppt) in the remaining Coorong. Salinities in the South Lagoon were around 66 ppt, reduced by half compared to the drought years. Improved water quality was also seen with higher dissolved oxygen concentration and saturation levels. The Lower Lakes were a freshwater environment and sediments submerged. Dissolved oxygen was within the range of previous surveys from the lakes.
- This monitoring documents that an improvement in macroinvertebrates and mudflats occurred in the Murray Mouth and most of the North Lagoon, while no recovery could be found in the South Lagoon and Lower Lakes. In the Murray Mouth and northern North Lagoon, macroinvertebrate food supply for arriving migratory shorebirds had increased over previous surveys.

2. Introduction

This report is presenting findings from the 2013/14 survey of The Living Murray (TLM) Program Condition Monitoring of macroinvertebrates and accompanying environmental data. This program provides an assessment of the Lower Lakes, Murray Mouth and Coorong icon site, its habitat values and state of recovery of key species (Maunsell 2009). Macroinvertebrates are a key component in the system, responding quickly to environmental changes and playing an important role in estuarine and aquatic food webs as prey items for higher trophic levels, such as birds. This monitoring is thus providing an assessment of food availability for shorebirds at the Ramsar site.

The Lower Lakes, Murray Mouth and Coorong are a wetland of international importance, which has undergone extreme environmental changes over the last decade (Wainwright and Christie 2008, Paton et al. 2009, Kingsford et al. 2011). Following the Millennium Drought (Leblanc et al. 2012), flow resumed in spring 2010 and has been continuous since, albeit with some fluctuation with season and water management (Figure 1).

This long-term monitoring commenced in 2004 and has so far captured the loss of habitat quality and macroinvertebrate species and populations during the drought, and the commencing recovery since flows resumed in late 2010. While no improvements in macroinvertebrate communities were seen in the first year since flows resumed (2010/11), signs of recovery emerged in the monitoring data from the 2011/12 and 2012/13 surveys (Dittmann et al. 2012, 2013a,b). Following an initial increase in abundances of chironomid larvae and amphipods after flow commenced (Geddes 1987, Dittmann et al. 2006, 2012, 2013a,b), more macroinvertebrate species started to appear again last year and abundances as well as biomass increased (Dittmann et al. 2013a).

While flow continued during the 2013/14 monitoring, the volume of flow was lower than in the previous three years (Figure 1). This monitoring thus allowed evaluating the further response of macroinvertebrates to the improved environmental conditions of the system. Recolonisation of macroinvertebrates in estuarine sediments is subject to environmental conditions (Chainho et al. 2010; Kanaya 2014), and estuarine recovery from degradation can take several years or decades (Borja et al. 2010). With increased climate variability, the availability of water for environmental flows will be a long-term issue. Outcomes of the TLM condition monitoring can inform decision makers and improve future management of water resources.

To allow comparisons over time, the same sampling sites were surveyed as in previous years, using the same methods. All sites correspond with ongoing shorebird monitoring and most overlap with sites for the assessment of further parameters (e.g. fish) for the TLM monitoring. The findings of the current monitoring were analysed in comparison to investigations from previous years and with other estuarine systems. Several sedimentary and water quality parameters were assessed to interpret possible causes of temporal and spatial changes at the sites. It was expected that an improvement in macroinvertebrate populations and communities has occurred in this fourth summer since flows were restored.

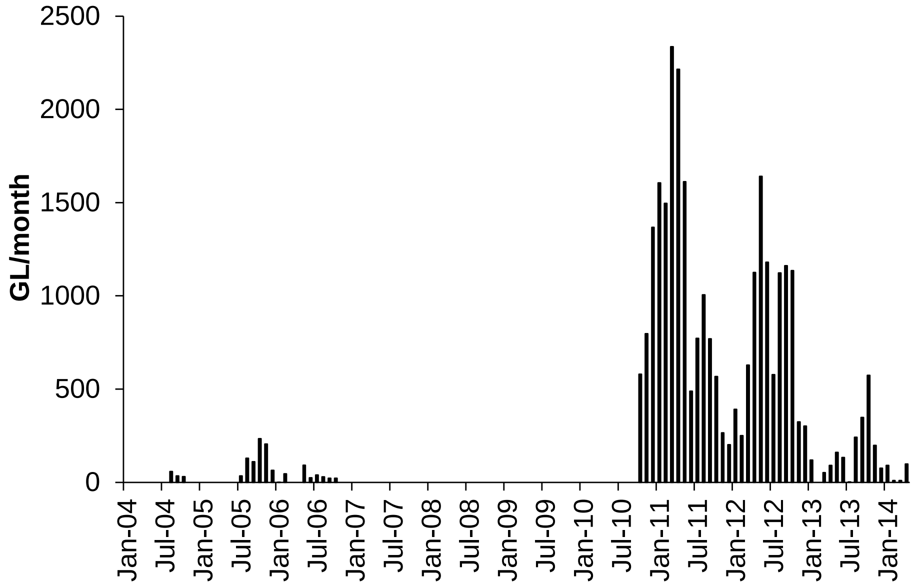

Figure 1: Monthly barrage flow from the Lower Lakes into the Murray Mouth and Coorong during the years of macroinvertebrate and mudflat monitoring. Based on modelled monthly barrage outflow data from the MDBA.

This report presents findings from the 10th year of condition monitoring for the assessment of macroinvertebrate food availability for shorebirds and other higher trophic level organisms prevalent in the Murray Mouth, Coorong and Lower Lakes. It contributes to a number of condition monitoring objectives for 'The Living Murray' program, which are; I-1 – 'Maintain or improve invertebrate populations in mudflats', M-1 – 'Facilitate frequent changes in exposure and submergence of mudflats', M-2 – 'Maintain sediment size range in mudflats', and M-3 – 'Maintain organic content for mudflats' (Maunsell 2009). It also contributes to W-1 – 'Assessment of estuarine conditions between Goolwa Barrage and Pelican Point' with measurements of water quality taken at the time of invertebrate monitoring in late spring/early summer. The report is structured around the targets with detailed data analysis provided as supplementary material (table and figure reference prefix SM-).

To deliver the targets (I-1, M-1 to M-3) of 'The Living Murray' program, this report addresses the following questions for the spring/summer of 2013/14:

1) To describe the current environmental conditions of the Murray Mouth, Coorong and Lower Lakes
2) To determine the spatial and temporal distribution of macroinvertebrates, in terms of species composition, diversity, abundances and biomass in the Murray Mouth, Coorong and Lower Lakes since 2004.
3) To explore the relationship between environmental parameters and macroinvertebrate assemblages.

3. Materials and Methods

3.1 Sampling sites and dates

The sampling design was continued from the previous monitoring and as described in the LLCMM Icon Site Condition Monitoring Plan (Maunsell 2009).In the Lower Lakes, five of the sites added in 2008 during the drought were discontinued since last year. Benthic macroinvertebrate fauna was sampled at a total of 26 sites in the Murray Mouth region (5 sites), Coorong (6 sites) and Lower Lakes (15 sites) during the 2013/14 summer survey (Figure 2). Sampling occurred between the 25th November 2013 and the 4th February 2014 (SM-Table 1), with the Murray Mouth and Coorong sampled in late 2013, and the Lower Lakes in January/February 2014.

Sites sampled in the Murray Mouth, between the Goolwa Barrage and the southern end of the Tauwitchere Barrage, included sites 1 (Monument Road), HC (Hunters Creek), 4 (Mundoo Channel), 6 (Ewe Island), and 20 (Pelican Point). Sites 22 (Mulbin Yerrok, near Long Point), 26 (Noonameena) and 24 (Parnka Point) are located in the North Lagoon of the Coorong. The South Lagoon sites were 19 (Villa de Yumpa), 16 (Jack Point), and 14 (Loop Road south of Salt Creek) (Figure 2).

Sampling sites in the Lower Lakes were differentiated by their location in Goolwa Channel (sites L1 inside of the Goolwa barrage, L7 opposite Currency Creek on Hindmarsh Island); Lake Alexandrina (10 sites) and Lake Albert (3 sites) (Figure 2; SM-Table 1). Sampling at Hindmarsh Island (site L7) had to be slightly shifted as the sediment was too rocky. In the results, sites in Lake Alexandrina are depicted by increasing distance from the barrages; site L2 east of the regulator at Clayton, L16 inside Mundoo Channel barrage, L17 inside Ewe Island barrage, L6 inside Tauwitchere barrage near Pelican Point, L11 Loveday Bay (near the fisherman's hut), L9 Narrung, L4 Milang, L5 Poltalloch, L3 Tolderol, and L18 Mosquito Point at Boggy Lake. Sites in Lake Albert are L13 (Seacombes), L8 (Waltowa) and L12 (Vanderbrink). For analysis of longer term developments in the Lower Lakes, sites from previous monitoring (Currency Creek (CC1), at the confluence of the Tookayerta and Finniss (TF), Teringie (L10), Eckerts Road (L15) and Albert Station (L14)) were also considered.

Water levels in the Murray Mouth and Coorong varied during the sampling in late 2013. At sites such as Monument Road, Hunters Creek, Mundoo Channel, Ewe Island and at the South Lagoon sites, approximately 200 m of mudflat was exposed at low tide. In the North Lagoon and at Pelican Point sampled in early December, less than 1 to 10 m of sediments were exposed from shore, yet this was recent inundation as wider mudflats were seen when subtidal sampling took place a few days before during an accompanying project. The variable water levels, especially in the North Lagoon, resulted from water release from the barrages to enable *Ruppia* restoration, wind and tides. In the Lower Lakes sampling was completed in late January to early February 2014 as the earlier high water levels were not idea for sampling, yet all sites were still under water at the time of sampling.

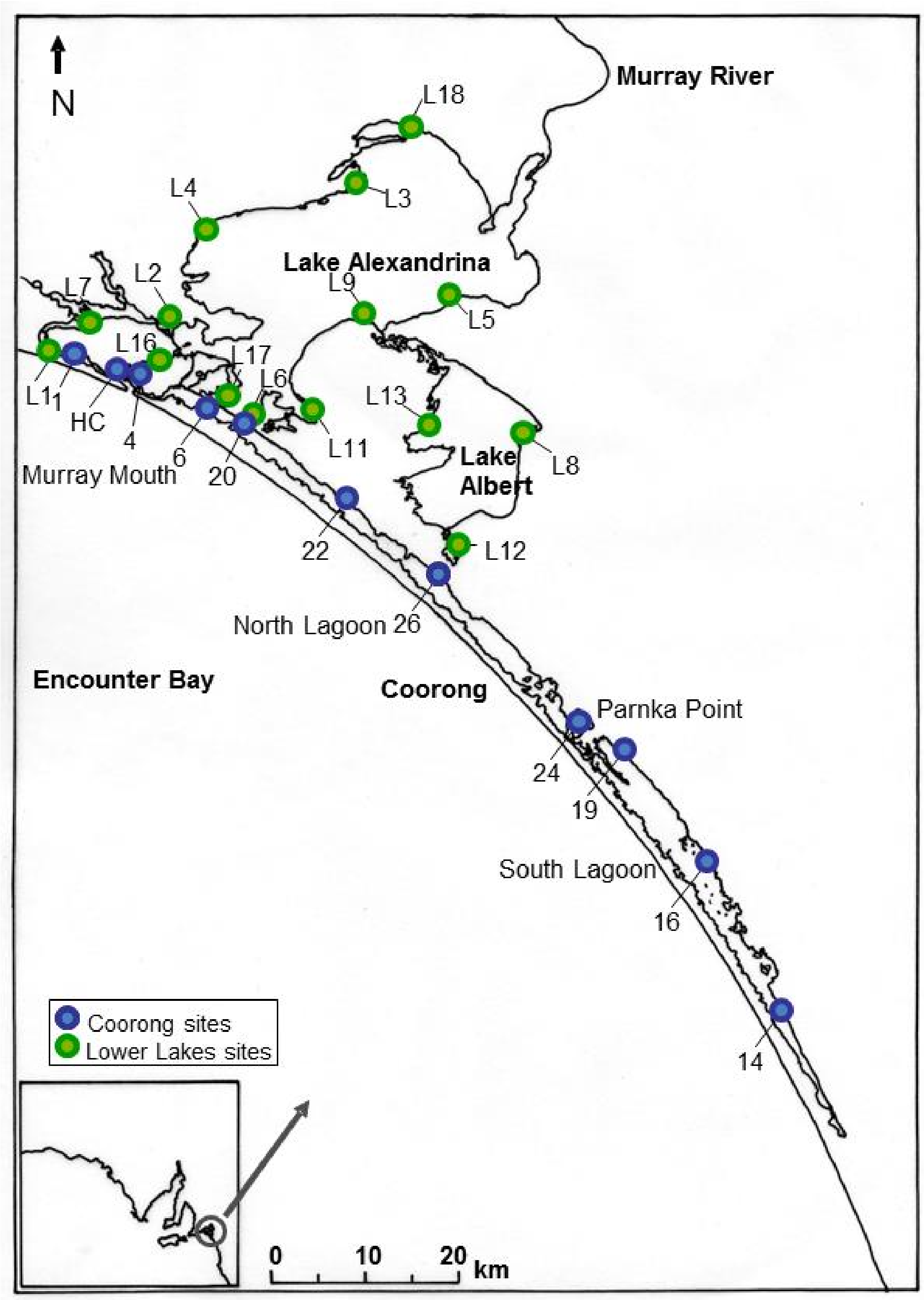

Figure 2: Location of study area and sampling sites for each region of the Murray Mouth, Coorong and Lower Lakes from the survey undertaken during the late spring/summer of 2013/14.

3.2 Environmental parameters

Environmental characteristics (water temperature, salinity, oxygen content and saturation, sediment grain size, organic matter and chlorophyll-*a*) were recorded to establish the environmental conditions at the sites and analyse whether sediment size ranges and organic matter were maintained (objectives M-2 and M-3 of the Condition Monitoring), and to characterise the salinity regime at the time of sampling (objective W-1), and identify environmental parameters affecting the macrobenthic communities (Maunsell 2009).

Water Quality

Water quality characteristics (temperature, salinity, dissolved oxygen concentration, oxygen saturation and pH) at the sampling sites were measured *in situ* using hand held electrodes. Measurements were taken with a YSI Pro2030 multi-parameter electrode (for temperature, salinity, oxygen concentration and saturation) and pH indicator strips (for pH water and sediment; Acilit 0-14). A refractometer was used at some sites to measure salinity in the overlying water and additionally from the residual pore water of the core sampling, which showed comparable salinities to the overlying water. Three replicate measurements for each parameter were taken.

Sediment analyses

Sediment samples were obtained from each site for the analysis of grain size, organic matter content and chlorophyll-*a* (as a proxy for microphytobenthic biomass). All sediment samples were stored on ice and frozen upon return to the laboratory and until further analysis. Samples for sediment organic matter were extracted using a cut off 60 mL syringe (6.6 cm^2 surface area). To account for spatial variation, three replicate samples were taken and analysed separately for each sediment parameter. To obtain a bulk parameter of organic matter as % dry weight (d.w), sediment samples were dried to constant weight using an Ohaus MB45 Moisture Balance. Sediment samples were homogenously distributed onto aluminium trays and dried using the standard drying protocol (controlling the temperature profile at 80 ºC). The profile burn was automatically completed after all moisture content was dried and remained stabilised for 30 seconds. Samples were then burnt in a muffle furnace at 450 ºC for 5 hrs.

For sediment grain size, samples were taken using a cut-off 60 mL syringe (surface area 6.6 cm^2). Three replicate samples were taken per site. Samples were stored on ice in the field and frozen until further analyses in the laboratory. Grain size was determined by laser diffraction using a particle size analyser (Malvern Mastersizer 2000). Sediment grain size samples were thawed and the fraction >1 mm sieved off manually to avoid blockage in the machine. To correct for this procedure, the weight of this fraction and of the remaining sediment were determined and normalised in the data set. Median and quartiles as well as percentages of various particle sizes were obtained from the Mastersizer output. Sediment sorting was calculated using the formula $S_o = (P_{25}/P_{75})^{1/2}$, based on the metric scale. At several sites at the Murray Mouth and North Lagoon, as well as at Villa de Yumpa (Site19), sediment grain size compositions had slightly bimodal distributions. For sediments composed of finer soft sediment and larger grain particles, the obscuration level of the Mastersizer is more sensitive to finer than larger particles.

For chlorophyll-*a* in the sediment surface, three replicate samples were taken per site using a 5 mL vial inserted 1 cm into the sediment. Subsequently, 5 mL of methanol was added to extract the chlorophyll, and the vial was vigorously shaken before being wrapped in aluminium foil (Seuront and Leterme 2006). Samples were placed on ice in the field and upon return to the laboratory, were frozen for later analysis with a fluorometer (Turner 450). After the initial reading for total chlorophyll, drops of 0.1 M HCl were added to the samples to correct for phaeophorbides.

3.3 Macrofauna

To investigate macroinvertebrate species composition and abundance within the sediment, handheld PVC corers (83.32 cm^2 surface area) were used to sample the benthos in the littoral zone. At three sites in the Lower Lakes the water level was too high to use handheld corers, and therefore samples were taken with a small benthic Ekman grab (225 cm^2 surface area) inserted approximately 10 cm into the sediment. The sites were L17 (Ewe Island Lake, Lake Alexandrina), L8 (Waltowa, Lake Albert) and the first two samples at L9 (Narrung, Lake Alexandrina).

Ten replicate samples were taken per site, scattered haphazardly between the mid to low shore levels around the respective water margin. To assess differences in food availability for birds with different bill lengths (Zwarts and Wanink 1993), the vertical distribution of benthic fauna was investigated by splitting the sediment samples taken with the corers into two horizons (0-3 cm and 3-15 cm) in the Murray Mouth and Coorong sites. In the Lower Lakes, sediment horizons were not separated and samples were taken for the entire sediment core (0-15 cm) or using an Ekman grab at sites where the water level was too high for safe access.

All benthic samples were sieved through 500 µm mesh size in the field and sorting of live samples occurred in the laboratory within a few days of collection. Specimens were identified and counted in the laboratory, either straight after sorting or, if time did not allow this due to large sample volumes and high individual numbers encountered, from specimens preserved in 70% ethanol. Specimens were identified to the lowest possible taxonomic level and the numbers of individuals of each species were counted. Amphipods were not differentiated to species, as shorebirds are unlikely to be selective towards particular amphipod species as prey. All polychaete specimens with a complete anterior region (prostomium) were included in abundance counts. For measuring biomass, polychaete fragments were included with the complete specimens. The larval and pupae stages of insects were recorded, while all adult winged life stages were excluded as they are highly motile and not part of the benthic macrofauna.

All identified organisms were preserved in 70 % ethanol until they were used for biomass determination. Biomass was analysed for the total benthos per replicate sample and not differentiated per phyla, given the understanding of the main taxa contributing to the biomass gained from previous monitoring. Each sample was dried to constant weight (d.w.) using an Ohaus MB45 Moisture Balance. Specimens were homogenously distributed onto aluminium trays and dried using the standard drying protocol (controlling the temperature profile at 80 ºC). As samples with <0.5 g can give inaccurate results with the moisture balance, samples with very few specimens were dried in an oven at 80 ºC until constant dry weight (d.w.) was achieved (at least 24 hours). Samples were then placed in a muffle furnace at 450 ºC for 5 hours. Samples were removed from the furnace and cooled in a desiccator before final weighing. The weight after burning was subtracted from the dry weight to obtain the biomass measurement as ash free dry weight (AFDW).

3.4 Data Analysis

The approach taken for data analysis follows the previous monitoring (see Dittmann et al. 2013a). Data are presented separately for the Murray Mouth and Coorong, and for the Lower Lakes. Data are further compared according to their upstream and downstream locations relative to the barrages. The regions are differentiated in the analysis design and correspond to the ‘sub-regions’ in the Condition Monitoring Plan. These are the Murray Mouth, North Lagoon and South Lagoon of the Coorong; and for the Lower Lakes the Goolwa Channel, Lake Alexandrina and Lake Albert. The Goolwa Channel was separated as a further sub-region for Lake Alexandrina because of its different history with the Goolwa Channel Water Level Management Project.

To assess whether TLM condition monitoring target parameters were maintained or improved, comparisons were carried out using previous survey data since December 2004. With the extreme changes in environmental conditions over that time span, and the lack of quantitative historic data, reference state or dynamics are difficult to define. The approach taken here was to divide the entire monitoring time span into three periods characterised by different flow conditions (see Figure 1): 2004-2006 with no or small flow (in 2005), 2007-2009 being the years of the extreme drought without water releases from the barrages, and 2010-2012 as the period of flow, which commenced in spring 2010. Some parameters, such as Chl-*a*, or sites (e.g. around the Lower Lakes) were added later (2007 and 2008) and temporal comparisons respectively adjusted.

The design used for statistical analyses of environmental or biotic data was regions (fixed factor) and sites nested within regions (random factor), with the survey year as a further fixed factor for temporal comparisons. The analysis for temporal differences of environmental parameters was based on average values per site at each survey, due to a lower number of replicates in the data set prior to 2007, and a design using the survey year (fixed factor) and region (fixed factor), with sites as replicates for each respective region. This design was also used for testing diversity indices.

Tests were carried out using PERMANOVA (permutational analysis of variance) using the software PRIMER v6 with PERMANOVA add-on. Prior to analysis, environmental and biotic data were transformed as needed (square root, fourth root or log (x+1)). Environmental data were normalised when parameters with different units were included in the analysis. Similarities of sampling sites based on environmental factors were explored with principle component analyses (PCA), with vector overlays for defining variables, or trajectories to display temporal change. Tests of homogeneity of dispersion (PERMDISP) were included for some environmental and biotic data to assess variability within factor levels. For environmental data and univariate analysis of biotic data (e.g. tests for differences in total abundances or total biomass), Euclidean distance was used to create the resemblance matrix. In all multivariate analyses of biotic data, Bray-Curtis similarity was used, with a dummy value of 1 added when many zero values occurred in the data.

To explore differences in macroinvertebrate communities, principal coordinate analysis (PCO) plots were used with vector overlays (Spearman correlation) to illustrate species contributing to the differentiation of communities along the PCO axes. PERMANOVA tests were carried out for community differences, following the designs explained above. SIMPER analyses revealed the species contributing most to the similarity within sites and those differentiating sites. ANOSIM (Analysis of similarity) tests were run between regions for each year to obtain the test statistic Global R, indicating community differences. To illustrate community changes over time, nMDS ordination plots were created with trajectories linking consecutive years, and significantly different clusters based on SIMPROF tests are indicated with circles around respective years.

To explore links between macroinvertebrate assemblages and environmental data, distance-based linear models (DISTLM) were calculated and visualised using distance-based redundancy analysis (dbRDA). Some sites or parameters had to be excluded from these analyses due to missing values for some environmental factors in previous years or cases of autocorrelation. Detailed test outcomes are provided in the Supplementary Material.

4. Results – Murray Mouth and Coorong

4.1 Mudflat habitats in the Murray Mouth and Coorong

4.1.1 Salinity regime and water level

The water in the Murray Mouth and northern reaches of the North Lagoon was fresh to brackish, with salinities increasing between Mulbin Yerrok (site 22) and Noonameena (site 26), from where on hypersaline conditions (>40 ppt) occurred at all further sampling sites in the Coorong (Figure 3a). During the sampling in November/December 2013, salinity levels were very similar to the last three years since flow resumed in late 2010 (Figure 3b). While the characteristic salinity gradient from the Murray Mouth into the Coorong lagoons persisted, salinities in late 2013 were on the lower margin of the range of salinities recorded at the study sites in the entire monitoring period since 2004 (SM-Figure 1). With the continued flow since 2010, salinities in the South Lagoon were more comparable to those recorded in the North Lagoon during previous periods (Figure 3b). Based on the measurements taken during the sampling for macroinvertebrates, the condition monitoring target W-1: '*Establish and maintain variable salinity regime with >30% of area below sea water salinity concentrations in Murray Mouth Estuary and North Lagoon*' continued to be exceeded, with all of the Murray Mouth and about half of the North Lagoon having salinities below sea water during the sampling period (Figure 3a, b).

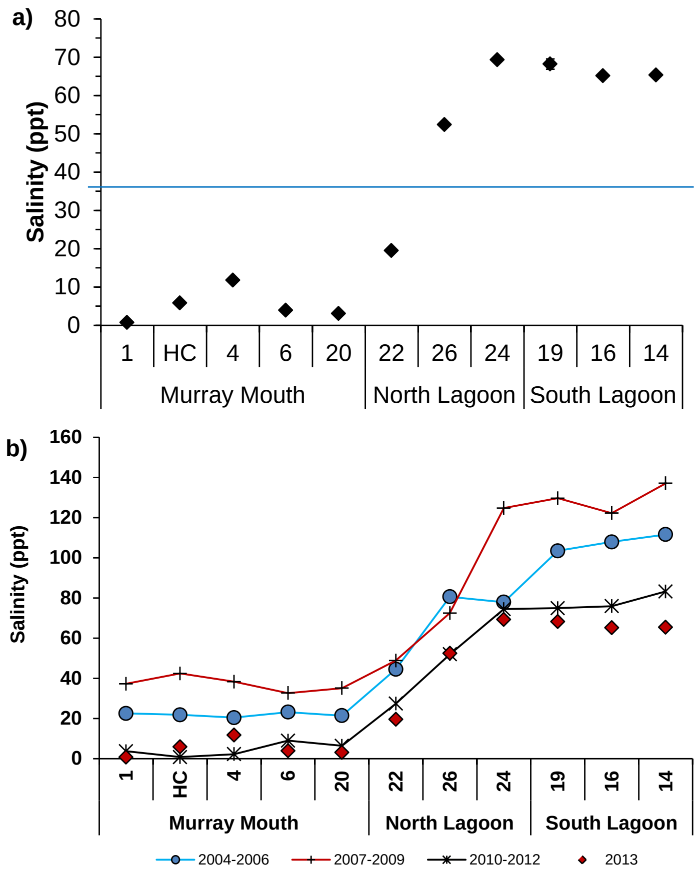

Figure 3: Salinity (mean ppt ± S.E.) in the water overlying the mudflats of the Murray Mouth and Coorong (a) during the survey in 2013/14, and (b) in comparison to average salinities recorded in previous monitoring periods (mean values shown only for clarity), grouped into three year intervals for the early drought period (2004-2006), the severe drought period 2007-2009, and the first three years since flow resumed (2010-2012) (see Figure 1). Salinities from the current monitoring (2013) are indicated separately in (b). The blue line in (a) indicates sea water salinity.

On the various sampling trips, the widths of the exposed mudflats varied. Yet, for condition monitoring target M-1: '*Facilitate frequent changes in exposure and submergence of mudflats*', only observations from single days can be provided here. The water level had increased between the sampling trips in late November and early December in the Coorong, affected by water releases over the barrages, wind and tides. Longer term data sources need to be considered to evaluate this target.

4.1.2 Water quality

Several other water quality parameters were measured in waters overlying the mudflats. Water temperature was 21 ºC on average. At Monument Road (site 1) and Hunters Creek (Site HC), slightly warmer water was observed than in the long term range of temperatures recorded in previous monitoring years, while temperatures were within the range or slightly cooler at the other sites in the Murray Mouth and Coorong (SM-Figure 2). Dissolved oxygen concentrations in the water were high (average of 9.5 mg/L), ranging from 6 – 14 mg/L between sites. These values were similar to or exceeding dissolved oxygen concentrations recorded in previous years at the sites (SM-Figure 3). Similarly, dissolved oxygen saturation was above the ANZECC trigger value (90%) at all sites, and 127% on average. The highest oversaturation of 237% was recorded in the water overlying the sediment at Villa de Yumpa (site 19) (SM-Figure 4). At most sites, saturation levels were within the upper range or higher than previously recorded values (SM-Figure 4). Water and sediment showed a lower pH than in the last few years, with pH 6 on average (SM-Figure 5), which could have been affected by the different method used (pH strips instead of electrode).

4.1.3 Sediment size ranges

Sediments in the studied mudflats were sandy and mostly well sorted, with sites in the Murray Mouth having very fine to medium sand, and sites in the Coorong fine to coarse sand (Table 1). At Villa de Yumpa (site 19) and Jack Point (site 18), sediments were composed of a range of grain sizes, including very coarse sand (SM-Figure 6). Apart from a higher median grain size at Jack Point (site 18), the median grain sizes were comparable to values from previous years (Figure 4). At Mulbin Yerrok (site 22), where coarser sediment was found last year, the median grain size was again within the range of earlier records. At Pelican Point, the median grain size was also similar to earlier years, clarifying that the outlying low value from 2012 was likely a measurement error (Figure 4).

The sediment grain size composition at study sites in the Murray Mouth and North Lagoon appears to have become muddier in the 2012 and 2013 surveys (see vertical split on PC2 in Figure 5). Yet, median grain sizes were not statistically different across the survey years, but differed by region (SM-Table 2). Thus, the condition monitoring target M-2 '*Maintain sediment size range in mudflats*' is met.

Table 1: Sediment characteristics of mudflats in the Murray Mouth and Coorong region during summer 2013/14. Organic matter content (in per cent dry weight) within the sediment and the median grain size of sediment (in µm) along with the sorting coefficient S_o, are provided as characteristics of mudflat sediment. The verbal description of sediment grain size and sorting follows Blott and Pye (2001).

Site		Organic matter (% dw)	Grain size			
			Median		Sorting	
			size	description	S_o	description
Murray Mouth	1	1.31	191.02	Fine sand	0.42	Well sorted
	HC	1.28	105.46	Very fine sand	0.44	Well sorted
	4	0.62	92.27	Very fine sand	0.35	Well sorted
	6	0.94	130.90	Fine sand	0.48	Well sorted
	20	1.05	287.23	Medium sand	0.68	Moderately well sorted
North Lagoon	22	1.56	175.91	Fine sand	0.65	Moderately well sorted
	26	0.97	190.62	Fine sand	0.74	Moderately sorted
	24	1.74	231.01	Medium sand	0.73	Moderately sorted
South Lagoon	19	5.33	237.55	Medium sand	0.26	Very well sorted
	16	1.81	770.99	Coarse sand	0.51	Moderately well sorted
	14	2.69	243.22	Medium sand	0.73	Moderately sorted

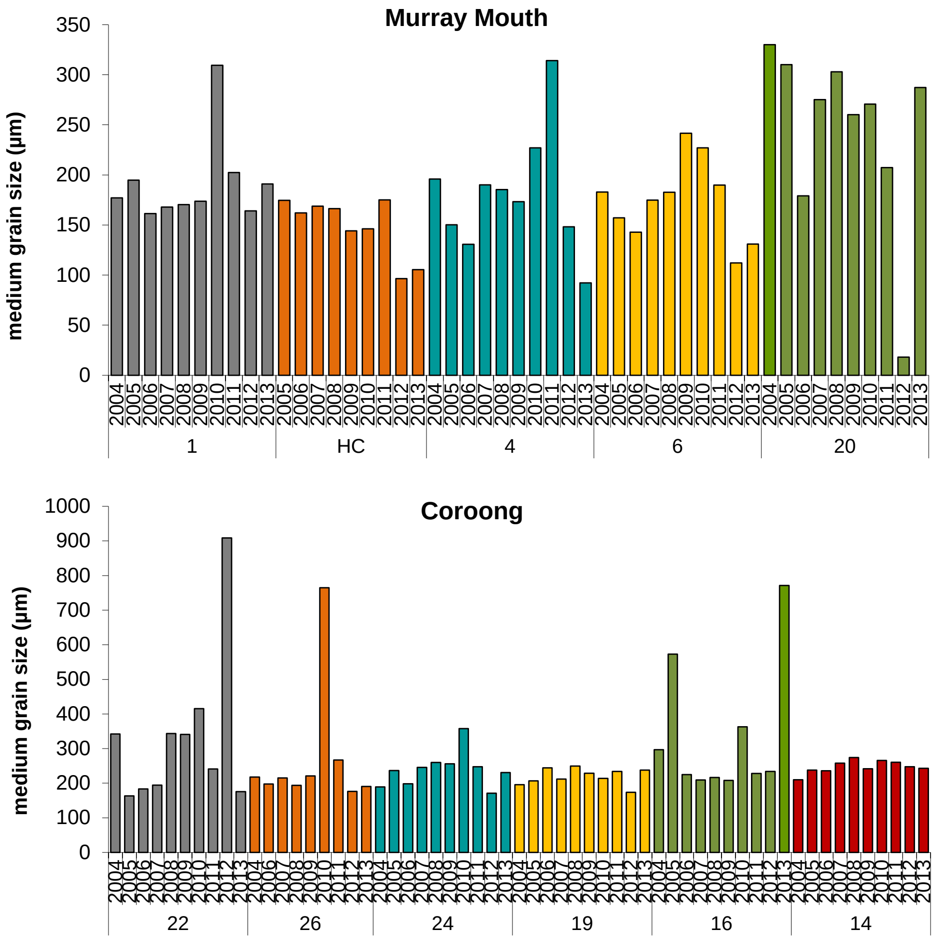

Figure 4: Median grain size values recorded in mudflats at each of the sites in the Murray Mouth and Coorong during monitoring surveys since 2004. Hunters Creek (HC) was included in 2005, and site 26 was not sampled that year. Note the different y-axes scales due to some outlying coarser sediment in the North Lagoon. See Figure 2 for site locations.

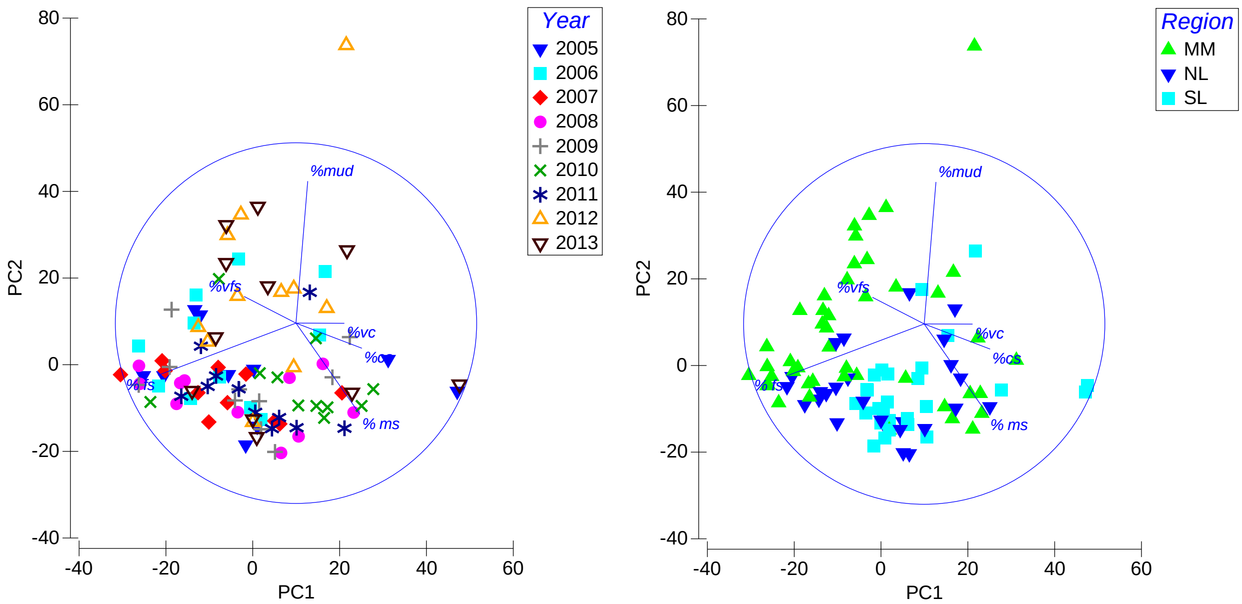

Figure 5: PCA (Principal component analysis) of sediment grain size compositions (% of major fractions, size in µm) in mudflats in the Murray Mouth and Coorong for the summer surveys from 2005 to 2013/14. Sites or regions are not shown in the figure. The same plot is shown for the survey years (left) and the regions Murray Mouth (MM), North Lagoon (NL) and South Lagoon (SL) (right). 2004 is not included as a different method was used for grain size analysis. The PCA axes explained 41.5 % (PC1) and 36.4 % (PC2) of the variation.

4.1.4 Sediment organic matter and chlorophyll-*a*

Sediments of the investigated mudflats had low contents of organic matter (1.75 % dry weight on average, range 0.6 (Mundoo Channel, site 4) – 5.3 (Villa de Yumpa, site 19)) and varied significantly between sites in each region (Figure 6, SM-Figure 7, SM-Table 2). As in the previous year, higher sediment organic matter values were recorded from sites in the South Lagoon. Across all monitoring years, sediment organic matter varied significantly between regions and between the survey years (SM-Table-2). Variability was highest at Mundoo Channel (site 4) and Villa de Yumpa (Site 19), yet overall, values for sediment organic matter from November/December 2013 fell within the range of values recorded in previous years (Figure 6). Thus, the condition monitoring target M-3 '*Maintain organic content for mudflats*' was met.

The sediments had very low microphytobenthic biomass, as estimated by the Chlorophyll-*a* content. Values for Chl-*a* were 0.88 mg m^{-2} on average, ranging from 0.08 (Parnka Point, site 24) – 0.88 (Mulbin Yerrok, site 22) (Figure 7), and did not differ significantly between regions or sites within regions in 2013 (SM-Table 2). Microphytobenthic biomass was also low in the 2010/11 and 2011/12 monitoring measurements, and values from the 2013/14 monitoring fell within the lower range of values recorded for Chl-*a* since 2007 (Figure 7). However, Chlorophyll-*a* contents varied significantly between surveys and regions over the monitoring years since 2007 (SM-Table 2).

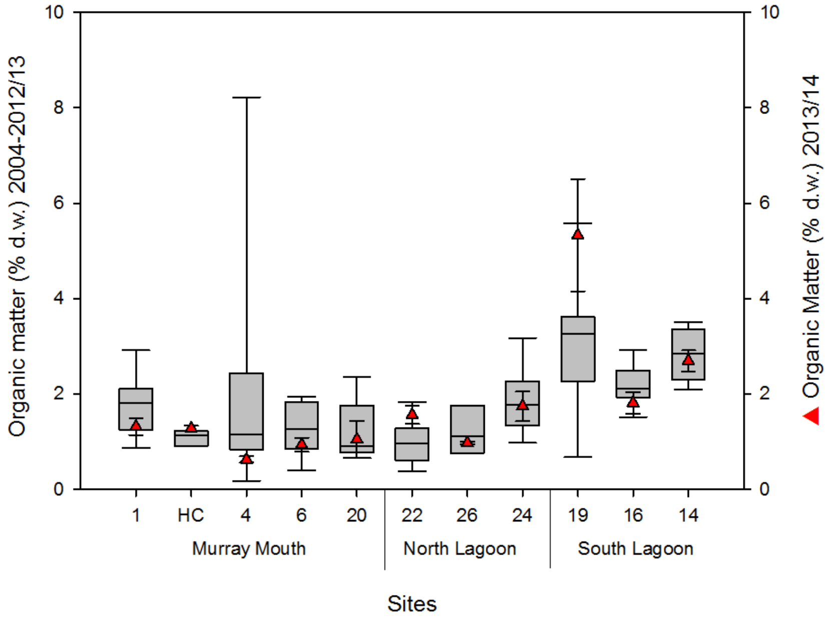

Figure 6: Sediment organic matter (as % dry weight) of mudflat sediments in the Murray Mouth and Coorong Lagoons during surveys from 2004 – 2012/13 (boxplot) and during the survey in summer 2013/14 (red triangles ▲; average ± SE).

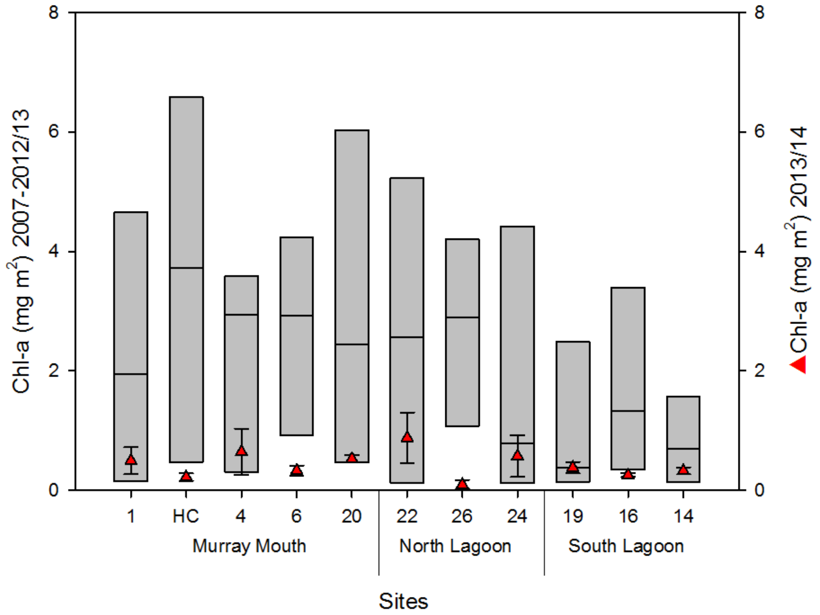

Figure 7: Sediment chlorophyll-*a* content (in mg/m^2) of mudflats in the Murray Mouth and Coorong Lagoons during surveys from 2007 – 2012/13 (boxplot) and during the survey in summer 2013/14 (red triangles ▲; average ± SE).

4.1.5 Trajectory for environmental conditions between years

Based on the environmental variables measured alongside the macroinvertebrate monitoring, sites in the three regions of Murray Mouth, North and South Lagoon of the Coorong provided different habitat characteristics (SM-Figure 9). Villa de Yumpa in particular was characterised by very distinct environmental conditions to the other sites. Similar to the previous year, the Coorong was more saline, and sediments contained more organic matter.

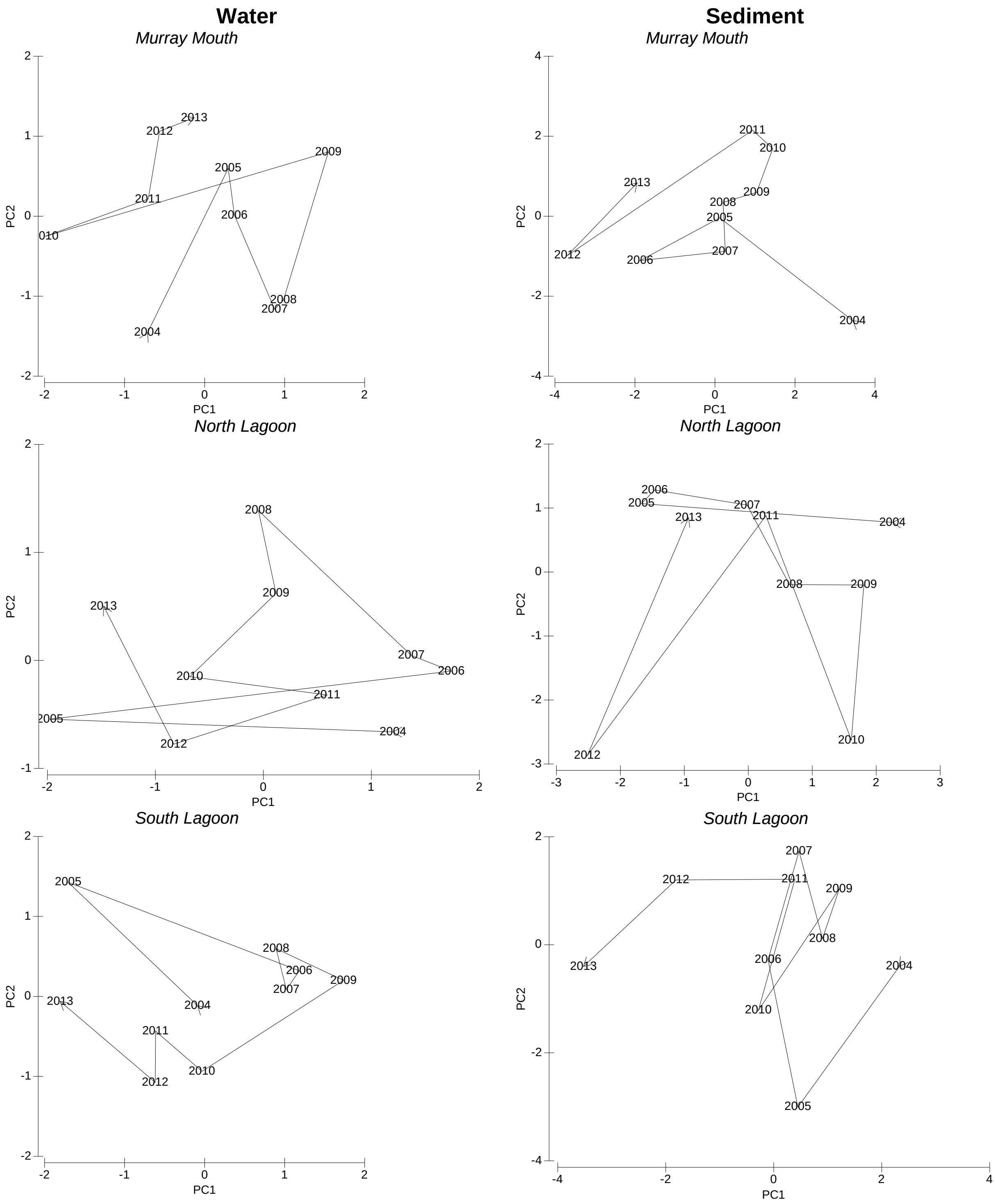

Figure 8: PCA (Principal component analysis) with trajectories of change in water parameters (salinity and dissolved oxygen saturation, left column), and sediment parameters (grain size fractions and organic matter, right column), for each of the regions of the Murray Mouth, North and South Lagoon since monitoring began in 2004. PC1 and PC2 are the first two PCA axes.

Trajectories of environmental conditions for the water and sediment parameters measured continued to show change in each region (Figure 8). While these trajectories are not indicating a return to conditions at the beginning of the monitoring in 2004, periods of extreme drought (2007-2009) were more similar to each other in most cases. For the Murray Mouth, the commencement of water flow over the barrages in late 2010 set trajectories into a new direction (Figure 8). In the North Lagoon, trajectories reflect the high rate of variability in environmental conditions. In the South Lagoon, the trajectories are indicating a clear shift away from the conditions during the drought years.

4.2 Macroinvertebrate populations

To address whether the Condition Monitoring Target I-1: '*Maintain or improve invertebrate populations in mudflats*' has been met, the report focusses here on comparisons over time, in particular since flows resumed in late 2010. Key parameters for macroinvertebrate populations are evaluated, namely, diversity, abundance and distribution, biomass and community structure. More details on the findings from the 2013/14 survey are presented in the supplementary material.

4.2.1 Macroinvertebrate diversity and distribution

In total, 26 macroinvertebrate taxa occurred in the samples from late November/early December 2013, with highest species numbers in the Murray Mouth (18 species), followed by 14 species in the North Lagoon and 10 species in the South Lagoon (Table 2, SM-Figure 10). These numbers were an increase over previous years and an indication of improved macroinvertebrate diversity in the study regions (Figure 9).

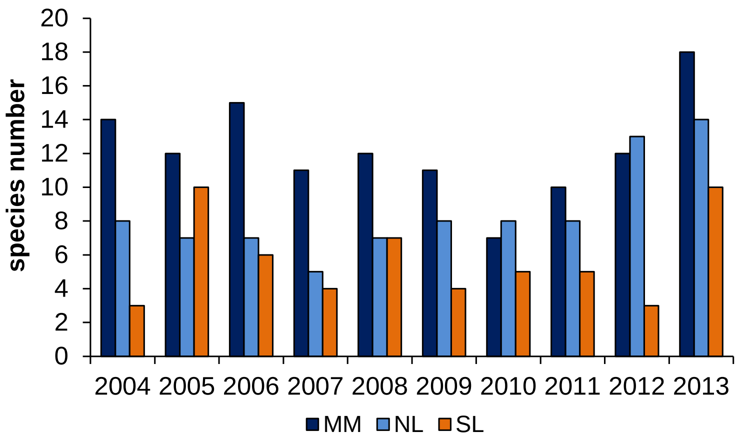

Figure 9: Total number of macroinvertebrate species by region in the Murray Mouth (MM), North (NL) and South (SL) Lagoons of the Coorong in all monitoring years since 2004.

The species of macroinvertebrates found in the sediments of the Murray Mouth and Coorong study sites were similar to those recorded in previous monitoring years. Several morphologically distinct species of small sized snails (Hydrobiidae) were differentiated (see Appendix 11), which accounted for the overall higher number of species found. Mollusca thus contributed most to the number of species in the macroinvertebrate community (11 taxa), followed by Annelida (polychaetes and oligochaetes, six taxa), Crustacea (five taxa) and Hexapoda (insects, four taxa). The juvenile bivalves found comprised several species difficult to differentiate. The micro-mollusc *Arthritica helmsi,* which was common in the regions before the drought, was recorded at several sites, specifically in the Murray Mouth and at Mulbin Yerrok (site 22).

As in the previous year, chironomid larvae and amphipods continued to be most prominent in macro-invertebrate samples throughout the study sites, with amphipods missing again in sediment from Parnka Point (site 24) (Table 2). Most of the polychaetes and molluscs were confined in their distribution to sites in the Murray Mouth and northern North Lagoon, yet single specimens of *Capitella* sp and *Simplisetia aequisetis* were also recorded from sites in the South Lagoon (Table 2, SM-Figure 10). Sediments at the South Lagoon sites were previously inhabited by insect larvae only, yet contained representatives of several other taxa as well in this survey.

Table 2: Occurrence of macrobenthic taxa and species numbers during the summer 2013/14 survey (see Figure 2 for site location). The number of taxa is also indicated per site and region. Sampling sites were: Site 1 = Monument Road; HC = Hunters Creek; Site 4 = Mundoo Channel; Site 6 = Ewe Island; Site 20 = Pelican Point; Site 22 = Mulbin Yerrok; Site 26 = Noonameena; Site 24 = Parnka Point; Site 19 = Villa de Yumpa; Site 16 = Jack Point and Site 24 = Loop Road.

Phyla/Class/Order		Family/Genus/Species	Murray Mouth					North Lagoon			South Lagoon		
			1	HC	4	6	20	22	26	24	19	16	14
Annelida	Oligochaeta							✓	✓				
	Polychaeta	*Capitella sp.*						✓	✓	✓		✓	✓
		Simplisetia aequisetis	✓	✓	✓	✓	✓	✓				✓	
		Australonereis ehlersi				✓			✓				
		Nephtys australiensis				✓							
		Boccardiella limnicola	✓	✓	✓	✓	✓						
Crustacea	Amphipoda		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	Isopoda									✓			
	Decapoda	*Paragrapsus gaimardii*		✓									
	Ostracoda									✓	✓		
	Mysidacea							✓					
Mollusca	Bivalvia	*Arthritica helmsi*		✓	✓	✓	✓	✓			✓		
		Soletellina alba				✓		✓					
		Unident. juv bivalve		✓	✓	✓		✓					
	Gastropoda	Hydrobiidae sp. 1		✓									
		Hydrobiidae sp. 2	✓	✓	✓	✓	✓						
		Hydrobiidae sp. 3	✓	✓	✓	✓	✓						
		Hydrobiidae sp. 4			✓		✓						
		Hydrobiidae sp. 5	✓	✓			✓						
		Hydrobiidae sp. 6	✓			✓	✓						
		Salinator fragilis	✓	✓									
		cf. *Coxiella striata*											✓
Hexapoda	Diptera	Chironomidae (larvae or pupae)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Ceratopogonidae (larvae)											✓
		Ephydridae (larvae)					✓		✓		✓	✓	
		Dolichopodidae (larvae or pupae)							✓	✓		✓	
Total species number per site			**9**	**12**	**9**	**12**	**11**	**9**	**7**	**5**	**5**	**6**	**5**
Species number per region					**18**				**14**			**10**	

In previous years, more species were found in the surface layer of the sediment than in the lower sediment horizons of samples, yet in the sampling in November/December 2013, a similar or even higher number of macroinvertebrate species was recorded from the lower sediment horizons from many sites in the Murray Mouth and Coorong (SM-Figure 11). At Monument Road (site 1), Hunters Creek (site HC) and Pelican Point (site 20) as well as Jack Point (site 19) and Loop Road (site 14), species numbers were still higher in the surface layer. Most of the small hydrobiid snails occurred in the surface sediment only (SM-Table 3). The polychaete *Aglaophamus (Nephtys) australiensis* was only found in the deeper sediment layer.

On a regional scale, diversity values (Shannon-Wiener index H') continued to be low for most sites, but were higher at the three South Lagoon sites, which also had a higher evenness (J') than in previous years (Figure 10, SM-Table 4). While the total number of species was much lower at the sites in the South Lagoon, the few individuals of these species occurred in similar numbers, contributing to the higher diversity values. At the Murray Mouth and North Lagoon sites, single species, such as amphipods, chironomid larvae or capitellid polychaetes dominated the abundances, and hence resulted in lower evenness and diversity indices. Both species numbers and the diversity index H' were significantly different between the three regions (SM-Table 5).

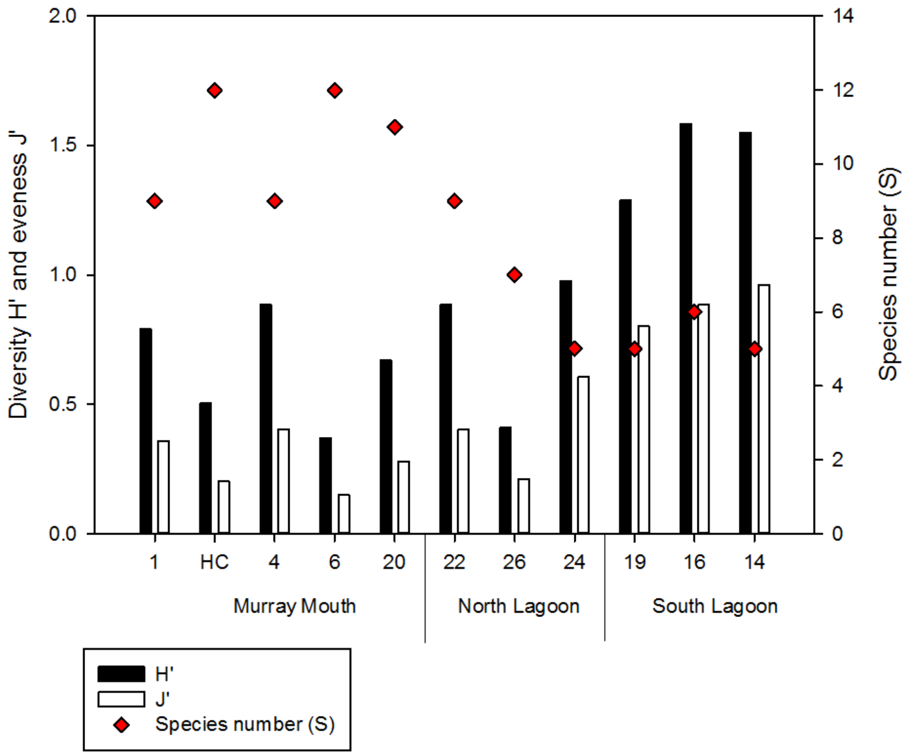

Figure 10: Total number of macroinvertebrate species (red symbols), Shannon-Wiener diversity H' (black bars, based on $\log_e$) and evenness J' (white bars) at sites in the Murray Mouth (MM), North (NL) and South (SL) Lagoons of the Coorong in the 2013/14 monitoring. See Figure 2 for site locations.

At a site specific level, species numbers, diversity (H') and evenness (J') were higher in 2013 than in previous monitoring periods at Monument Road (site 1), Hunters Creek (site HC), Mundoo Channel (site 4), as well as Parnka Point (site 24) and the three South Lagoon sites; Villa de Yumpa (site 19), Jack Point (site 16) and Loop Road (site 14) (Figure 11). Compared to the severe drought period of 2007-2009, diversity measures were higher in the recent survey at Pelican Point (site 20), Mulbin Yerrok (site 22), Parnka Point (site 24) and Loop Road (site 14) (Figure 11). An increase in species numbers was also apparent for most of the study sites in the Murray Mouth and Coorong over each monitoring year (SM-Figure 12). Species numbers (S) and the diversity index H' varied significantly over all surveys and regions (SM-Table 5).

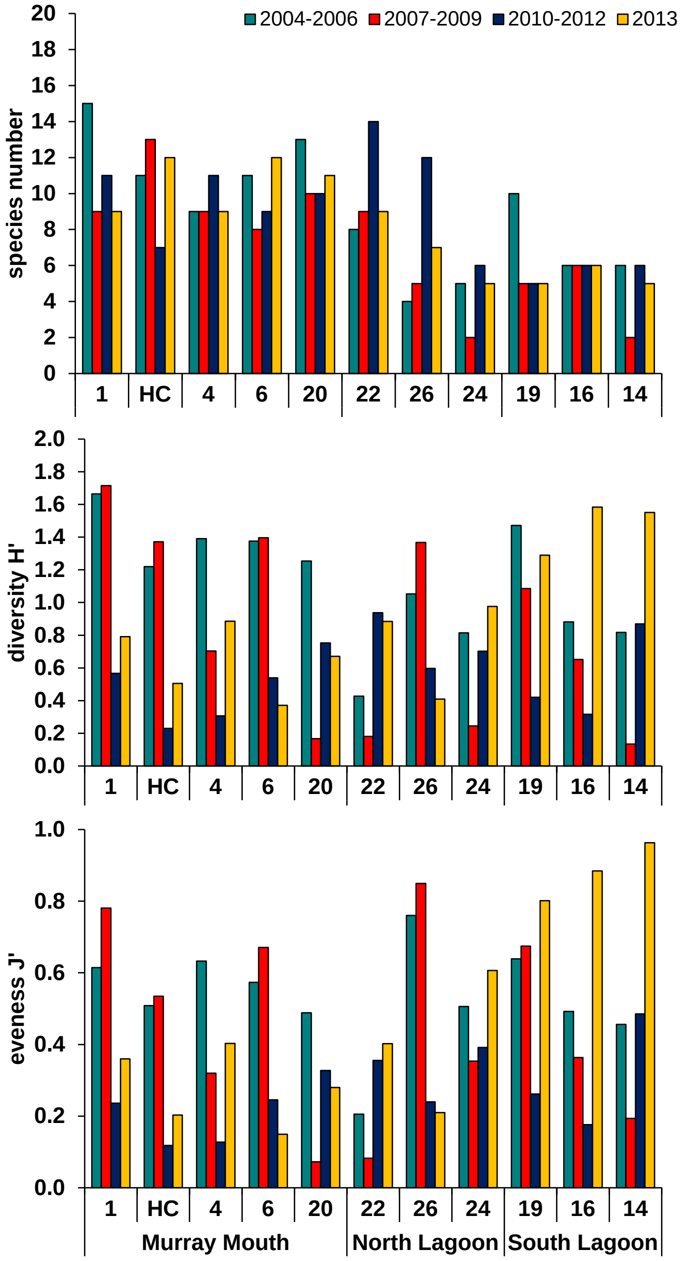

Figure 10: Changes in diversity of benthic macroinvertebrates over time, illustrated by species numbers, Shannon-Wiener index H' and Pielou's evenness index J' at sampling sites in the Murray Mouth and Coorong lagoons (see Figure 2 for site locations). Diversity from the sampling in November/December 2013 is shown against previous periods in the monitoring since 2004, divided into three year intervals of early drought/small flow (2004-2006), severe drought (2007-2009) and restored flow (2010-2012).

The distribution ranges of macroinvertebrate species were either similar to previous years (e.g. chironomid larvae), increased with species found at more sites than in the previous years (e.g. *A. helmsi, S. aequisetis*), or had contracted (e.g. oligochaetes, *N. australiensis*) (Figure 11). *Arthritica helmsi*, which had decreased in occurrence during the drought and has been missing from the study sites since flow resumed in late 2010, occurred again at almost as many sites as it did in 2006 (Figure 11). Most species that had a contracted distribution range or disappeared during the height of the drought from the Coorong, are now present again at more study sites and in all three regions (Murray Mouth, North Lagoon and South Lagoon) (Figure 11).

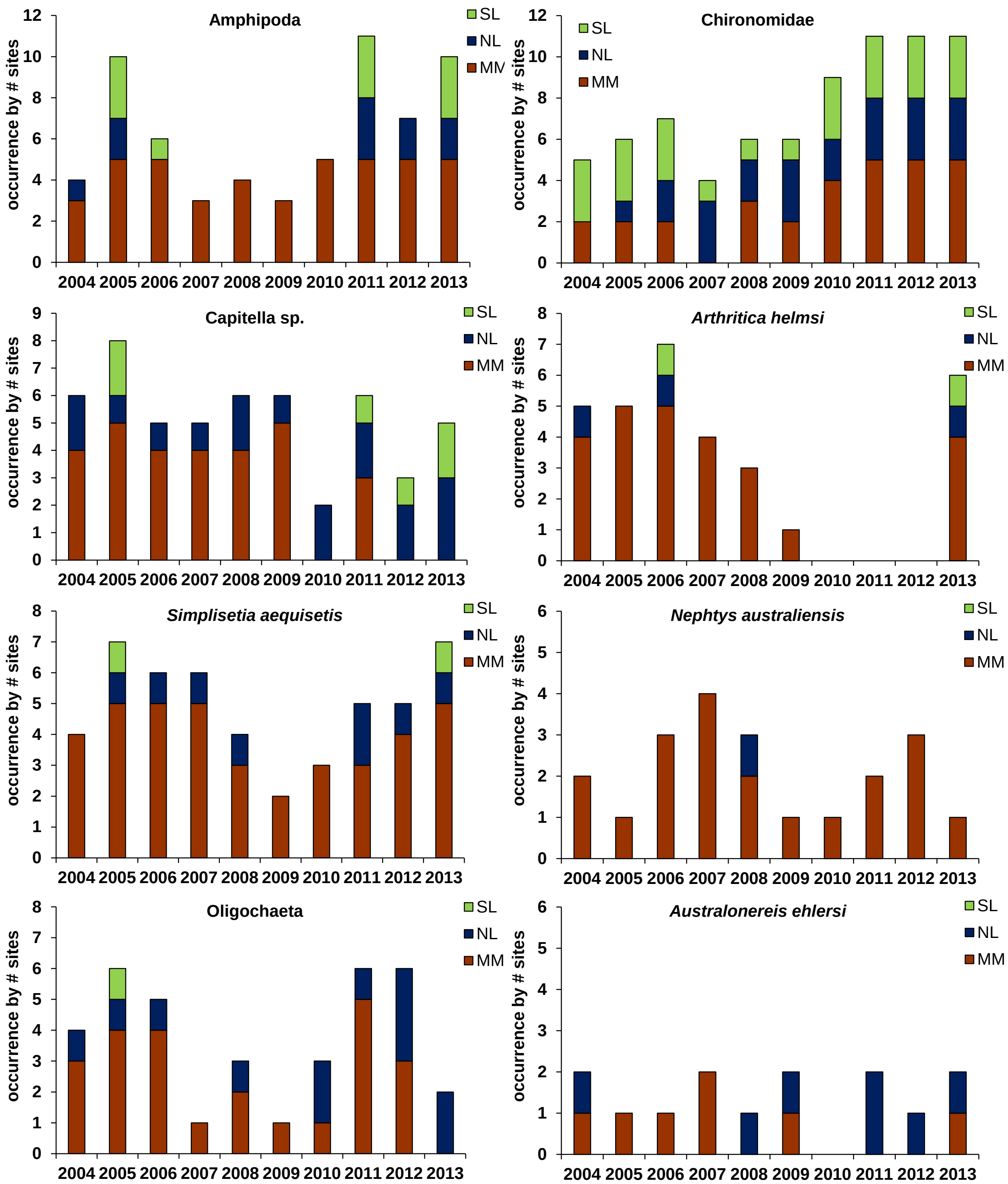

Figure 11: Changes in the distribution range of key macroinvertebrate taxa in the Murray Mouth (MM), North (NL) and South (SL) Lagoon of the Coorong across all monitoring years. The maximum number of sites across these study regions is 11. The number of sites at which each species/taxon occurred indicates how extensive or contracted its distribution range was. Note the different scales on the y-axes.

4.2.2 Macroinvertebrate abundances and distribution

Abundances of macroinvertebrates were high at several sites in the Murray Mouth region and at Mulbin Yerrok (site 22) at the northern end of the North Lagoon, but decreased at the study sites further south into the Coorong, with few specimens found in sediments at the South Lagoon sites (Figure 12). Average densities of macroinvertebrates were similar between the Murray Mouth and North Lagoon, and >200 times higher than in the South Lagoon sites (SM-Table 6). The abundances of all macroinvertebrates found in the samples (total benthos) and most of the major phyla or single species were significantly different between sites within regions as well as across regions (SM-Table 7). With abundances at sites in the northern end of the North Lagoon more similar to those recorded in the Murray Mouth, a split in macroinvertebrate occurrence of the Coorong occurred within the North Lagoon region, between Noonameena (site 26) and Parnka Point (site 24).

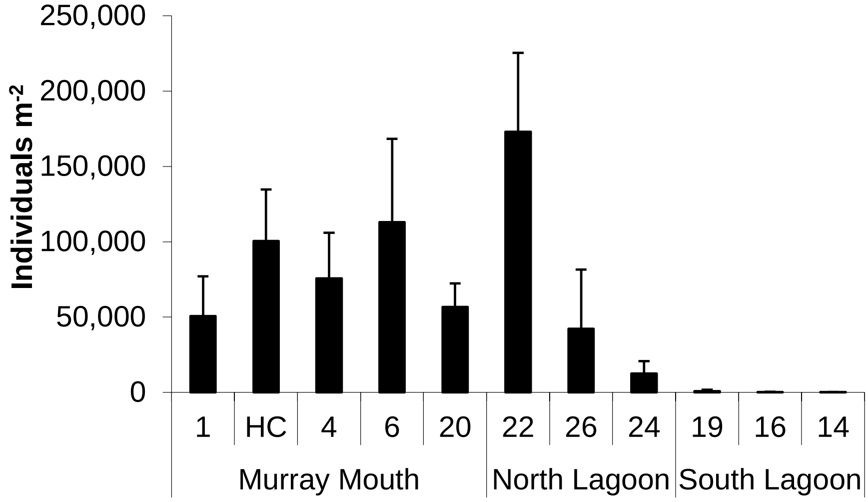

Figure 12: Mean abundance (ind. m^{-2}) and standard deviation (±S.D.) (n = 10) of benthic macrofauna recorded at sampling sites in the Murray Mouth and Coorong during the 2013/14 summer survey.

Compared to previous monitoring periods, abundances recorded in November/December 2013 were as high or higher than in the last few years since flow resumed and more comparable or, at North Lagoon sites, higher than in the early monitoring period from 2004-2006 (Figure 13, SM-Figure 13). While there is some fluctuation between years (SM-Figure 13), a continuing increase in macroinvertebrate abundances throughout the Murray Mouth and North Lagoon indicates the recovery of the system. This applies, however, mostly to the Murray Mouth and North Lagoon, whereas abundances in the South Lagoon continue to be very low (Figure 13).

The recovery in macroinvertebrate populations was also apparent from the higher abundances of several species throughout an extended distribution range (SM-Figure 14), whereas they were only found with higher abundances at single sites in the last survey (Dittmann et al. 2013a). Several other species, however, continued to be recorded from single sites only (SM-Figure 14). The overall pattern of abundances was still driven by amphipods, yet *Capitella* sp., chironomid larvae and *Simplisetia aequisetis* contributed as well to the higher abundances in 2013/14 (Figure 12 and SM-Figure 14). Key species with indicator value and functioning as an important food source for shorebirds and fish were common again in the Murray Mouth and northern section of the North Lagoon.

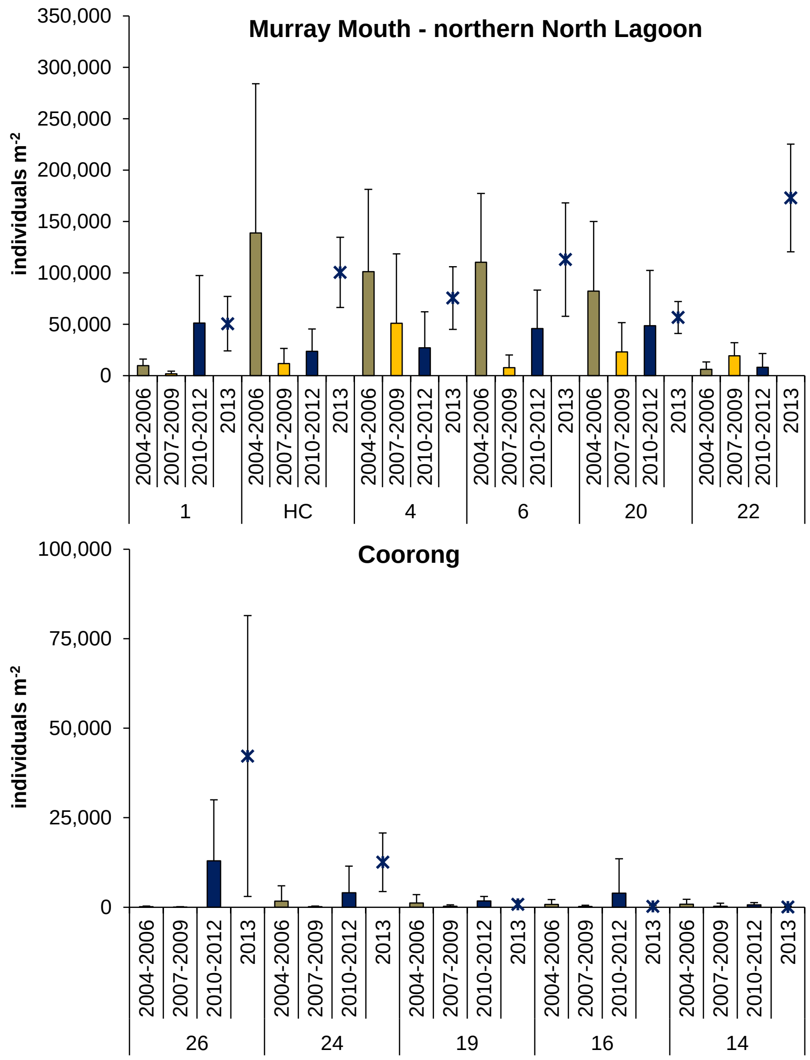

Figure 13: Mean abundances (ind. m^{-2}) and standard deviation (±S.D.) (*n* = 10) of benthic macrofauna recorded at sampling sites in the Murray Mouth and northern section of the North Lagoon (top figure) and remaining Coorong (bottom figure) over the monitoring time frame since 2004, divided into periods of early drought/small flow (2004-2006), severe drought (2007-2009) and restored flow (2010-2012). Abundances from the current monitoring in 2013/14 are separately indicated with asterisks. Note the difference in y-axes scales.

Amphipods accounted for the majority of the Crustacea recorded, and occurred at all sites in the Murray Mouth and, for the first time, also in large numbers at Mulbin Yerrok (site 22) in the North Lagoon (Figure 14, SM-Figures 14 - 16). Their average abundances have increased continuously since flow resumed (Figure 14).

Annelida were most abundant at Mulbin Yerrok (site 22) and Noonameena (site 26) in the North Lagoon due to the high numbers of *Capitella* sp. found in the sediments at these sites (Figure 14, SM-Figures 14 and 15). In the previous year, *Capitella* sp. was only recorded from Noonameena (site 26) (Dittmann et al. 2013a), yet found at all sites in the North Lagoon in the recent survey (Figure 14). This species[1] is renowned worldwide as a pollution indicator, yet the occurrence of *Capitella* sp. at the study sites did not concur with the observation of anoxic sedimentary conditions in the North Lagoon.

[1] *Capitella capitata* is a species complex, with similar ecology (Grassle & Grassle 1976; Mendez *et al.* 2000).

Oligochaetes, which were recorded at several sites in the Murray Mouth and North Lagoon last year (Dittmann et al. 2013a) were only found at two sites in the North Lagoon (SM-Figure 14).

Other polychaetes like *Simplisetia aequisetis* and *Boccardiella limnicola* were abundant throughout the Murray Mouth, apart from the Ewe Island mudflat (site 6), and *S. aequisetis* was for the first time also abundant at Mulbin Yerrok (site 22) in the North Lagoon (Figure 14, SM-Figure 14). Abundances of *S. aequisetis* were the highest seen for this species for several years (Figure 14). Polychaetes like *Nephtys australiensis* and *Australonereis ehlersi* were found at single sites only (SM-Figure 14). *Nephtys australiensis* had been more widespread and common in the early monitoring years, but was mainly found at Ewe Island (site 6) in recent surveys (Figure 14).

Another key species, the reef building tube worm *Ficopomatus enigmaticus*, was not quantitatively assessed using core samples in this monitoring, yet live tube worms were seen at Monument Road, Mulbin Yerrok and Long Point. At Monument Road, the size of the reefs appeared larger than in previous years.

Abundances of Mollusca have been dominated by the micro-mollusc *A. helmsi*, yet this once numerous bivalve had not been recorded during the drought (Figure 14). In the recent survey, *A. helmsi* was recorded from sites throughout the Murray Mouth and was most abundant at Mulbin Yerrok (site 22) in the North Lagoon, where it was rarely found before (Figure 14, SM-Figure 14). A larger bivalve species occurring deeper in the sediment (*S. alba*) was found at Ewe Island (site 6) and Mulbin Yerrok (site 22). Small grazing snails occurred at sites in the Murray Mouth.

Chironomid larvae were found at all sites, and most abundant in the Murray Mouth between Monument Road (site 1) and Ewe Island (site 6), and at Parnka Point (site 24) in the North Lagoon. They have been abundant since flow resumed, albeit with fluctuating numbers at the various study sites over the years (Figure 14, SM-Figure 14). While other insect larvae were found as well, chironomids accounted for the majority of Hexapoda in the samples (Figure 14 and SM-Figures 15 and 16).

Overall, abundances were significantly different across the surveys from 2004 to 2013 and sites (nested in regions) for total macroinvertebrates as well as the major macroinvertebrate taxa and single key species (SM-Table 7).

While the findings from the recent monitoring clearly indicate a recovery, they also illustrate that there is no uniform response of macroinvertebrates to the changing environmental conditions in the system. The species specific distribution patterns, recovery times and abundances indicate that populations of macroinvertebrates can display idiosyncratic response pathways to environmental changes. High numbers of macroinvertebrates were found during the entire monitoring period at the salinity range measured in late 2013, and abundances recorded in late 2013 fitted well within the pattern from previous years (Figure 15, SM-Figure 17). With salinities thus benign again for macroinvertebrate populations, factors other than salinity must account for the species specific recoveries and differences between sites.

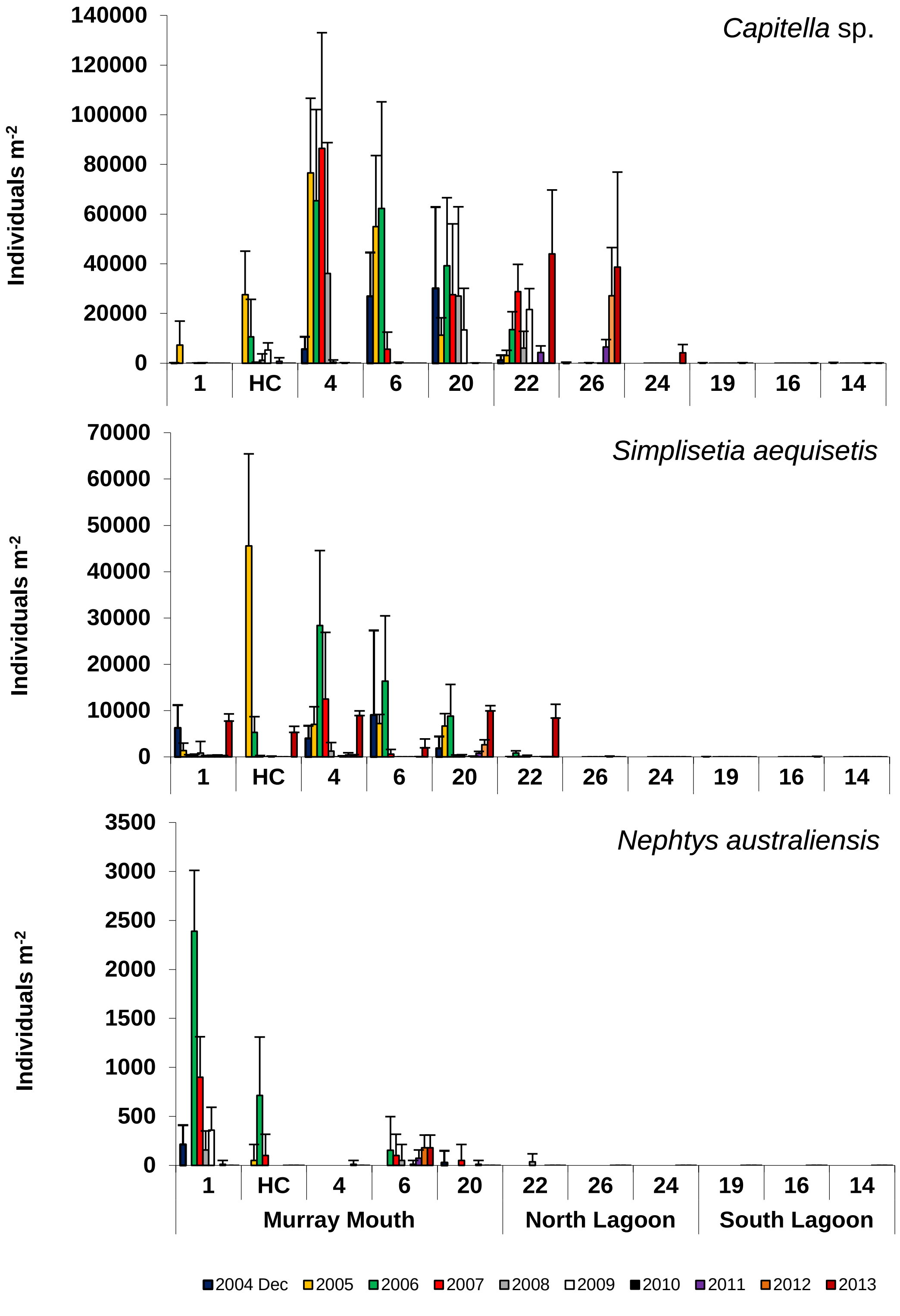

Figure 14, continued…

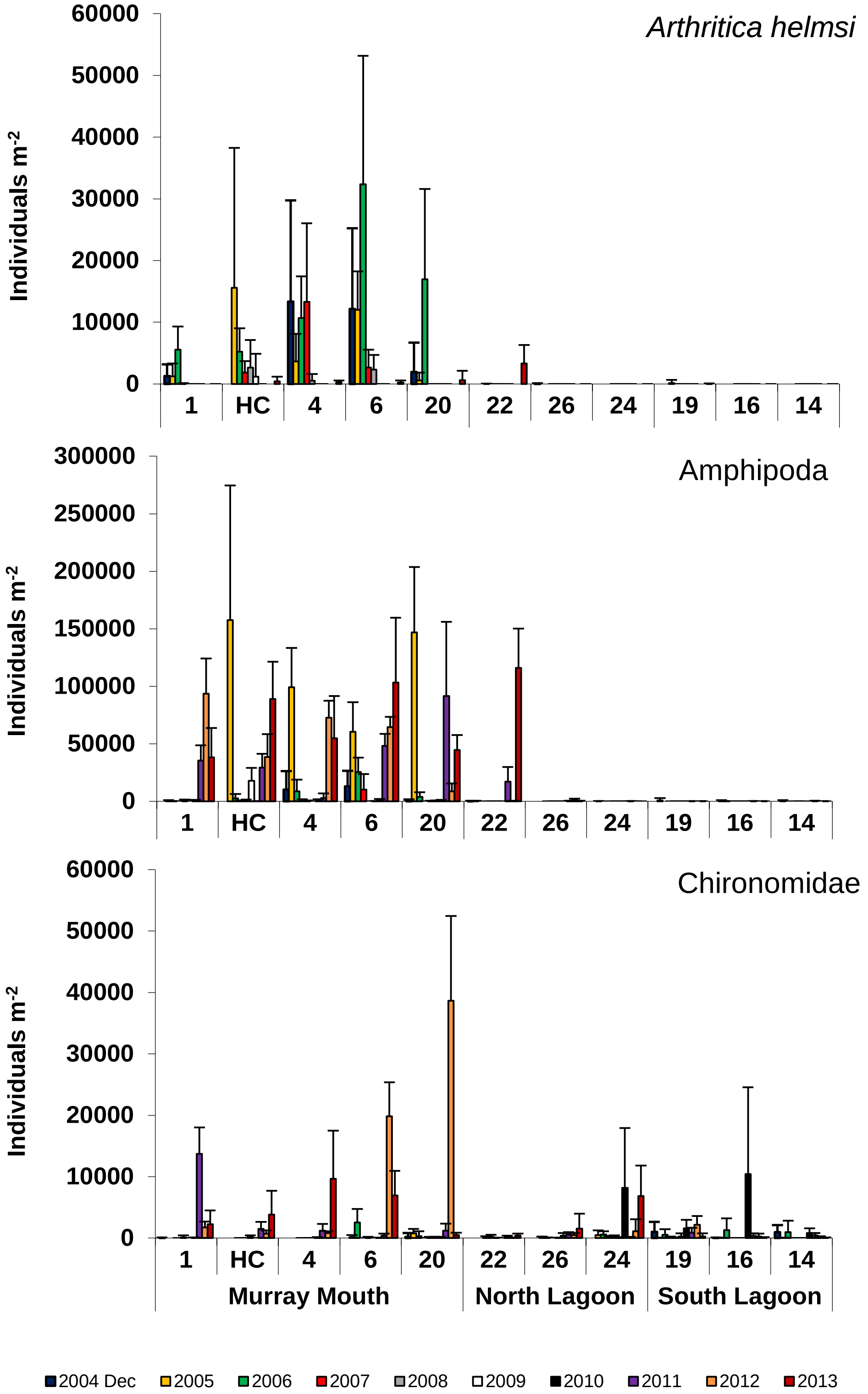

Figure 14. Mean abundances (ind. m^{-2}) and standard deviation (± S.D.) (*n* = 10) of key species and taxa identified in the TLM condition monitoring plan (Maunsell 2009), recorded at sites around the Murray Mouth and Coorong since 2004. Note not all sites were sampled during each survey and the different scales of the y-axis.

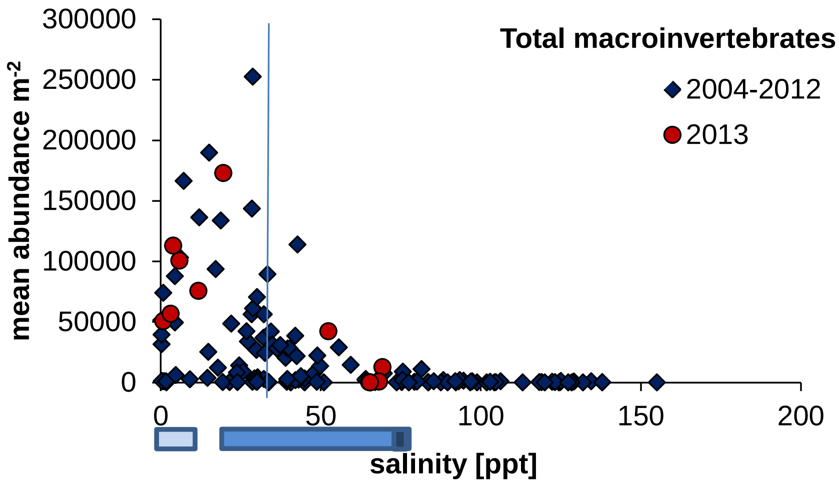

Figure 15. Mean abundances (ind. m^{-2}) of total macroinvertebrates, based on all records from the Murray Mouth and Coorong over the entire monitoring time span from 2004 to 2013/14, in relation to the salinity at the sites and time of sampling. Abundances from the monitoring in November/December 2013 are highlighted by red circles and the salinity range recorded in the study regions during this recent sampling indicated in bottom bars with colours from light blue (Murray Mouth, 0.8-11.8 ppt) to blue (North Lagoon ,19.5-69 ppt) and dark blue for the South Lagoon (65-68 ppt). See Figure 3 for changes in salinities over the monitoring periods. The vertical line indicates the salinity of seawater.

4.2.3 Vertical distributions

Abundances of macroinvertebrates were much higher in the surface layer of the sediment than in the deeper bottom sediments with 78-95 % of total abundances occurring in the top 3 cm (Figure 16). Only at Villa de Yumpa (site 19), an almost even distribution occurred with sediment depth, yet abundances were low at this site. Amphipods, chironomid larvae, *Arthritica helmsi* and hydrobiid snails occurred almost exclusively in the surface layer, where they were easily accessible as food for short-billed shorebirds and fish (SM-Figure 18). *Simplisetia aequisetis*, *Boccardiella limnicola*, as well as *Capitella* sp. and oligochaetes were found in similar numbers in each sediment horizon (SM-Figure 18). The specimens of *Nephtys australiensis*, *Soletellina alba* were found in deeper sediment layers

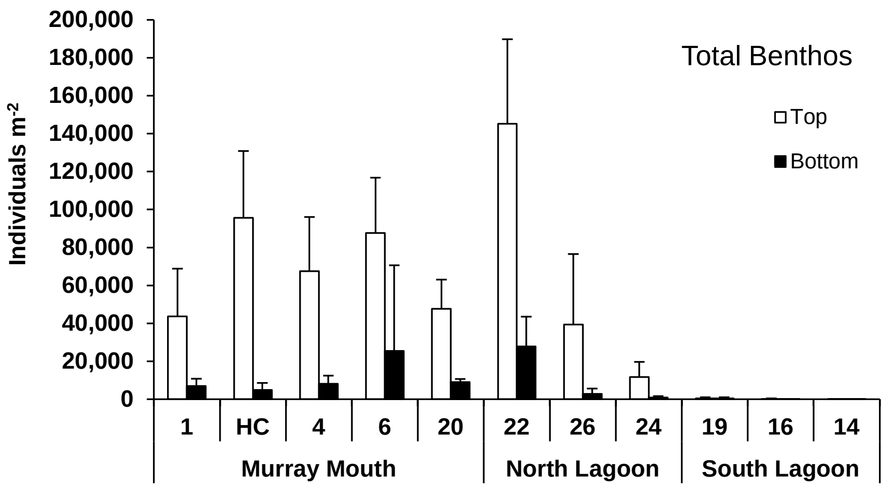

Figure 16: Vertical distribution of total benthic macrofauna (mean abundances (ind. m^{-2}) and standard deviation (± S.D.) (*n* = 10) recorded during the 2013/14 mudflat survey. Top horizon = 0 – 3 cm, bottom horizon = 3 – 15 cm sediment depth.

only. Compared to previous years, more mudflat sites in the Murray Mouth and northern Coorong lagoon provided prey for longer-billed shorebirds.

4.2.4 Macroinvertebrate biomass

Corresponding with the higher abundances of macroinvertebrates, biomass has also increased throughout the Murray Mouth and northern North Lagoon (Figure 17, SM-Table 6). Average biomass (ash free dry weight AFDW) across all sites was about 8 ± 14 g AFDW m^{-2}, and highly variable between sites. Biomass was significantly different for sites nested within regions as well as between regions (SM-Table 7).

Biomass was consistently high at nearly 9 ± 4 g AFDW m^{-2} throughout the Murray Mouth (SM-Table 6), yet the highest average value for biomass was recorded for Mulbin Yerrok (site 22), where a larger bivalve (*Soletellina alba*) occurred in the samples (Figure 17, SM-Figure14). Mulbin Yerrok had the highest macroinvertebrate abundances as well (Figure 12), and amphipods, chironomid larvae and polychaetes (*Capitella* sp., *Simplisetia aequisetis*) would have been the main contributors to the high biomass in addition to *S. alba*.

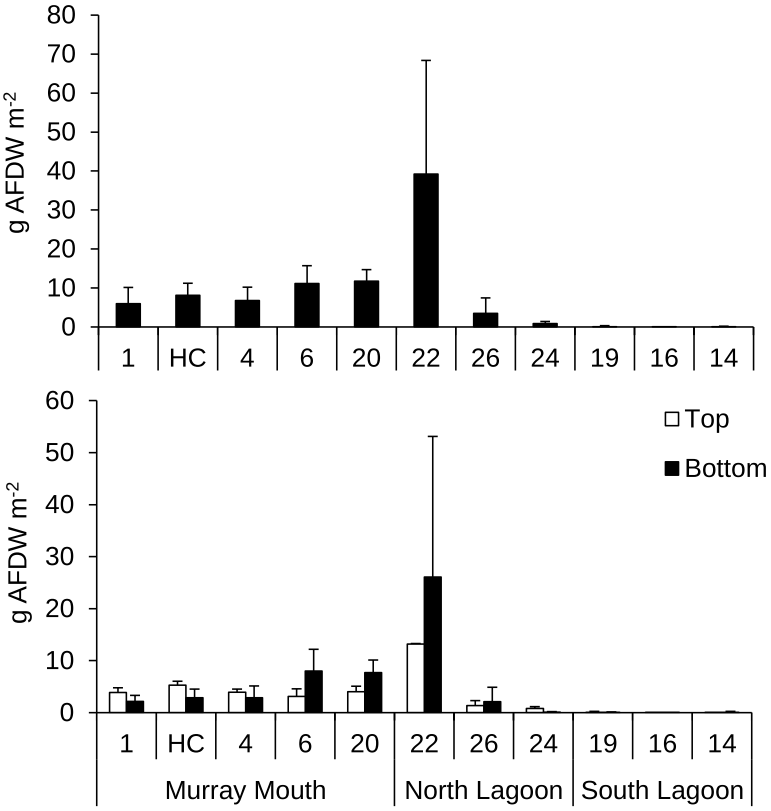

Figure 17: Mean biomass (g AFDW m^{-2}) and standard deviation (± S.D.) (*n* = 10) of benthic macrofauna recorded at sampling sites during the 2013/14 summer survey. Biomass is shown in total over the entire sediment sample depth (top figure), and for the two depths horizons (top = 0-3 cm, bottom = 3 – 15 cm) (bottom figure).

The contribution of *S. alba* to the biomass at Mulbin Yerrok (site 22), as well as Ewe Island (site 6) was also evident from the depth distribution, as this bivalve was only recorded in the bottom horizon, and both of these sites had higher biomass with greater sediment depth (Figure 17 and SM-Figure

18). The higher biomass with sediment depth at Pelican Point (site 20) was due to the abundance of *S. aequisetis* in the bottom horizon at this site (Figure 17 and SM-Figure 18). This finding is similar to records from the last monitoring in December 2012, and indicates that this site offers a rich food supply for shorebirds with medium to long bill length.

Throughout the Murray Mouth, several macroinvertebrate species were present with greater abundances at all sites (SM-Figure 16) and would have contributed to the high biomass recorded in that region (Figure 17). At Noonameena (site 26), the polychaetes *Capitella* sp. and *Australonereis ehlersi* were abundant and contributed to the biomass at this site (Figure 17 and SM-Figure 16). Throughout the Murray Mouth and northern North Lagoon of the Coorong, macroinvertebrate biomass was the highest recorded for many years and at several sites more comparable to pre-drought levels (Figure 18, SM-Figure 19). There was high variability in biomass within a site in 2013 as well as in some earlier monitoring years, yet biomass values were significantly different between the monitoring

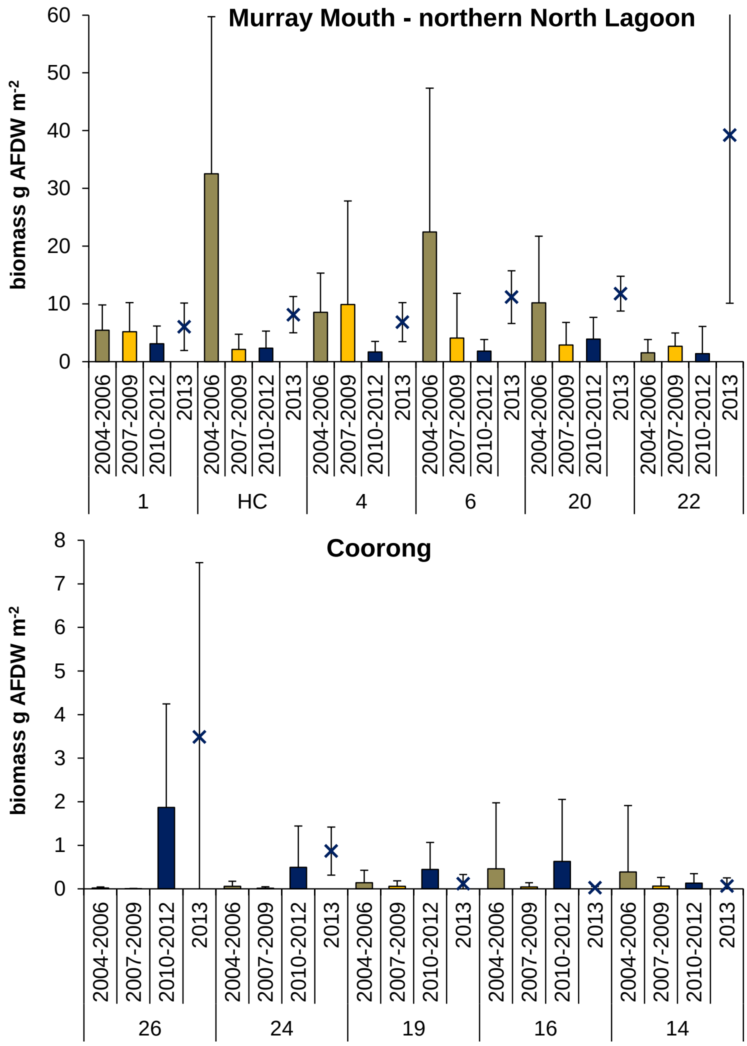

Figure 18: Biomass of benthic macrofauna (g AFDW m^{-2}) (mean and standard deviation, n=-10) at sites sampled in the Murray Mouth and northern section of the North Lagoon (top figure) and remaining Coorong (bottom figure) over the monitoring time frame since 2004, divided into periods of early drought/small flow (2004-2006), severe drought (2007-2009) and restored flow (2010-2012). Biomass from the current monitoring in 2013/14 is separately indicated with asterisks. Note the order of magnitude difference in the y-axes scales.

years and sites nested in region (SM-Table 7, SM-Figure 19). The sampling sites in the Coorong south of Noonameena (site 65) continued to have very low biomass of macroinvertebrates (Figure 18, SM-Figure 19).

Based on the abundance and biomass data, food availability for shorebirds and fish in late spring/early summer 2013 was one of the highest recorded since the early monitoring years, and indicate the recovery of macroinvertebrate populations.

4.2.5 Macroinvertebrate communities

The benthic community at the Murray Mouth sites and Mulbin Yerrok (site 22) from the North Lagoon formed a well-defined cluster, distinct to the community found at the two other sites in the North Lagoon and the South Lagoon sites (Figure 19). The macroinvertebrate communities were significantly different between regions (Pseudo-F = 10.341, $P_{(perm)}$ = 0.0004) and sites nested in regions (Pseudo-F = 9.693, $P_{(perm)}$ = 0.0001).

The major break between benthic communities was between Mulbin Yerrok (site 22) and Noonameena (site 26). Characteristic species for the benthic community at the Murray Mouth sites and Mulbin Yerrok (site 22) were amphipods, *Simplisetia aequisetis*, chironomids, and *Boccardiella limnicola* (SM-Table 8, Figure 19). Species characteristic for the benthic community at Noonameena (site 26), Parnka Point (site 24) and Villa de Yumpa (site 19) were *Capitella* spp., chironomids and ostracods. Among the South Lagoon sites, samples from site 19 (Villa de Yumpa) were a bit more similar to the North Lagoon sites, while the remaining two sites from the South Lagoon were less well defined and different to all other sites (Figure 19).

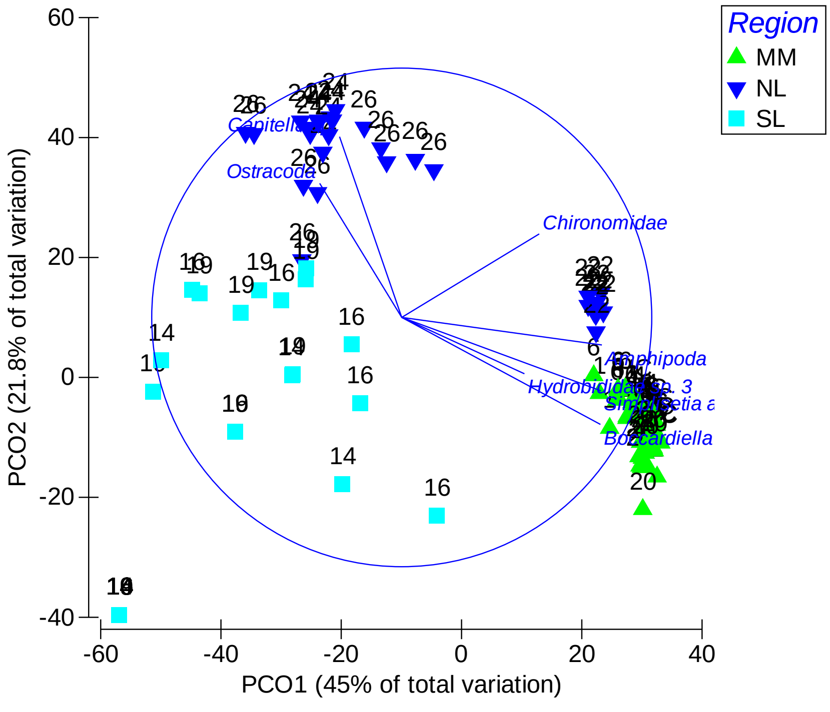

Figure 19: Principal coordinate analysis (PCO) of macroinvertebrate data from the mudflat survey in summer 2013/14, with the regions MM=Murray Mouth (sites 1, HC, 4, 6 and 20), NL=North Lagoon (sites 22, 26 and 24) and SL=South Lagoon (sites 19, 16 and 14). The circle represents a vector overlay (Spearman correlation) illustrating the contribution of the respective species to the PCO axes.

Seen across all monitoring years, regional differences in benthic communities were apparent, with communities from the Murray Mouth and South Lagoon most distinct from each other, while the benthic community in the North Lagoon was less well defined and showed similarities with either adjacent region over the years (SM-Figure 20). For the Murray Mouth, the years since flow resumed in 2010 group closer to each other than the earlier monitoring years (SM-Figure 20). The macroinvertebrate communities were significantly different across all survey years, subject to the sites within each region (SM-Table 9).

A greater distinction between benthic communities of the three regions becomes apparent from plotting the Global R value from a test statistic (Figure 20). At the start of the monitoring, in 2004-2006, the three regions had distinct communities, shown by a high value for R. During the drought, the macroinvertebrate assemblages between the Murray Mouth, the North and South Lagoon were more similar to each other, with few species and individuals occurring in the sediments at almost all sites. Since flow resumed in 2010, the differentiation between any two combinations of regions, as well as between all three regions, has become greater again, due to the recovery being more prominent in the Murray Mouth and northern North Lagoon. This recovery in the North Lagoon causes the greater differentiation with the South Lagoon, as the higher values for R between these two regions indicate (Figure 20).

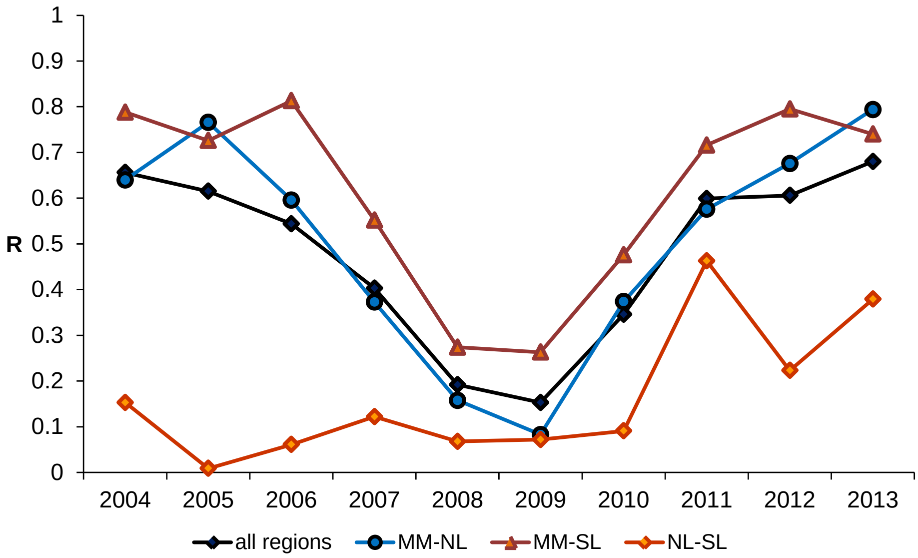

Figure 20: Differences in the similarity of macroinvertebrate communities between the three regions in the Murray Mouth (MM) and Coorong (North Lagoon = NL, South Lagoon = SL) over the monitoring years, based on the Global R statistic from ANOSIM tests. R indicates the degree of separation, with R-values closer to 1 indicating greater differences, and R-values closer to 0 indicating greater similarity between regions. Differences are shown for any combination between regions, and the black line indicates differences between all regions.

Does a greater distinction in the macroinvertebrate communities of the three regions imply a return to the same communities that occurred in the early monitoring period before the drought? To explore this question, the community change over time was followed with trajectories (Figure 21). For the Murray Mouth, the macroinvertebrate community developed in a new direction since the onset of flow in 2010, different from the community that existed at these sites before and during the drought. In the North

Lagoon, no significantly different clusters were found, but the community present in the years of drought (2006-2009) grouped more closely and 2010 emerged as an outlier with a different community in response to the large freshwater impulse. In the following years, the macroinvertebrate community in the North Lagoon took a trajectory towards the early monitoring years, but started to deviate in 2013. For the South Lagoon, no clear direction of community development during the monitoring years emerged, and no significantly different clusters of years with greater macroinvertebrate community similarity were found.

The overall trajectory for macroinvertebrate communities in the entire Murray Mouth and Coorong is thus mainly driven by developments in the Murray Mouth (Figure 21). The communities at the height of the drought (2009), the onset of flow (2010) and during the initially slow recovery (2011) are clearly different from earlier monitoring years and the community which is developing in the system now.

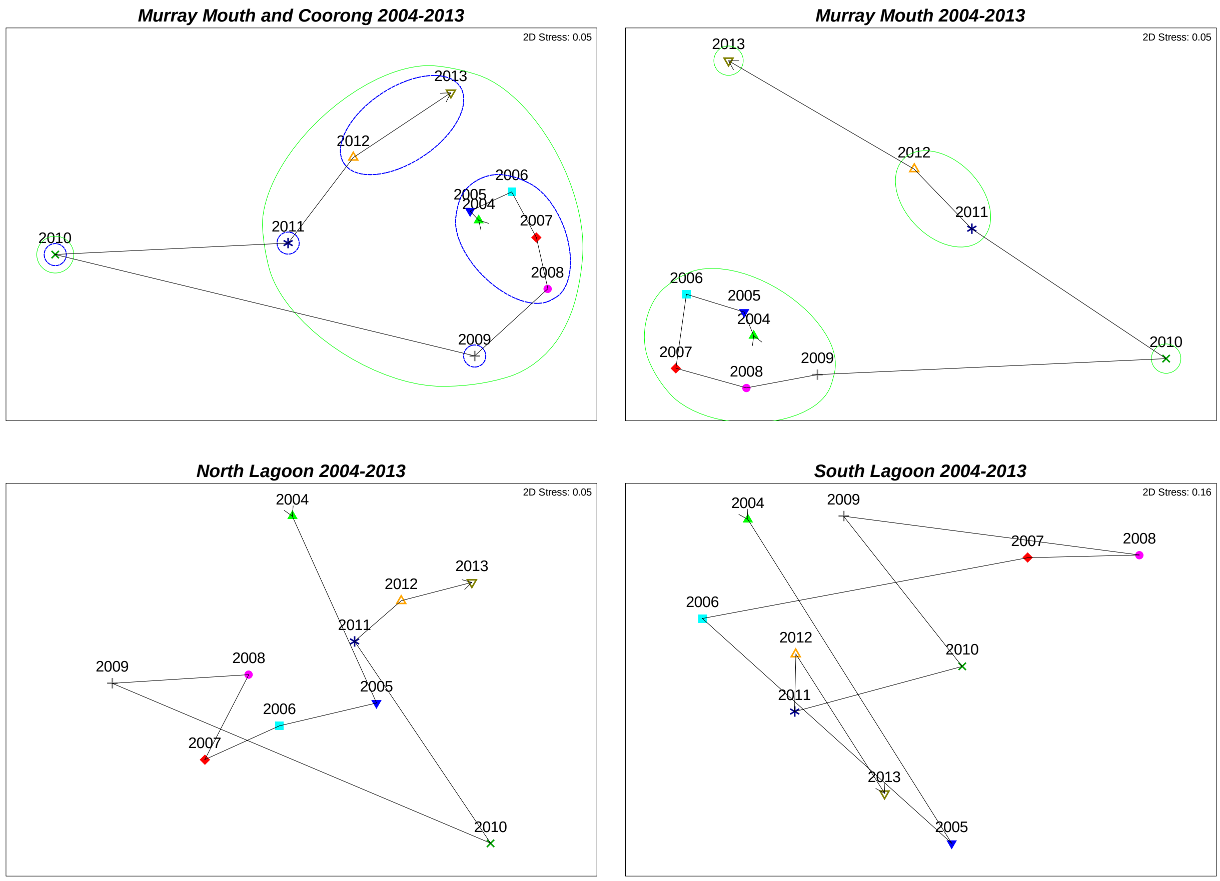

Figure 21: nMDS ordination plots showing trajectories of change in macroinvertebrate communities in the mudflats from each of the regions of the Murray Mouth, North and South Lagoon, as well as for the entire Murray Mouth and Coorong, in the monitoring from 2004 to 2013. The lines are connecting consecutive years. The circles are delineating significantly different clusters, based on SIMPROF tests, showing 50 and 70% similarity for the Murray Mouth and Coorong, and clusters with 60% similarity for the Murray Mouth.

4.2.6 Environmental conditions as predictor variables for macroinvertebrate communities

The main environmental variable contributing to the pattern of macroinvertebrate communities in the Murray Mouth and Coorong in 2013 was salinity, which explained 51% of the variation in the macro-invertebrate data. Nearly 53% of the total variation in the macroinvertebrate community data was explained by the considered water and sediment variables (Figure 22). Sediment organic matter contributed 23% and sediment Chl-*a* 20% to the community differentiation, while sediment grain size, sorting or dissolved oxygen saturation had no statistically significant contribution. The dbRDA plot is illustrating that the main differentiation of macroinvertebrate communities between the Murray Mouth and Mulbin Yerrok (site 22) in the North Lagoon was driven by a range of environmental conditions, primarily salinity (Figure 22).

The changes in macroinvertebrate communities over time described above (chapter 4.2.5) can be mainly attributed to changes in salinity. For each of the three regions, salinity explained between 13% (South Lagoon) and 21% (Murray Mouth) of the variation in the community data between 2004 and 2013 (SM-Table 10). Other environmental variables contributed less than 10% or not at all to the variation in macro-invertebrate communities. Chlorophyll-a, which was included since 2007 as a

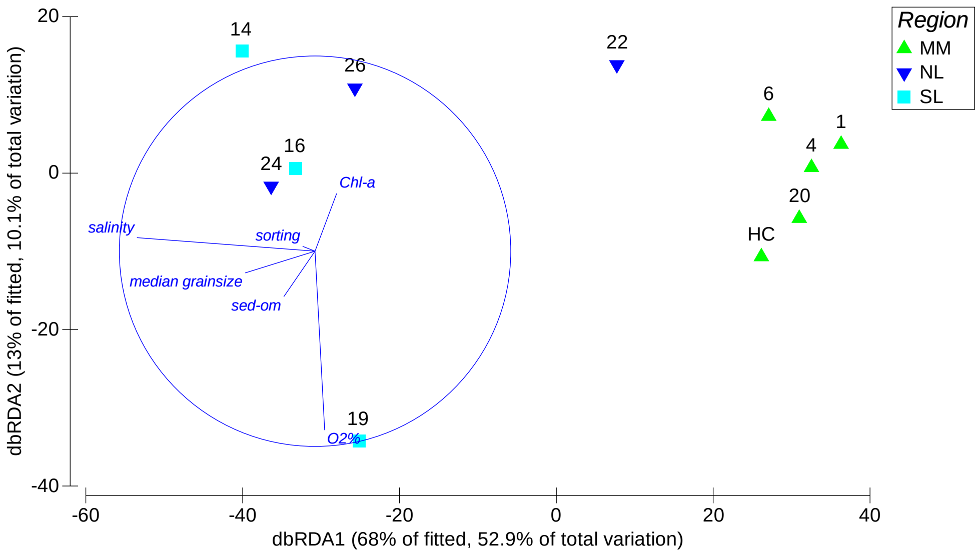

Figure 22: dbRDA (distance based redundancy analysis) illustrating relationships between environmental parameters and the benthic community at the study sites in summer 2013/14. The vector overlay uses base variables of environmental data. The site codes are 1, HC, 4, 6 and 20 for the Murray Mouth, 22, 26 and 24 for the North Lagoon, and 19, 16 and 14 for the South Lagoon (see Figure 2).

further sedimentary variable affecting macroinvertebrates, explained between 7% (Murray Mouth) and 18% (South Lagoon) of the variation (SM-Table 10).

In the dbRDA plots for relationships between the environmental conditions and macroinvertebrate communities, the years since flow resumed appear separate from pre-flow years (towards the left of the figures for the Murray Mouth and South Lagoon, Figure 23). For the North Lagoon, such a distinction was less clear (Figure 23), yet became more apparent in the data series since 2007 when Chl-*a* was included (SM-Figure 21), suggesting that further habitat conditions were relevant for structuring the macroinvertebrate community.

The first axis of the dbRDA plots explained only between 15 and 27% of the total variation in macroinvertebrate communities in each region over the time frames (2004-2013 Figure 23; 2007-2013 SM-Figure 21). Based on the DISTLM analyses, over the time frame from 2004 to 2013, all five variables explained only 28-31% of the variation, while in the time period from 2007 to 2013, when

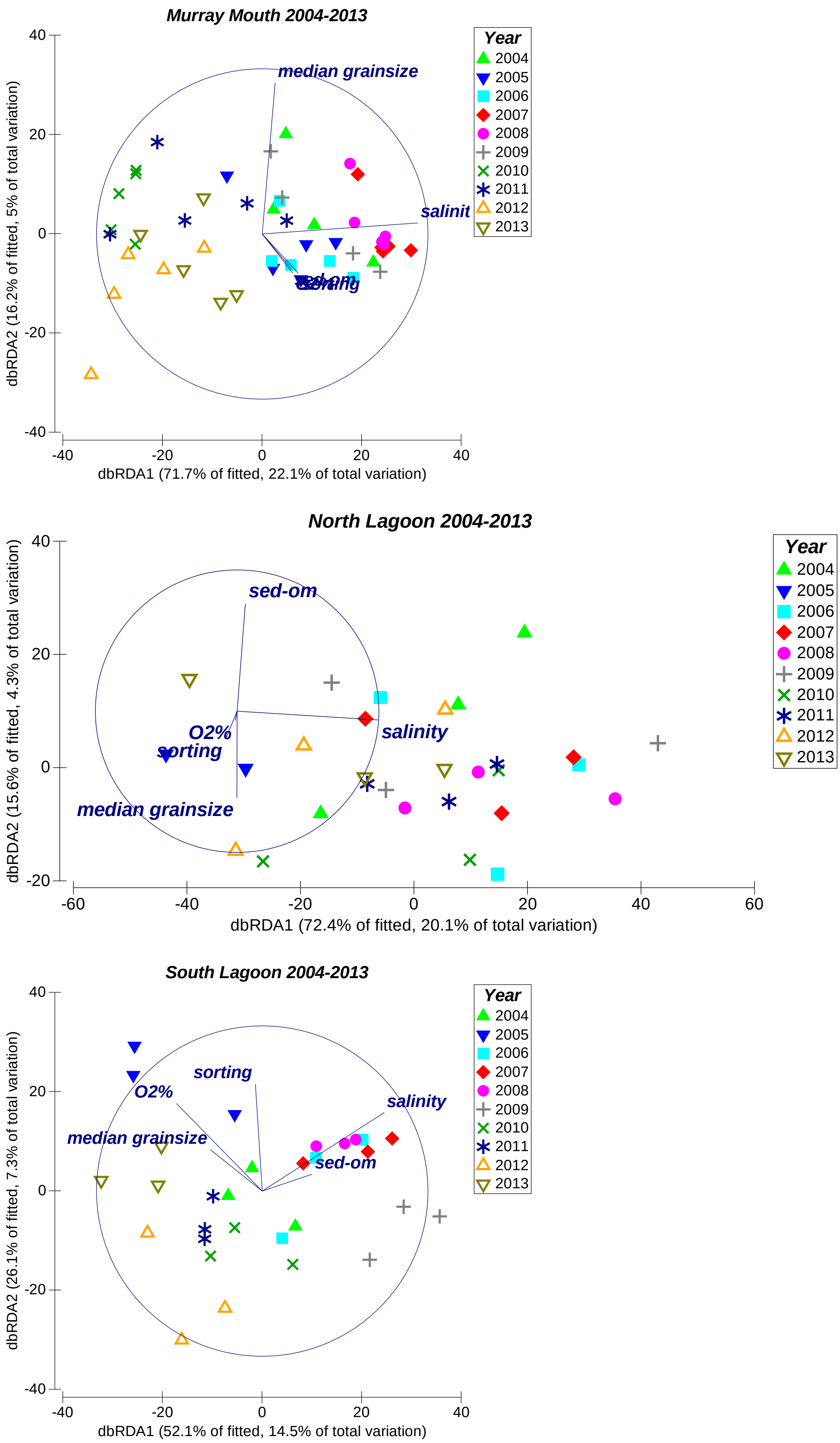

Figure 23: dbRDA (distance based redundancy analysis) plots for the three separate regions Murray Mouth, North and South Lagoon of the Coorong, illustrating relationships between environmental parameters and the benthic community at the study sites in the surveys from December 2004 to December 2013. The vector overlay uses base variables of environmental data that explain the patterns in macroinvertebrate communities.

Chl-*a* was also measured in sediments, the six variables together explained 40-47% of the variation in macroinvertebrate communities in the Murray Mouth and Coorong lagoons. Further environmental or biotic factors that are not assessed in this monitoring must be affecting the macroinvertebrates occurring throughout the Murray Mouth and Coorong.

As presented throughout chapter 4.2, the assessment of macroinvertebrate populations in the recent survey and in relation to the previous monitoring, the condition monitoring target I-1 '*Maintain or improve invertebrate populations in mudflats'* has been met. The recovery of macroinvertebrate populations in the fourth year of continued flow was apparent in the data. As the trajectories of macroinvertebrate community change were not showing a return to the pre-drought conditions ten years ago when the monitoring started, further recolonisation is needed, and the system may develop beyond the arbitrary reference point of 2004, as environmental conditions improve.

5. Results – Goolwa Channel and Lower Lakes

5.1 Environmental conditions

5.1.1 Salinity regime and water level

Salinities in the Lower Lakes were fresh (0.44 ppt on average) in the Goolwa Channel and Lake Alexandrina, to slightly brackish (1.67 ppt on average) in Lake Albert (Figure 24). As in the previous year, salinities were below 1 ppt in the Goowa Channel and Lake Alexandrina, and up to 2 ppt at Narrung and Lake Albert. Salinity measurements in the Lower Lakes during 2013/14 were among the lowest salinity values recorded over the entire monitoring timeframe, reflecting the continuous freshwater influx from the Murray River since flows resumed in late 2010 (Figure 24, SM-Figure 22).

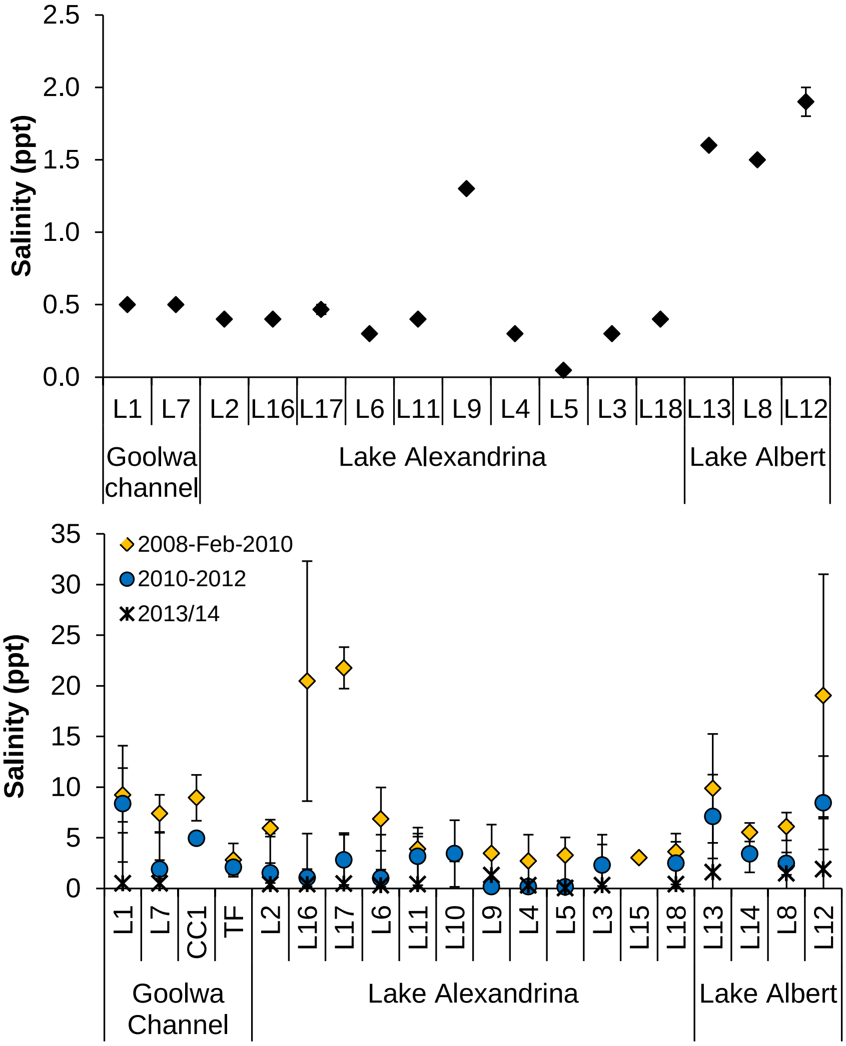

Figure 24: Salinity (mean ppt ±S.E.) of waters overlying sediments in the Goolwa Channel, Lake Alexandrina and Lake Albert during the survey in summer 2013/14 (top figure) and during surveys since December 2008, averaged across three years of severe drought (2008-February 2010) and since river flows resumed (2010-2012) (bottom figure). Salinities from the current monitoring year are separately displayed in the bottom figure. Sites were L1=Goolwa Channel, L7=Hindmarsh Island, L2=Clayton, L16=Mundoo Channel (Lake), L17=Ewe Island (Lake), L6=Pelican Point (Lake), L11=Loveday, L9=Narrung, L4=Milang, L5=Poltalloch, L3=Tolderol, L18=Boggy Lake, L13=Seacombes, L8=Waltowa, L12=Vanderbrink (see Figure 2). Note that not all sites were included in the monitoring each year, and the large difference in scale of the y-axis between plots.

Salinity differed significantly among sites (SM-Table 11) due to the slightly higher salinities recorded at Narrung (site L9) and at sites in Lake Albert (sites L13, L8 and L12). Narrung is located at the connection between Lakes Alexandrina and Albert, and the slightly higher salinity in Lake Albert could have locally increased salinity at Narrung, but not reached nearby sites in Lake Alexandrina (e.g. site L5: Poltalloch) (Figure 24). The real difference in salinity was only a range of 0 – 2 ppt across all sites, which in ecological terms, is unlikely to affect macroinvertebrate communities.

Salinity was also significantly different across the survey years (SM-Table 11), with highest salinities recorded at most sites during the drought (2008 – 2009), then steadily decreasing as flow commenced in late 2010. Freshwater conditions prevailed in the Lower Lakes during the last two surveys (*i.e.* 2012/13 and 2013/14) (SM-Figure 23). Barrages were open during the survey time, but freshwater conditions recorded on the lake sides of the barrages (i.e. sites L1, L6, L17 and L16; Figure 24) indicated that no influx of seawater occurred.

Regarding the condition monitoring target M-1 '*Facilitate frequent changes in exposure and submergence of mudflats'*, the continuous river flow since 2010 and high water levels in the Lower Lakes have kept sediments permanently submerged and inaccessible for foraging shorebirds. This target has thus not been met for the Lower Lakes.

5.1.2 Water Quality

The average water temperature in the Lower Lakes was 22 ºC (range 16 – 25 ºC) at the time of sampling in January and February 2014, which was within the range or lower than temperatures recorded in previous monitoring (SM-Figure 24). Dissolved oxygen (DO) concentration in the water was 8 mg L^{-1} on average, ranging from 5 – 11 mg L^{-1}, and DO saturation (DO%) was 94% on average, ranging from 56 – 122%. In both cases, the lowest DO values were recorded at Clayton Bay (site L2) and the highest at Poltalloch (site L5). Dissolved oxygen saturation was around or above the ANZECC trigger value of 90% saturation at most sites, and only lower at Clayton Bay (site L2), in the Goolwa Channel (sites L1 and L7), Narrung (site L9), and Waltowa (site L8). Yet overall, the DO concentration and saturation values fell within the range of values reported in earlier monitoring years (SM-Figures 25 and 26). In the 2013/14 monitoring, there were no significant differences in DO saturation across the regions of the Lower Lakes, but between the sites within the regions (SM-Table 11). In the monitoring since 2008, significant differences in DO% were detected over survey years (SM-Table 11), and irrespective of any site or region, DO% in the Lower Lakes were higher in 2008 and 2009 than in subsequent surveys, including the most recent one in summer 2013/14 (SM-Figure 27). The pH in the water was 6.0 on average, with little variation across the sites, and was lower during 2013/14 compared to previous monitoring periods (SM-Figure 28), which could have been affected by the pH strips used.

5.1.3 Sediment size ranges

Sediments were mainly classed as fine to medium sands (Table 3). The sites with slightly coarser sediment were around the north-western shores of Lake Alexandrina, at Boggy Lake (site L18), Poltalloch (site L5), Narrung (site L9), at Waltowa (site L8) in Lake Albert, and on the lake side of Pelican Point (site L6). The lake side of Ewe Island (site L17) had the finest sediment. Goolwa Channel (site L1) and Tolderol (site L3) had similar sediment compositions, dominated by fine sands. Sediments at Clayton (site L2), Pelican Point (Lake) (site L6), Seacombes (site L13) and Waltowa (site L8) were characterised by a mix of silts and very course sands (SM-Figure 29). Most sediments were moderately to moderately well sorted (Table 3). There were no significant differences in the median grain size across regions, but there were differences between sites within regions (SM-Table 11, SM-Figure 30).

Table 3: Sediment characteristics of sampling sites in the Lower Lakes survey in summer 2013/14. Organic matter content (per cent dry weight) within the sediment and the median grain size of sediment (in µm) with the sorting coefficient, are provided as characteristics of sediment. The verbal description of sediment grain size and sorting follows Blott & Pye (2001).

Site		Organic matter (% dw)	Grain size			
			Median		Sorting	
			size	description	S_o	description
Goolwa Channel	L1	0.56	169.26	Fine sand	0.77	Moderately sorted
	L7	0.26	156.50	Fine sand	0.59	Moderately well sorted
Lake Alexandrina	L2	4.27	182.32	Fine sand	0.24	Very well sorted
	L16	1.20	161.13	Fine sand	0.44	Well sorted
	L17	1.09	78.19	Very fine sand	0.33	Very well sorted
	L6	1.15	254.28	Medium sand	0.53	Moderately well sorted
	L11	0.28	244.47	Fine sand	0.75	Moderately sorted
	L9	0.87	467.23	Medium sand	0.55	Moderately well sorted
	L4	3.08	212.61	Fine sand	0.58	Moderately well sorted
	L5	0.12	472.82	Medium sand	0.75	Moderately sorted
	L3	0.20	181.77	Fine sand	0.78	moderately sorted
	L18	0.21	378.38	Medium sand	0.68	Moderately well sorted
Lake Albert	L13	2.19	236.81	Fine sand	0.46	Well sorted
	L8	5.44	276.75	Medium sand	0.22	very well sorted
	L12	0.22	237.95	Fine sand	0.76	Moderately sorted

Over the monitoring years, sediments at most of the Lower Lake sampling sites were dominated by medium and coarse sands during 2008/09 and 2011/12, and while coarser sediments were still present, the sediments encountered in the last two years were often finer sands and mud (separated along PC1, Figure 25). Apart from two outliers, the median grain size did not differ significantly between regions and over the years (SM-Table 11; Figure 26). Thus, the condition monitoring target M-2 '*Maintain sediment size range in mudflats*' was met for sediments in the Lower Lakes as well.

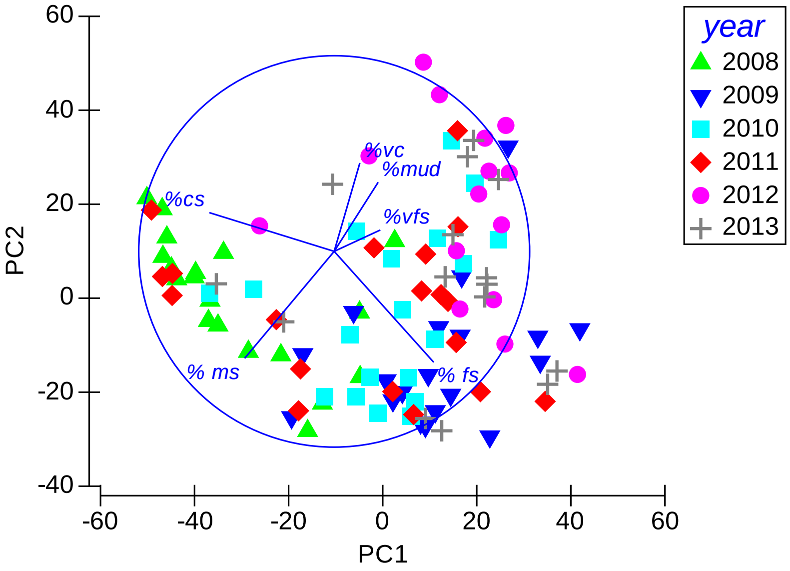

Figure 25: PCA (Principal component analysis) of sediment grain size compositions (% of major fractions, size in µm) in sediments around the Lower Lakes during the summer surveys from 2008 to 2013/14, when most sites were sampled annually (right plot) (PC1 = 50.5; PC2 = 29.8).

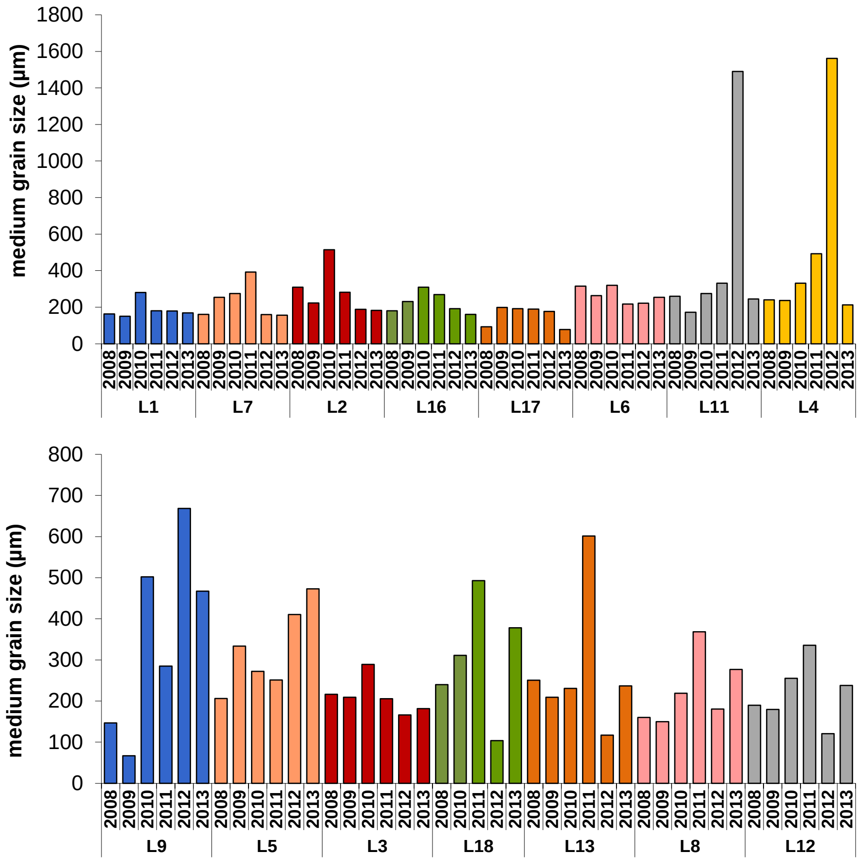

Figure 26: Median grain size values recorded in sediments around the Lower Lakes, sampled since 2008. Note the different y-axes labels due to some outlying coarser sediment at Loveday and Milang. Sites were L1=Goolwa Channel, L7=Hindmarsh Island, L2=Clayton, L16=Mundoo Channel (Lake), L17=Ewe Island (Lake), L6=Pelican Point (Lake), L11=Loveday, L4=Milang, L9=Narrung, L5=Poltalloch, L3=Tolderol, L18=Boggy Lake, L13=Seacombes, L8=Waltowa, L12=Vanderbrink (see also Figure 2).

5.1.3 Sediment organic matter and chlorophyll-*a*

The sediment organic matter content was low on average (1.4 % dry weight), and ranged from 0.1 to 5.4 % dry weight, with highest values recorded at Waltowa (site L8), Clayton (site L2) and Milang (site L4) (Figure 27). These sites had high sediment organic matter in previous monitoring and the values recorded in summer 2013/14 fell well within this range. At most of the other sites, sediment organic matter was also within the range of previous records or lower (Figure 27). While significant differences in sediment organic matter were found between sites in 2013/14, no significant differences occurred over the monitoring years, nor between regions within the Lower Lakes (SM-Table 11). Thus, the condition monitoring target M-3 '*Maintain organic content for mudflats*' was met for sediments around the shores of the Lower Lakes.

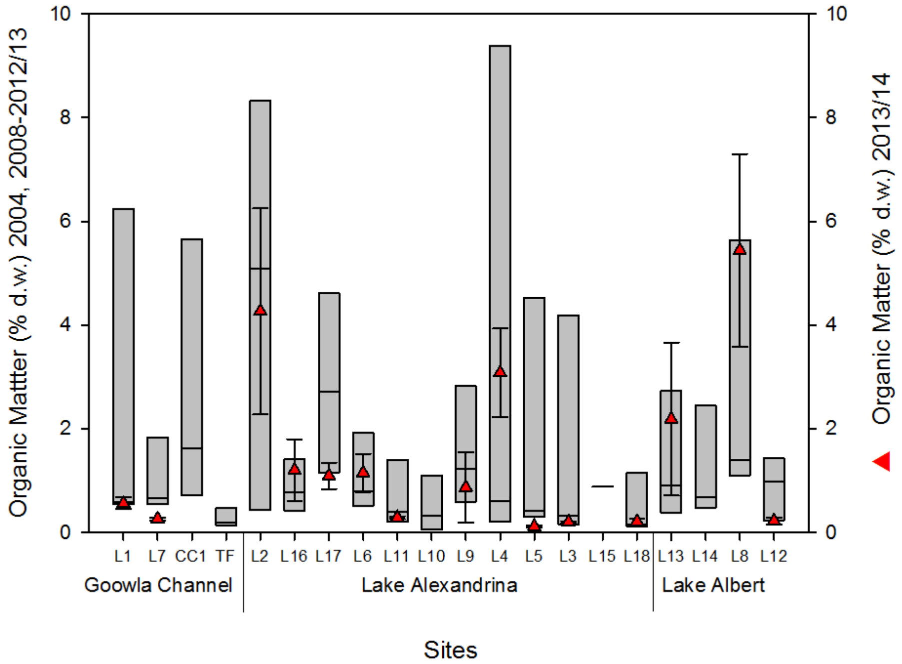

Figure 27. Sediment organic matter (as % dry weight) at sites in the Goolwa Channel, Lake Alexandrina and Lake Albert during surveys from 2004 – 2012/13 (boxplot) and during the survey in summer 2013/14 (red triangles ▲; average ± SE).

The chlorophyll-*a* content of sediments around the Lower Lakes was 1.3 mg m^{-2} on average, and varied significantly between sites, ranging from 0.1 – 3.2 mg m^{-2}, with no apparent pattern across sites or regions (Figure 28, SM-Table 11). Several sites in Lake Alexandrina (Mundoo Channel (site L16), Pelican Point (site L6), Loveday (site L11), Narrung (site L9), Milang (Site L4) and Poltalloch (site L5)) as well as Vanderbrink (site L12) in Lake Albert had higher microalgal biomass in the sediments, yet the standard deviations also show that there was variability within each of these sites (Figure 28). At these sites, values for Chl-*a* fell within the upper range of records since 2008, whereas Chl-*a* values were at the lower end of previously recorded values at other sites (Figure 28). Chlorophyll-*a* varied significantly between years, but not between regions, nor at site level within regions when analysed for the monitoring since 2008 (SM-Table 11).

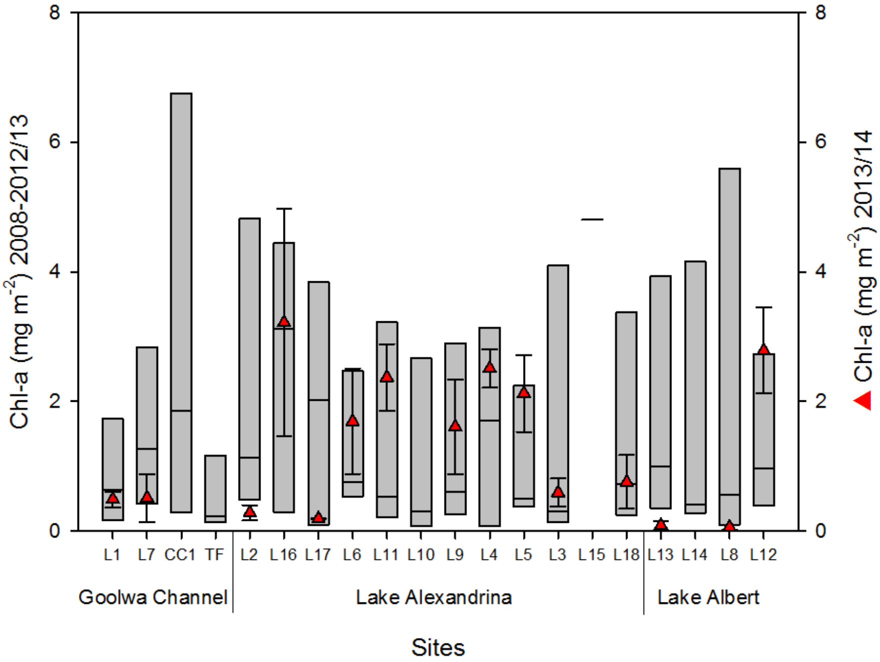

Figure 28. Sediment chlorophyll-*a* content (in mg/m²) at sites in the Goolwa Channel, Lake Alexandrina and Lake Albert during surveys from 2008 – 2012/13 (boxplot) and during the survey in summer 2013/14 (red triangles ▲; average ± SE).

5.1.5 Changes in environmental conditions between years

The combination of environmental variables measured did reveal some differentiation of sites around the Lower Lakes in the 2013/14 monitoring, with Clayton (site L2), Waltowa (site l8) and to some extent also Seacombes (site L13) characterised by lower dissolved oxygen saturation, higher organic matter, and slightly higher salinity (SM-Figure 31).

The measured environmental conditions in the water and sediments around the Lower Lakes showed some differentiation between years, with little overlap between 2008, 2009 and 2012 (Figure 29). In the recent survey in summer 2013/14, the environmental conditions were similar to those recorded in any other year before (Figure 29), and only salinity, dissolved oxygen saturation and Chl-a in sediments varied significantly between the surveys (SM-Table 11). Apart from salinity, the environmental conditions were not significantly different between the three regions (SM-Table 11).

The similarity of environmental conditions in 2013/14 with earlier monitoring years is also reflected in trajectories for each region (SM-Figure 32), which also showed that 2008 was different to the following years.

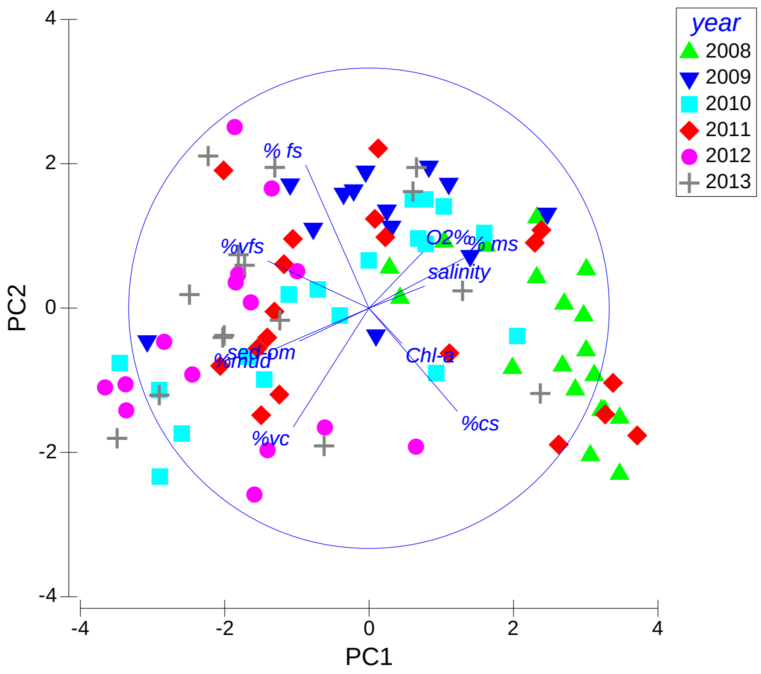

Figure 29: Principle component analysis (PCA) plot of environmental variables for each site sampled in the Lower Lakes from annual summer surveys since 2008 to 2013/14. Environmental variables included were salinity and dissolved oxygen content (O2%) from the water column, and from the sediment single grain size fractions, organic matter and chlorophyll-*a* (Chl-*a*). PC1 explains 36.8%, and PC2 24.2% of the variation.

5.2 Macroinvertebrate populations

The Condition Monitoring Target I-1: '*Maintain or improve invertebrate populations in mudflats*' is evaluated for the Lower Lakes based on continued sampling of sediments for benthic macro-invertebrates, which will be assessed for temporal changes. Detailed findings and outcomes from tests are presented in the Supplementary Material. The structure follows key parameters to assess improvements in invertebrate populations, namely diversity, abundances and distributions, biomass and community structures over time.

5.2.1 Macroinvertebrate diversity and distribution

The sediments around the Lower Lakes continue to be inhabited by few macroinvertebrate species, with most species found being larval stages of insects. In the summer 2013/14 survey, a total of 15 macroinvertebrate species were differentiated, with most of them (9 taxa) belonging to the Hexapoda (Table 4). Annelids, crustaceans and a mollusc accounted for the remaining species. Amphipods, chironomid larvae and oligochaetes occurred at almost all sampling sites around the lakes, whereas other species were recorded from single sites only (Table 4, Figure 30). A large oligochaete, *Branchiura sowerbyi,* was recorded at Narrung. This species is known globally to occur in organically enriched sediments and warm waters (Carroll & Dorris 1972). The spionid polychaete *Boccardiella limnicola*, which was also found in the Murray Mouth, occurred in the lake side of the Goolwa barrage (site L1). Ephippia (resting stages) of zooplanktonic water fleas (Daphniidae) were noted in the sediment samples from several sites.

More species were found at sites in Lake Alexandrina (11 taxa) and Lake Albert (8 taxa) than in the Goolwa Channel (4 taxa), yet the higher number of sampling sites around Lake Alexandrina has to be taken into account. The highest total number of species was recorded at Milang (site L4), which also had the highest diversity (H' = 1.5, Figure 30), similar to earlier monitoring years (SM-Table 12). Diversity measures continued to be low for macroinvertebrates at sampling sites around the Lower Lakes, combined with low eveness due to dominance of single taxa in the samples (SM-Table 12). The species density was very low overall and in each region, less than 2 species were found per sample on average. There were significant site specific differences in species density, but not between regions (SM-Table 13). Over the monitoring years since 2008, when most sites were more continuously sampled, species density differed significantly over the survey years and sites (SM-Table 13).

In each region of the Lower Lakes, both species numbers and diversity (H') were lower than in the survey 2012/13, but fell within the range of values recorded since 2008/09 (Figure 31). Per site, species numbers of macroinvertebrates were also lower or within the range of previously recorded values, but had increased over the very low species numbers recorded last year (Dittmann et al. 2013a) at Narrung (site L9), Milang (site L4) and Tolderol (site L3) (Figure 32, and see SM-Figure 33 for surveys since 2004). No pattern was apparent in the spatial or temporal variation of species diversity and distribution for macroinvertebrates in sediments around the Lower Lakes.

Table 4: Occurrence of macroinvertebrate taxa during the 2013/14 summer survey around the Lower Lakes, based on samples obtained by sediment core or grab samples. The total number of species per site and region is also provided as well as the average number of taxa (± standard deviation).

Phyla/Class/Order		Family/Genus/Species	Goolwa Channel		Lake Alexandrina										Lake Albert		
			L1	L7	L2	L16	L17	L6	L11	L9	L4	L5	L3	L18	L13	L8	L12
Annelida	Oligochaeta		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
		Branchiura sowerbyi								✓							
	Polychaeta	*Boccardiella limnicola*	✓														
Crustacea	Ostracoda										✓				✓		
	Amphipoda		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mollusca	Gastropoda	*Physa acuta*													✓		
Hexapoda	Diptera	Eristalis (larvae)									✓						
		Chironomidae (larvae and pupae)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
		Ceratopogonidae (larvae)									✓						
		Ephydridae (larvae)															✓
	Coleoptera	Hydrophilidae (larvae & pupae)											✓				
	Ephemeroptera	Caenidae									✓						
	Odonata	Zygoptera (nymph)														✓	
	Trichoptera	Ecnomidae (larvae)				✓		✓			✓						
	Hemiptera	Micronectidae									✓		✓		✓		✓
Species number per site			**4**	**3**	**2**	**4**	**3**	**4**	**3**	**4**	**9**	**3**	**4**	**3**	**6**	**4**	**3**
Species number per region			**4**		**11**										**8**		
Species density per region			**1.35 ± 0.88**		**1.5 ± 1.18**										**1.5 ± 0.9**		

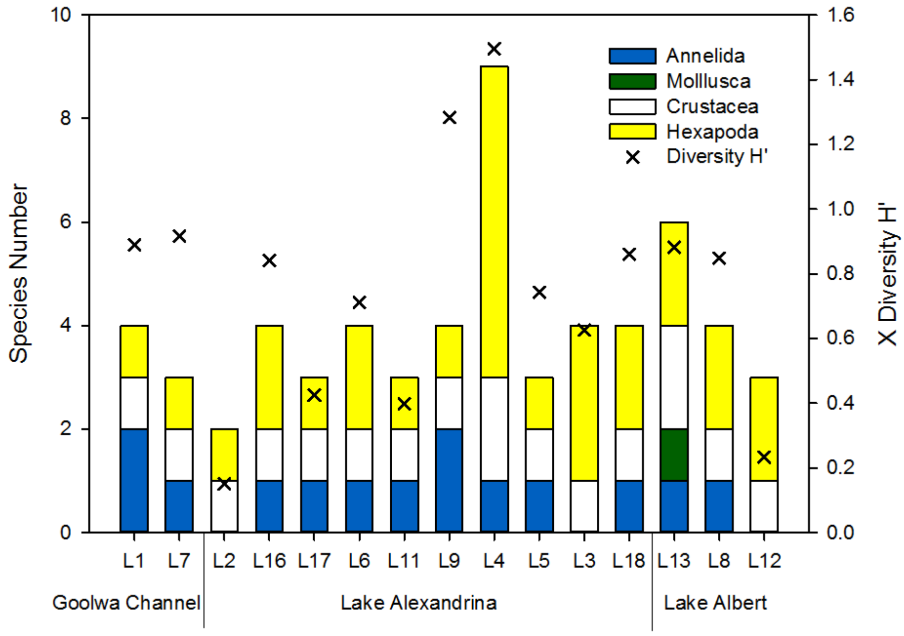

Figure 30: Total number of macroinvertebrate species recorded at the sampling sites around the Lower Lakes in summer 2013/14, based on samples taken using a sediment corer or grab. The major phyla or taxa constituting the total species count are indicated by colours. Asterisks are the Shannon-Wiener diversity index H' (base $\log_e$).

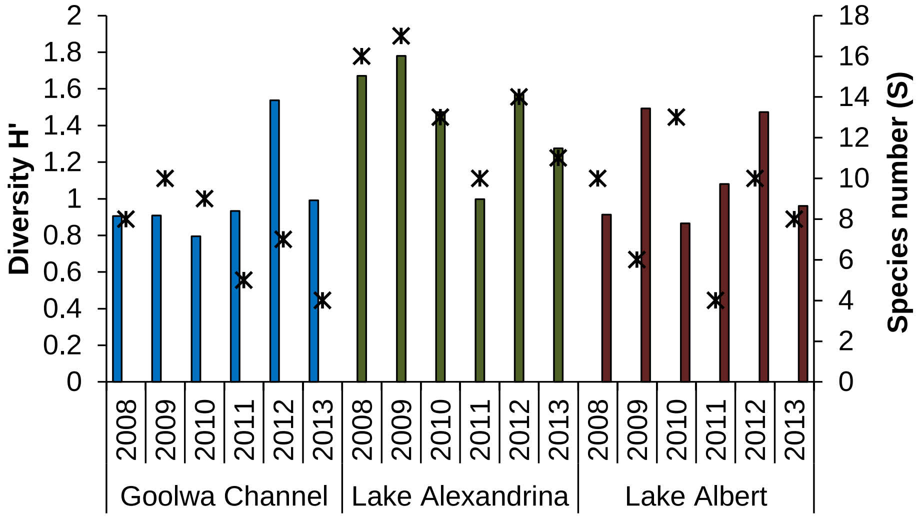

Figure 31: Changes in diversity in each of the three regions of the Lower Lakes in the monitoring periods from 2008 to 2013/14, based on samples taken with a sediment corer or grab. Bars indicate Shannon-Wiener diversity index H' (base $\log_e$) and asterisks are the species number. Note that the number of sites sampled per region differed between years.

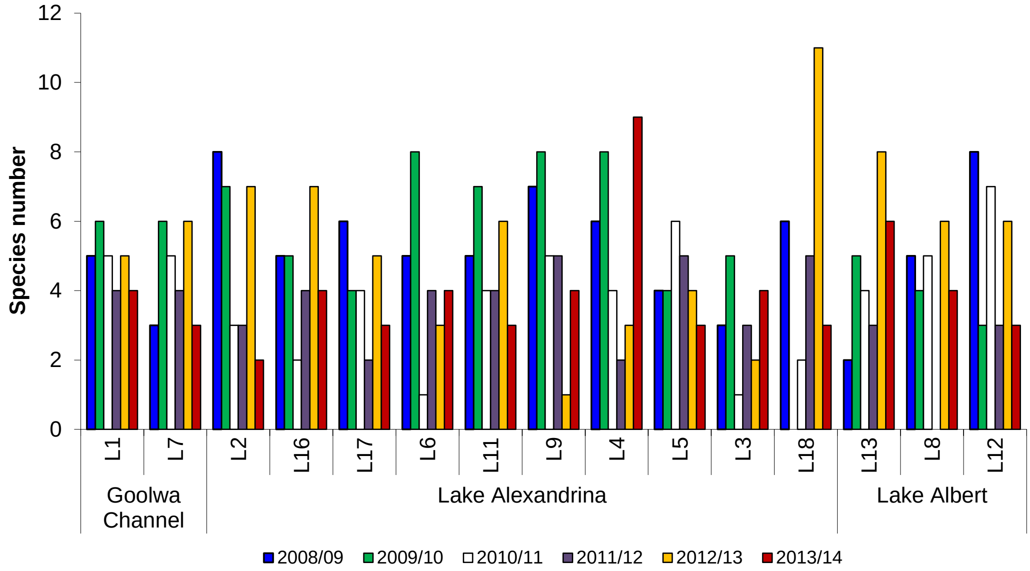

Figure 32: Total number of benthic macroinvertebrate species recorded at those sites sampled annually around the Lower Lakes since 2008, using a corer or grab.

5.2.2 Macroinvertebrate abundances and distribution

The abundance of macroinvertebrates in sediments around the Lower Lakes was very low in the 2013/14 survey, with 620 (± 748) individuals m^{-2} on average (SM-Table 14), approximately half the number observed during 2012/13 monitoring (1245 individuals m^{-2}; Dittmann et al. 2013a). The abundances were highly variable between sites, and ranged from very low abundances with just over 130 individuals m^{-2} on average at sites L7 (Hindmarsh Island), L18 (Boggy Lake) and L8 (Waltowa) to just over 1630 individuals m^{-2} on average at sites L4 (Milang) and L13 (Seacombes) (Figure 33). With a very high variability in abundances between sites, no regional differences were detected between the Goolwa Channel, Lake Alexandrina and Lake Albert (SM-Table 15).

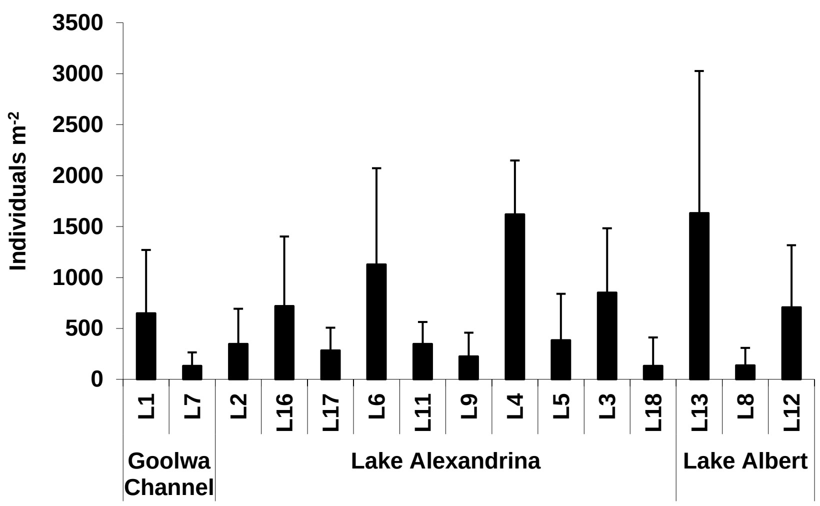

Figure 33: Mean abundances (ind. m^{-2}) and standard deviation (± S.D.) (*n* = 10) of benthic macroinvertebrates recorded at sites sampled around the Lower Lakes during the 2013/14 summer survey.

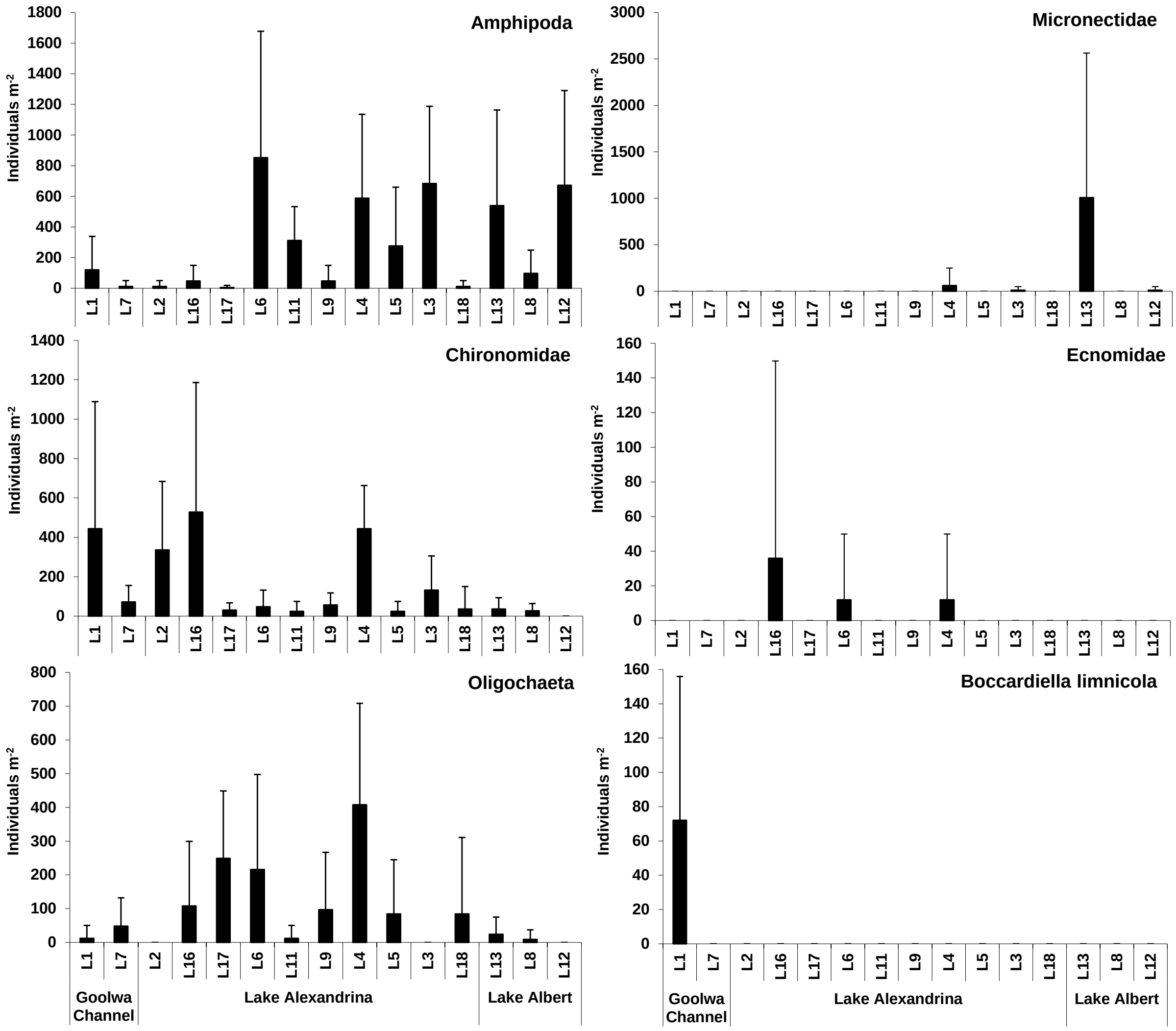

Figure 34. Mean abundances (ind. m^{-2}) and standard deviation (± S.D.) (*n* = 10) of key taxa and species of benthic macroinvertebrates recorded in corer/grab samples at sites around the Lower Lakes during the 2013/14 summer survey. Note different y-axes scales.

Chironomid larvae, amphipods and oligochaetes occurred most consistently across the sampling sites of the Lower Lakes and were abundant at several sites (Figure 34, and see SM-Figure 34 for corresponding distribution and abundances of higher taxa). Amphipods were abundant at several sites around Lakes Alexandrina and Albert, but low at sampling sites around Hindmarsh Island. Chironomid larvae occurred in higher abundances at these sites in the Goolwa Channel (sites L1 and L7), at Clayton (L2), on the lake side of the Mundoo barrage (site L16), as well as at Milang (site L4). Oligochaeta occurred in higher abundances at most sites in Lake Alexandrina. Caddisfly larvae (Ecnomidae) and aquatic bugs (Micronectidae) were found at several sites in low numbers, apart from a higher abundance of Micronectidae at Seacombes (site 13) (Figure 34). Other taxa, such as ostracods or the spionid polychaete *Boccardiella limnicola*, were found at single sites only and with very few individuals (Figure 34). The snail *Physa acuta* was recorded again at Seacombes (site L13), where it was found last year (Dittmann et al. 2013a), yet with one individual only.

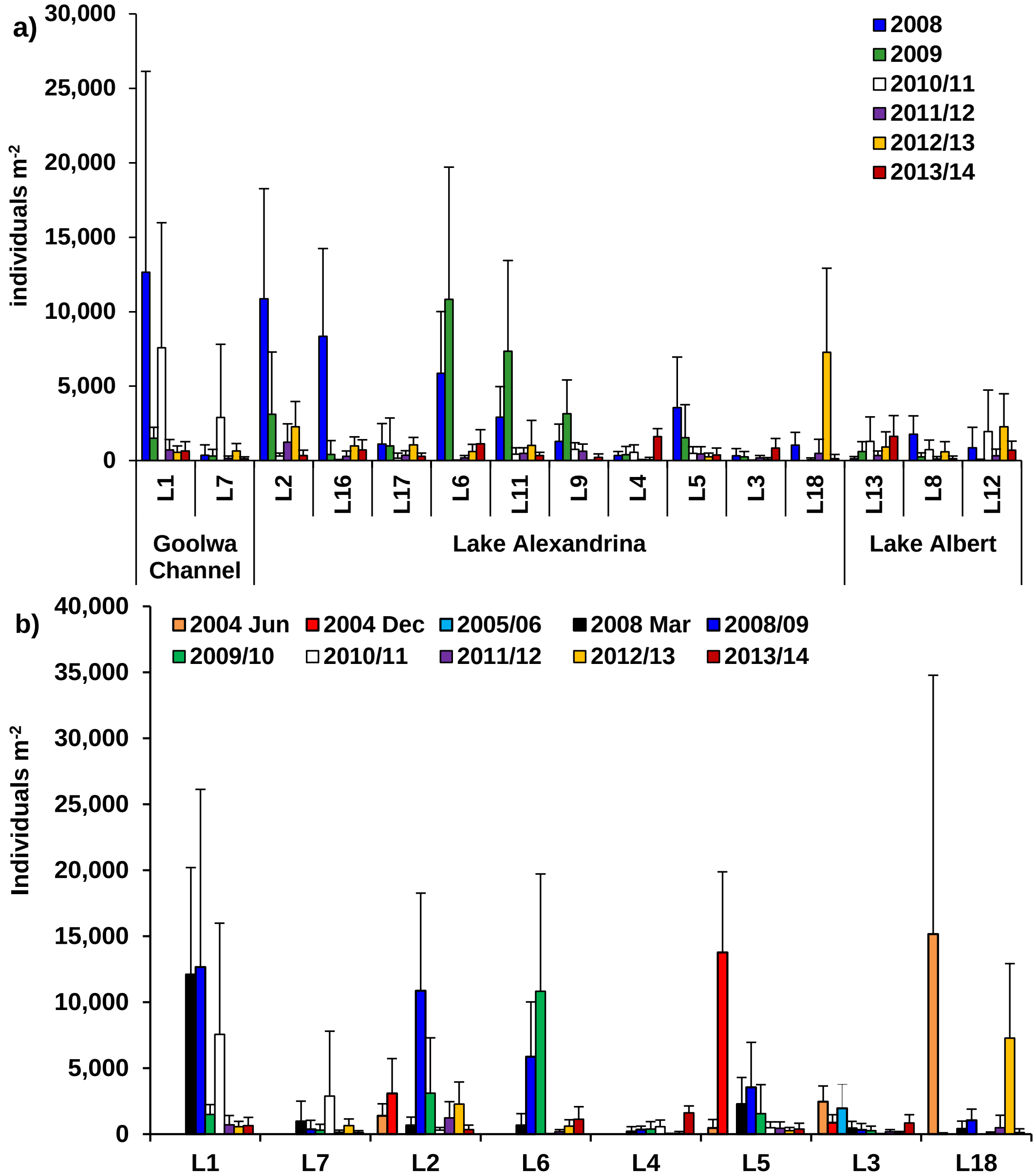

Figure 35: Mean abundances (ind. m^{-2}) and standard deviation (S.D.) of all benthic macroinvertebrates recorded at the sampling sites around the Lower Lakes. As the sampling frequency differed for the individual Lower Lakes sites, figures are shown separately for a) sites sampled annually in spring/summer from 2008 to 2013/14, and b) sites sampled during various surveys from 2004 until 2013/14. Note the different y-axes scales.

Compared to previous surveys, there has been almost no increase in total macroinvertebrate abundances (Figure 35), or for higher taxa (SM-Figure 35). The higher abundances recorded at a few sites last year appear as outliers amongst very low values during surveys over the last few years (see L18 for 2012/13 in Figure 35). Yet at Milang (site L4) and Tolderol (site L3) abundances were higher than last year (Figure 35), driven by amphipods, chironomid larvae and, at Milang, by oligchaetes as well (Figure 36). At Seacombes (site L13), Micronectidae accounted for the slightly higher abundance over last year. Differences in total abundances of macroinvertebrates and of single taxa varied significantly over the survey years and by sites (SM-Table 15).

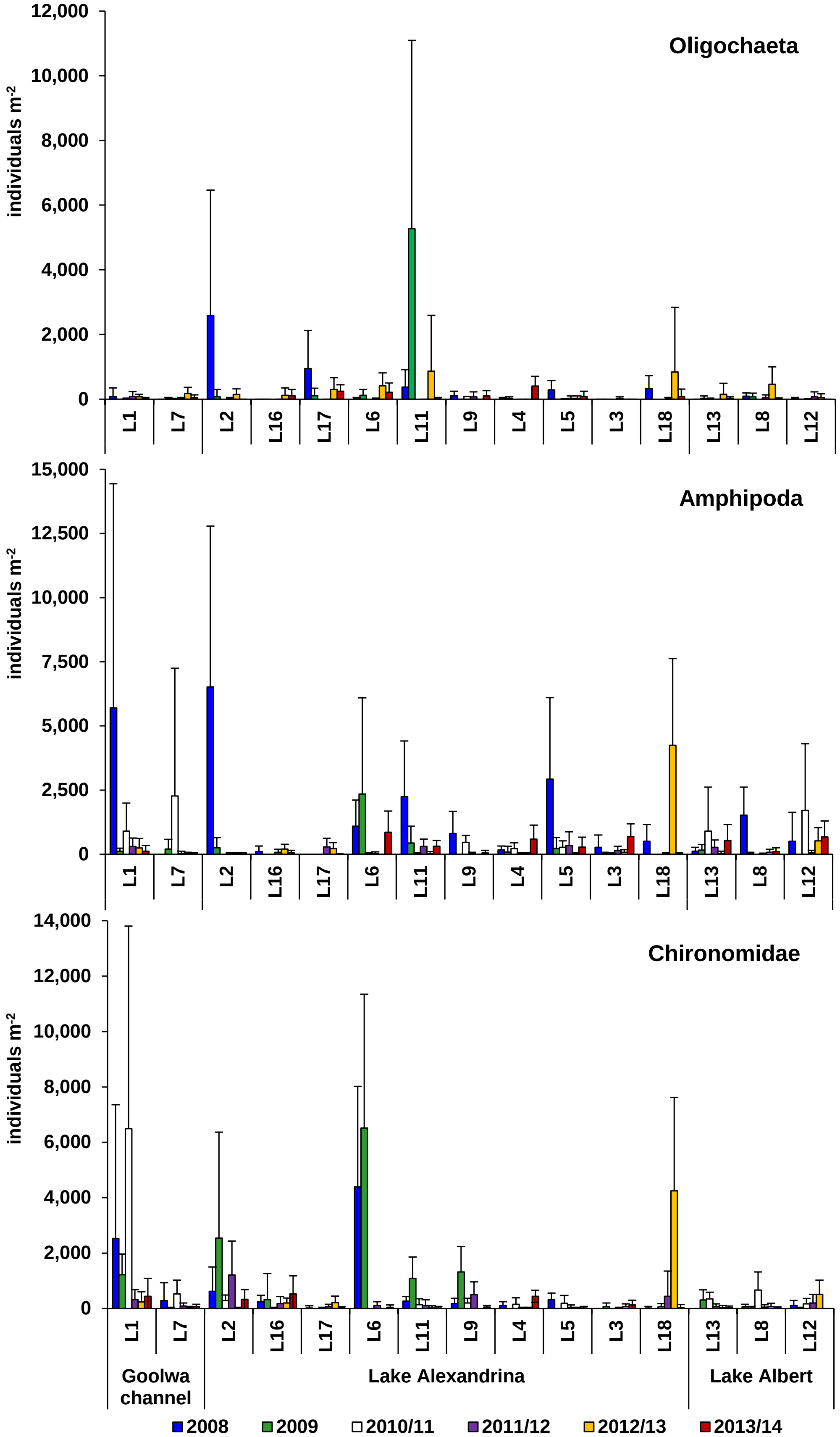

Figure 36: Mean abundances and standard deviation (*n* = 10) of macroinvertebrate taxa considered to be of indicator value for the Lower Lakes, recorded at the sampling sites continuously surveyed in early spring/summer from 2008 until 2013/14. Note variations in scale of the y-axis.

5.2.3 Macroinvertebrate biomass

With very low abundances of macroinvertebrates found at the study sites around the Lower Lake during the 2013/14 survey, the biomass was almost negligible (0.04 ± 0.09 g AFDW m^{-2}) (SM-Table 14). Only at Milang (Site L4), where amphipods, chironomid larvae and oligochaetes were found in relatively great abundance, was biomass higher than at other sites (Figure 37). At Goolwa Channel (site L1), spionid polychaetes (*Boccardiella limnicola*), together with chironomid larvae and amphipods, would have attributed to the slightly higher biomass at site L1. There were no differences in macroinvertebrate biomass between regions, but between sites in regions (SM-Table 15).

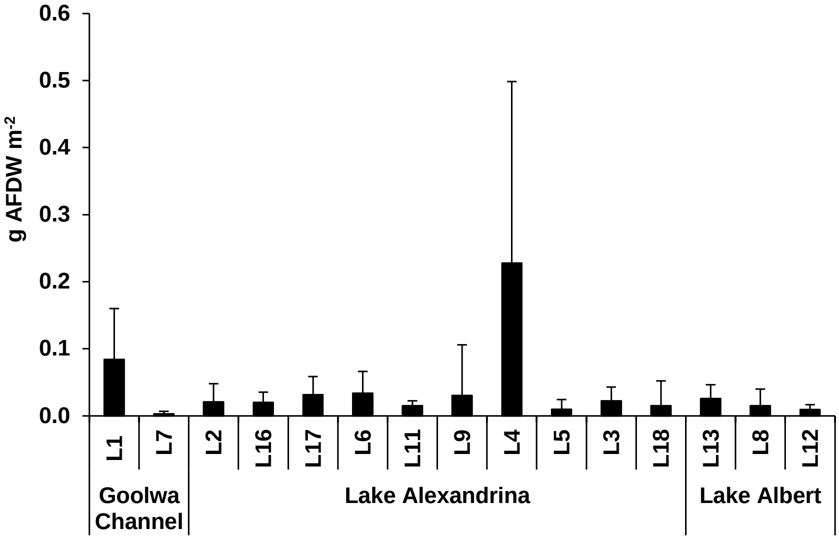

Figure 37: Average biomass of benthic macrofauna (g AFDW m^{-2} with standard deviation, *n* = 10) at sites sampled around the Lower Lakes during the survey in summer 2013/14.

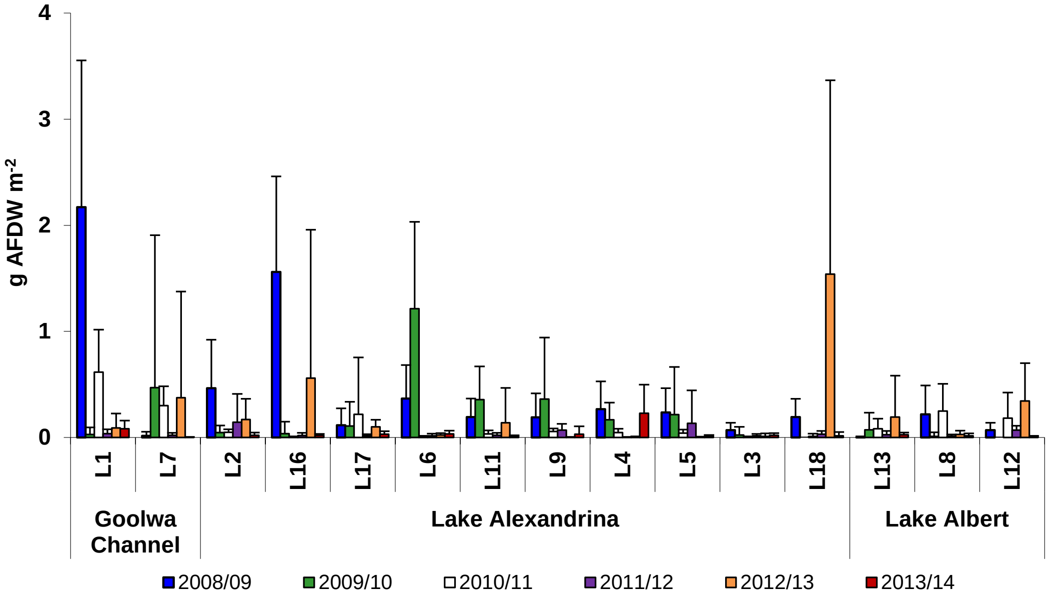

Figure 38: Biomass of benthic macroinvertebrates (mean and standard deviation, *n* = 10) at sites sampled around the Lower Lakes compared between early spring/summer surveys from 2008 to 2013/14.

As in previous surveys, biomass continued to be very low at the sampling sites around the Lower Lakes, apart from Milang and the Goolwa Channel (Figure 38). Corresponding with the drop in abundances (Figure 35b), sites with higher biomass in the previous survey had low values in this survey (Figure 38). Given the high variability in macroinvertebrate biomass within and between sites over the years as apparent in Figure 38, biomass differed significantly between the surveys and sites (SM-Table 15).

5.2.4 Macroinvertebrate abundances and biomass on either side of barrages

The changes in macroinvertebrate abundances and biomass over the drought and since flow resumed in late 2010 are illustrated by comparisons across the lake and estuary side of the barrages (Figure 39). During the drought, abundances and biomass were low on either side, or higher on the lake side of the Goolwa Channel (at times of the Goolwa Channel Water Level Management) than at Monument Road in the estuary. Since flow resumed in late 2010, abundances increased on the estuary side of the barrages since 2011, while no change occurred on the lake sides (Figure 39). Similarly, biomass of macroinvertebrates has been higher on the estuary side of the barrages since 2012, yet remained negligible on the lake sides (Figure 39).

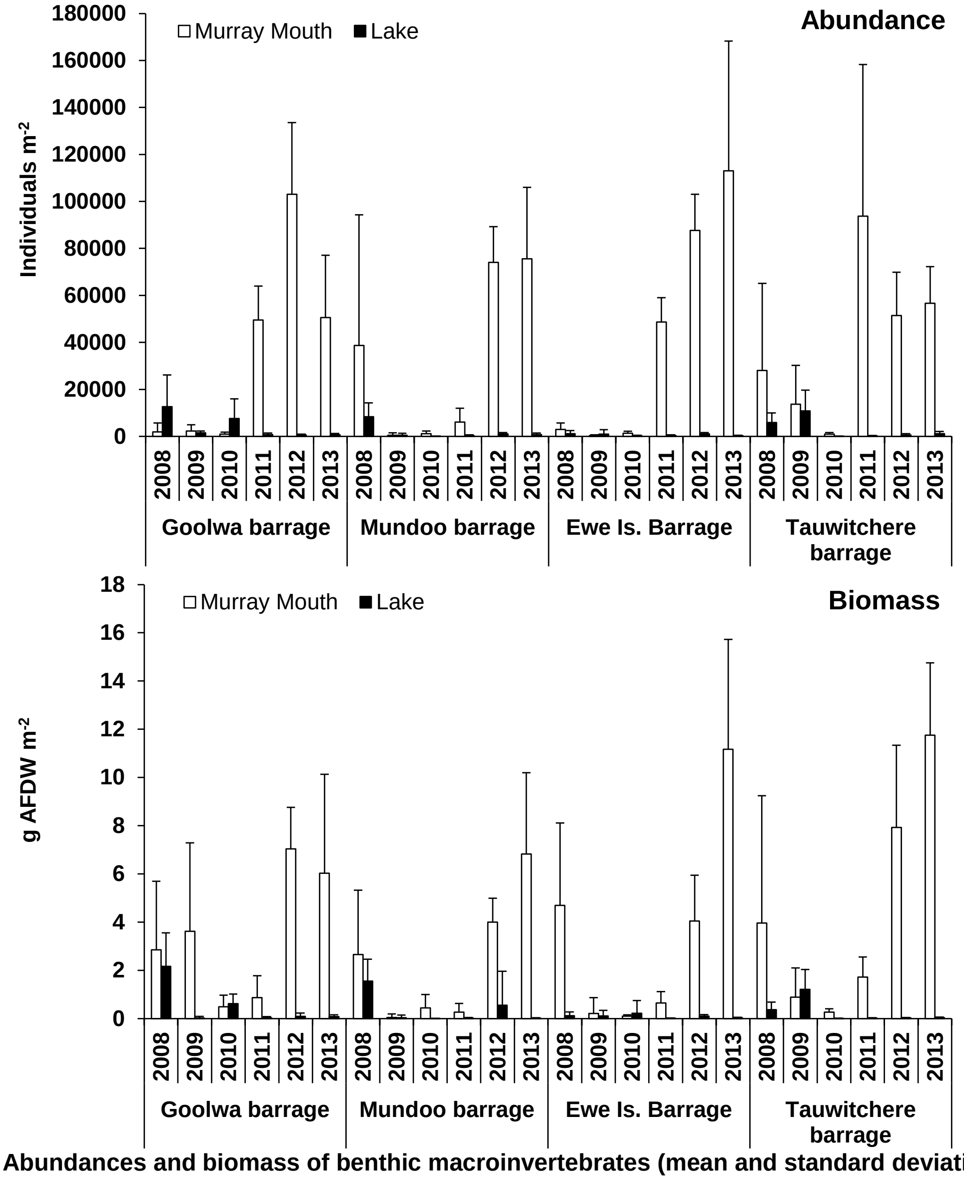

Figure 39: Abundances and biomass of benthic macroinvertebrates (mean and standard deviation, *n* = 10) at sites sampled on the estuary (white bars) and lake (black bars) sides of the Goolwa (sites 1 and L1), Mundoo (sites 4 and L16), Ewe Island (sites 6 and 17) and Tauwitchere barrages (sites 20 and L6) since 2008. Flow resumed in late 2010.

5.2.5 Macroinvertebrate communities

No defined pattern of macroinvertebrate communities could be differentiated around the Lower Lakes (Figure 40). Macroinvertebrate assemblages were significantly different between sites (nested in regions), but not between regions (SM-Table 13), corresponding with the variability in diversity and abundances within and between sites described in 5.2.1 and 5.2.2. The PCO plot separated sites with higher abundances and more species (sites L4 (Milang), L6 (Pelican Point) and L13 (Seacombes) from sites with lower abundances (grouped in the top left of Figure 40). Hydrophilidae and Ephydridae were only found at sites L3 (Tolderol) and L12 (Vanderbrink) respectively, which caused the separation of the macroinvertebrate assemblage of these sites.

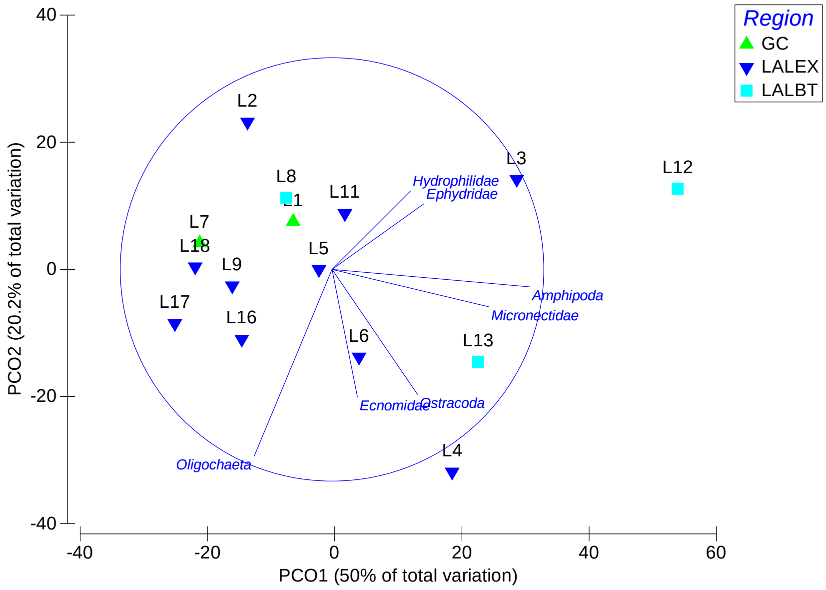

Figure 40: PCO (Principal Coordinates Analysis) plot of benthic macroinvertebrates from the survey in the Lower Lakes in summer 2013/14. The circle represents a vector overlay (Spearman correlation) illustrating the contribution of the respective species to the PCO axes.

Chironomid larvae, amphipods and oligochaetes were the main characterising taxa for the macroinvertebrate assemblages at sites around the Lower Lakes (SM-Table 16). SIMPER analysis showed low similarities within sites, reflecting the high variability, while dissimilarities between sites were high. In particular, the macroinvertebrate assemblages from almost all sites were very dissimilar to the ones found at Boggy Lake (Site L18) and Vanderbrink (site L12) (SM-Table 16).

The lack of any defined macroinvertebrate communities by regions within the lakes was similar to previous surveys (Dittmann et al. 2013a). Over the survey years since 2008/09, macroinvertebrate assemblages differed significantly by site and survey year (SM-Table 13). There was no detectible similarity of macroinvertebrate assemblages between particular sites or years in the PCO plots, and the axes of the plot are only explaining a small percentage of the variability (Figure 41).

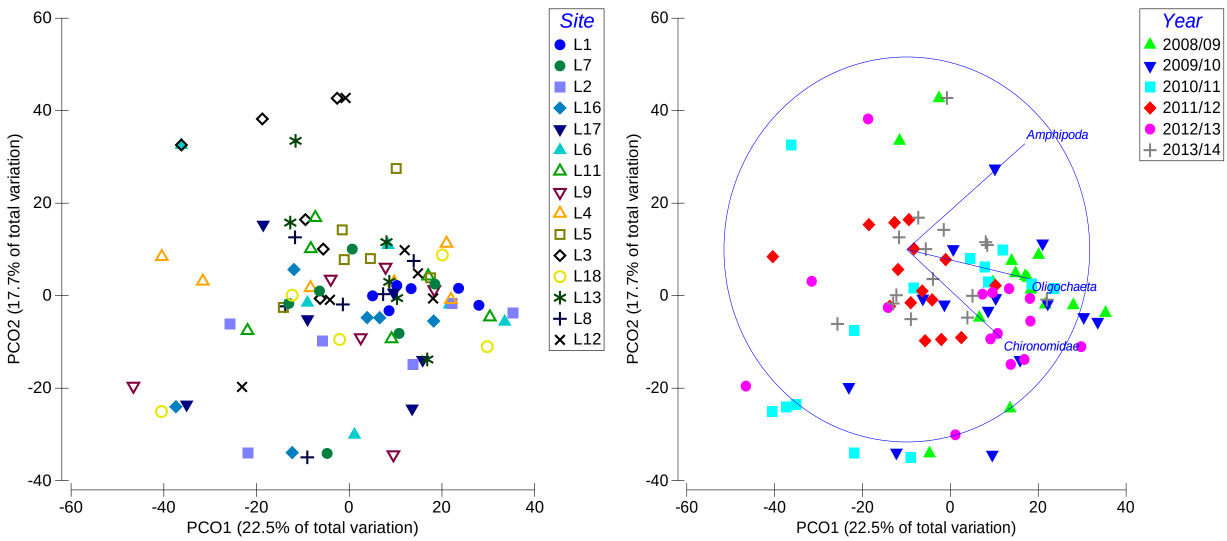

Figure 41: PCO plot of benthic macroinvertebrates around the Lower Lakes from the summer surveys since December 2008 to 2013/14, considering only those sites continued into the recent survey (site L18 was not sampled in 2009 because of acidity in sediments). The PCO is shown with highlighting the sites (left) or survey years (left). Sites L1 and L2 are in the Goolwa Channel, sites L2 to L18 in Lake Alexandrina, and sites L13, L8 and L12 in Lake Albert (see Figure 2).The circle represents a vector overlay (Spearman correlation) illustrating the contribution of the respective species to the PCO axes.

5.2.6 Macroinvertebrate communities and environmental conditions

There were no strong relationships between macroinvertebrate community structure and the measured environmental variables in the Lower Lakes regions during 2013/14 monitoring (Figure 42). While the illustration of the DISTLM analysis in the dbRDA plot (Figure 42) indicates that the macroinvertebrate assemblage at site 4 (Milang), which had some of the highest abundances and species found, may be linked to higher values for sediment organic matter content, chlorophyll-*a*, and grain size composition, the plot explained less than 50% of the total variation in the data. DISTLM analysis revealed that none of the variables tested (salinity, dissolved oxygen saturation, sediment organic matter content, medium grain size, sorting coefficient and chlorophyll-*a* content), either individually or in combination, explained a significant proportion of the variation in the patterns observed in macroinvertebrate community structure.

Over the survey years from summer 2008/09 to 2013/14, the macroinvertebrate assemblages around the Lower Lakes showed a clearer separation of samples from 2008/09, when salinities were higher, and sediments were only moderately sorted with finer coarser median grain size than in other surveys. The dbRDA plot, however, explains only a very small amount (<20%) of the total variation in the data (Figure 43). While all variables tested (salinity, dissolved oxygen saturation, sediment organic matter content, medium grain size, sorting coefficient and chlorophyll-*a* content) contributed significantly, they each explained only a small proportion (3-7 %) of the variation in the macroinvertebrate community of the Lower Lakes over the years. All six variables together explained only 23% of the variation.

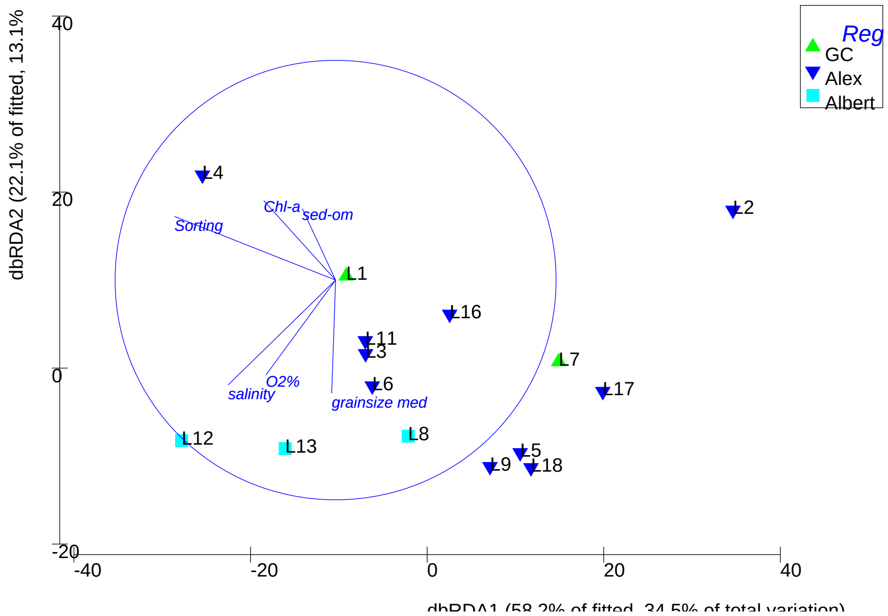

Figure 42: dbRDA (distance based redundancy analysis) plot illustrating relationships between environmental variables and benthic macro-invertebrates around the Lower Lakes in summer 2013/14, see Figure 2 for site details. The regions within the lakes are GC (Goolwa Channel) LALEX= Lake Alexandrina, LALB=Lake Albert. Parameters were transformed prior to analysis. The vector overlay uses base variables of environmental data, Spearman rank correlation.

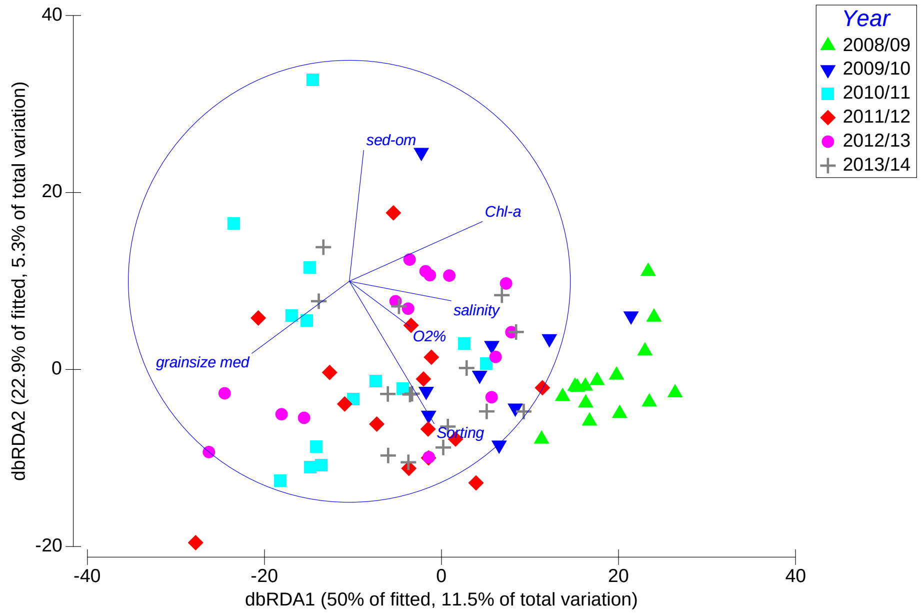

Figure 43: dbRDA (distance based redundancy analysis) plot illustrating relationships between environmental variables and benthic macro-invertebrates around the Lower Lakes for the annual surveys in summer 2008/09 to 2013/14. Note that some sites in 2009 and one site in 2010 had to be omitted because of some missing environmental variables. Parameters were transformed prior to analysis. The vector overlay uses base variables of environmental data, Spearman rank correlation.

Regarding Condition Monitoring Target I-1 '*Maintain or improve invertebrate populations in mudflats*', the analyses from the surveys showed that this target has not been met, as low abundances and species diversity persisted in sediments around the Lower Lakes and no improvement in macroinvertebrate populations was detected.

6. Discussion

The findings of the 2013/14 macroinvertebrate monitoring are discussed below against the condition monitoring objectives for 'The Living Murray' program (Maunsell 2009).

6.1 Macroinvertebrate populations

I-1 – 'Maintain or improve invertebrate populations in mudflats'

In this 10th year of monitoring macroinvertebrates in the Lower Lakes, Murray Mouth and Coorong Icon Site, a reestablishment of benthic communities has become apparent in the Murray Mouth and northern North Lagoon, while the southern sections of the Coorong as well as the Lower Lakes remain sparsely populated by macroinvertebrates. Several measures, such as species numbers, diversity, abundance and biomass, revealed an improvement to values more comparable to the first years of monitoring for the Murray Mouth and northern North Lagoon. The trajectories are, however, indicating that macroinvertebrate communities may move in directions that are different to the first survey years, highlighting the complication of assessing recovery without historic baselines for comparison.

As greater similarity to conditions before the Millennium Drought (Leblanc et al. 2012) was reached only four years after flows resumed, the reasons for the slow recovery time need to be explored. The system experienced two consecutive extreme events with a long drought period followed by a large freshwater pulse. Cumulative impacts from climate, eutrophication and pollution can have lasting effects in estuarine systems (Kennish 2002, Neto et al. 2010, Dolbeth et al. 2011, Grilo et al. 2011), and a disturbance history can reduce the resilience of estuarine organisms to stressors (Dolbeth et al. 2007). In the Murray Mouth and Coorong, the length of the drought period could have affected the resilience of macroinvertebrates. Changes going beyond a natural dry/wet cycle in estuaries could affect the typical variability of estuarine biota.

Species specific response pathways to drought and freshwater release revealed in this monitoring necessitate the inclusion of life history strategies, especially tolerances and dispersal pathways, in the discussion of recolonisation (Cañedo-Argüelles and Rieradevall 2010, 2011, Dunlop et al. 2008, see also review by Rolston et al. 2010). Amphipods and chironomids quickly increased in population size when flows resumed, and these taxa remained abundant in the following surveys. High reproductive output and response to hydrodynamics and organic loading can affect amphipod colonisation (Ford et al. 2001). Chironomids, spending their adult life in the air, can escape adverse aquatic conditions (Magni et al. 2008). The polychaete *Simplisetia aequisetis* could have flexibility in early life history as do other Nereididae, who can switch between pelagic and benthic larvae in response to particular estuarine conditions (Sato 1999), and thus be retained inside an estuary. After being found in higher numbers at one site (Pelican Point) in the Murray Mouth in the 2012/13 survey, the population size of *S. aequisetis* had increased throughout the Murray Mouth in the recent survey. *Capitella* sp. has reached high abundances at a few sites in the North Lagoon since flow resumed. Species of *Capitella* have short larval stages and are thus unlikely to undergo larger scale dispersal, with settlement affected by sediment organic matter (Thiyagarajan et al 2005). The contraction in distribution range of this indicator species for eutrophication and pollution (Grassle and Grassle 1976) could reflect improved conditions in the Murray Mouth. The spionid polychaete *Boccardiella limnicola*, which had increased in occurrence and abundance, is a more brackish water species and its widespread occurrence and abundance in the Murray Mouth may be in response to the lower salinities. This species was found on the lake side of the Goolwa Channel as well.

Bivalves and gastropods were slower in recolonising the mudflats, although they were detected earlier in subtidal sediments in an accompanying project (Dittmann 2013b). Several species of small sized bivalves (Hydrobiidae) were found in the recent monitoring. Hydrobiidae are common in intertidal and estuarine soft sediment systems and the co-occurrence of several species has been described for various locations, with habitat selection affected by salinity, dispersal rates and competition (Fenchel 1975, Siegismund and Hylleberg 1987, Ponder et al. 1991). The micro-mollusc *Arthritica helmsi*, which was a dominant species in the Murray Mouth before the drought and is a common inhabitant of estuaries in southern Australia (Wells and Threlfall 1981), had returned and was found at several sites in the Murray Mouth in the 2013/14 survey. As this species is well adapted to variable estuarine conditions (Kanandjembo et al. 2001), the slow recolonisation of *A. helmsi* could instead be linked to its reproductive mode, where females have a brood pouch and no pelagic larvae are produced (Wells and Threlfall 1982).

The macroinvertebrate recovery in the Murray Mouth and Coorong not only relies on life history, but suitable habitat conditions as well. Benthic macrofauna is a good indicator of environmental perturbations (Wildsmith et al. 2011) and recolonisation following disturbances is affected by sediment properties (Pearson and Rosenberg 1978, Kanaya 2014). High abundances of chironomids after disturbances have been linked to their sulphide tolerance (Magni et al. 2008, Kanaya 2014). Successional stages of recolonisation can be facilitated by sedimentary activities of early colonisers Rosenberg 2001). Following initial recolonisation of mudflat sediments by macroinvertebrates, bioturbation can improve sediment biogeochemistry and habitat conditions for other benthic fauna (Snelgrove and Butman 1994). Chironomids, oligochaetes, amphipods, polychaetes and others can build burrows or tubes in the sediment and affect benthic assemblages with their bioturbation (Nogaro et al. 2006, O'Brien et al. 2009). At several mudflat sites in the Murray Mouth and Coorong, black anoxic sediment reached close to the surface, whereas at other sites with higher abundances of bioturbating macrofauna, the sediment conditions had improved and more macroinvertebrates were found in deeper sediment layers. At sites in the South Lagoon, such as Villa de Yumpa, sediment conditions were affected by the possible collapse of an algal bloom, which could explain the high organic matter load at this site. Although single specimens of benthic macroinvertebrates other than insect larvae were found at the sites in the South Lagoon, no recovery has occurred here. A few individual amphipods were found in the South Lagoon, but amphipods were absent for a second year in a row at Parnka Point.

Species interactions can further account for some of the presence or absence of macroinvertebrate species at particular sites. Predation can affect diversity during colonisation (Frid et al., 1989, Tavares et al. 2008). The predatory polychaete *Aglaophamus (Nephtys) australiensis* was only found at the mudflats at Ewe Island, where abundances of *Simplisetia aequisetis* were lower than at other sites in the Murray Mouth. Related nepthyid polychaetes are known to prey on nereidid polychaetes like *S. aequisetis* (Schubert and Reise 1986), and such a predatory interaction could explain the findings of this survey. Signs for other trophic interactions were present, too. The higher abundance of grazing or surface deposit-feeding species, such as gastropods and bivalves, could explain the lower microphytobenthic biomass (Chl-*a*) recorded in the recent survey (Hagerthey et al. 2002).

With an extended distribution range of macroinvertebrates, higher abundances and biomass, food availability for arriving migratory shorebirds was higher throughout the Murray Mouth and northern sections of the North Lagoon in spring/early summer 2013/14 than recorded in previous years. Further sampling events over the summer months for an accompanying monitoring project (Dittmann et al. 2014) revealed a marked decrease in abundances, which could possibly be related to foraging (Schneider and Harrington 1981). The macroinvertebrate condition monitoring at the start of the overwintering period should continue to assess food availability.

This latest survey for the condition monitoring documented improvements of invertebrate populations in mudflats of the Murray Mouth and North Lagoon, yet larger areas of the Coorong and Lower Lakes remain scarcely inhabited by macroinvertebrates. The South Lagoon and the Lower Lakes contained mostly early life stages of insect larvae in very low numbers, which made the detection of any patterns difficult. The target *I-1 – 'Maintain or improve invertebrate populations in mudflats'* has thus only be met in certain regions. To further improve or maintain macroinvertebrate populations, favourable habitat conditions and connectivity have to be assured.

6.2 Habitat conditions

M-1 – 'Facilitate frequent changes in exposure and submergence of mudflats'; M-2 – 'Maintain sediment size range in mudflats', M-3 – 'Maintain organic content for mudflats' and *W-1 – 'Assessment of estuarine conditions between Goolwa Barrage and Pelican Point'*

Macroinvertebrate assemblages, their distribution patterns and abundances in estuaries and lagoons are affected by water exchange rates, submersion times, sediment grain size and organic matter (Gimenez et al. 2006, Correia et al. 2012, Rodrigues et al. 2012). As discussed above, the changes in macroinvertebrate populations seen over the last decade in the Lower Lakes, Coorong and Murray Mouth can be mainly linked to these environmental conditions. Regarding target *M-1*, the mudflats in the Murray Mouth were experiencing more frequent submergence and emergence with tides, wind seiching and the volume of water release over barrages, facilitated by the mouth opening and continued flow. These hydrodynamic conditions have also led to estuarine conditions (*W-1)* in the Murray Mouth and North lagoon, although the duration of brackish conditions in the Murray Mouth has been quite extended. In the Lower Lakes, target *M-1* was not met as sediments were permanently submerged and no mudflats exposed. Sediment properties (*M-2* and *M-3*) measured during this monitoring were well within the ranges of each variable as measured over the monitoring years.

6.3 Conclusion

The long-term condition monitoring for macroinvertebrates in sediments and mudflats of the Lower Lakes, Coorong and Murray Mouth documented the detrimental effects of a prolonged drought, followed by a slow recovery after flows were restored. Improvements in macroinvertebrate populations occurred in the Murray Mouth and parts of the North Lagoon, yet the South Lagoon and the Lower Lakes continue to be scarcely populated by macroinvertebrates. Species specific recolonisation patterns indicate complex recovery mechanisms affected by environmental and biotic processes. Food availability for migratory shorebirds was higher compared to previous years. Trajectories indicate a lack of return to conditions at the start of the monitoring; and further improvements in macroinvertebrate populations need to be supported by favourable environmental conditions. The ecological restoration of flows in the Murray River estuary have facilitated recovery, yet a natural restoration through secondary successions (Borja et al. 2010) has been slow and resilience may have been reduced by the history of environmental changes this estuary experienced. With a predicted return to an El Niño weather pattern, insight from the TLM Condition monitoring will be essential to advise environmental management in a renewed drought.

7. Acknowledgements:

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