Macroinvertebrate monitoring, analysis and synthesis for Coorong and Murray Mouth locations

Final report and response on Key Monitoring Questions

April 2016

Final Report

for the Department of Environment, Water and Natural Resources

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This report may be cited as: Dittmann, S., Baring R., Ramsdale, T. 2016: Macroinvertebrate monitoring, analysis and synthesis for Coorong and Murray Mouth locations, Final report and response on Key Monitoring Questions. Report for the Department of Environment, Water and Natural Resources, Adelaide.

Contents

Executive Summary

The information in this report is an update of the benthic monitoring program undertaken in the Murray Mouth and Coorong since the restoration of flows through the barrages in 2010. It also presents an advanced analysis of the data from 2010 to 2015 and reference to the historical assessment of benthic macroinvertebrates since 2004 as part of "The Living Murray" condition monitoring and early studies in the 1980's. Specific key questions were proposed as part of Schedule 3 in accordance with the Australian Government Monitoring and Adaptive Management Framework for the Murray Mouth and Coorong, of which are addressed with main findings herein.

Further detail regarding content that has been prepared for each key question is provided in the main body of this report and in the attached appendices. Throughout the following sections, references to those figures and tables in the appendix are indicated by a prefix of 'A'.

Table 1. Summary table of key questions and components that are addressed with main findings herein

Key Questions	Components
Stocktake of Monitoring to Date	• Table of data collection periodicities over time • Figures of total abundances, abundances of various taxonomic groups, and species richness, diversity indices and index of occurrence. • Percent contribution plots for 2010 – 2015 dataset. Includes comparisons for tidal position, years, regions and sites. • Explanation of patterns in the dataset. • Investigation of alternate monitoring design that compares low versus high taxonomic resolution.
Recovery	• Articulate hypotheses regarding response outcomes. • Assess evidence to evaluate hypotheses. • Evaluate hypotheses based on available information using monitoring data
Annual trends	• Define regions over years using macroinvertebrate communities and salinity data (LinkTREE, SIMPROF) • Explore community change over time using MDS trajectory plots • Identify species accounting for differences in communities using SIMPER • Relationship of macroinvertebrate communities to plankton and water quality. • Food web function with comparisons of macroinvertebrate data and other levels of food web (e.g. zooplankton, fish, birds).
Conceptual Models	• Detailed evaluation of species in the system, their environmental tolerances and species attributes • Comparison of historical and current communities • Species trends over time • Biological traits analysis • Conceptual models
Change in ecological character since listing (1985)	• Comparison of current and historical species distribution ranges • Comparisons of current and historical ecological character

1. Background

This report aims to provide updated information on recent benthic condition monitoring in the Murray Mouth and Coorong under Schedule 3 in accordance with the Australian Government Monitoring and Adaptive Management Framework. The information presented in this report is based on benthic response monitoring undertaken since the restoration of freshwater flows into the Murray Mouth and Coorong since 2010 after the millennium drought, which was influenced by climate shifts from El Niño to La niña (Leblanc et al. 2012). The implementation of key questions and objectives that were based around the benthic response of the Murray Mouth and Coorong to release of freshwater flows aimed to provide new thought into ecosystem processes and services with a more question-driven direction of investigation.

Included in this report are more advanced techniques for exploring long-term datasets such as Biological Trait Analysis (BTA) that provide new insights into benthic functioning with different water release regimes over time. Comparisons are also made to historical data for the system from monitoring since 2004 for “The Living Murray” condition monitoring (Dittmann et al. 2014a, Dittmann et al. 2015) and studies by Geddes in the 1980s (Geddes and Butler 1984, Geddes 1987) . In addition, information from similar systems in temperate Australia was considered for some questions, as was biological information for key species (where known) from the scientific literature and other key components (e.g. waterbirds, fish, zooplankton) from previous government reports. Such a synthesis of information provides direction and focused actions to key ecological questions for the long-term goal of a healthy, productive and resilient wetland according to the Adaptive Management Framework. The information in this report provides an update of the benthic condition and response of the Murray Mouth and Coorong with new insights that can be incorporated into further frameworks into the future.

2. Key questions and findings

2.1 Stocktake of Monitoring to Date

Since flow resumed across the barrages in 2010, yearly sampling events have occurred across the five years of sampling for macrobenthic communities at various sites in the Murray Mouth, and North and South Lagoons (Table A1.1, A1.2; Figure A1.1). In order to monitor water release effects and recovery in the Murray Mouth and Coorong, strategic sampling occurred across multiple seasons at many sites as the water release benthic monitoring program. Monitoring was also undertaken during those years as continuation of The Living Murray program (TLM). Intertidal and subtidal macrobenthic communities were sampled at sites in early years which then focused on intertidal sampling only in late 2014 and early 2015 sampling events (Table A1.1). Most of the sites in the north and south lagoon (except Mark Point) were not sampled in 2010/11 as part of the monitoring of water release and recovery program but were implemented as targeted sampling sites throughout later years (Table A1.1). Three sites in the Murray Mouth region were only sampled in the first and/or second year after the water release commenced (1/2 Way Beach, Boundary Creek and Sugars Beach) and were not included in subsequent surveys in order to have more focused sampling in the North Lagoon (Keuning et al. 2012; Table A1.1). For those regions in particular where sampling did not occur at sites in early years, data from The Living Murray (TLM) condition monitoring for macroinvertebrates and mudflats (Dittmann et al. 2014) was used to complement the dataset obtained from the water release response monitoring program. Throughout the 2010-2015 surveys, seven sites across the three regions (Murray Mouth: Monument Road, Hunters Creek, Ewe Island and Pelican Point; North Lagoon: Noonameena, Parnka Point North; South Lagoon, Villa de Yumpa) were sampled in conjunction with and overlapped TLM condition monitoring, which allowed for comparisons over longer time frames (Table A1.1).

During the 2015 water release monitoring survey, seven of the original sampling sites were re-sampled for benthic macroinvertebrates using the same methodology as in previous years (Dittmann et al. 2014). Four of the TLM sampling sites (Mundoo Channel, Mulbin-Yerrok, Jacks Point and Loop Road) that were not initially sampled in previous years of the benthic water release response monitoring, were targeted in the 2015 survey to provide long term comparison (Table A1.1). The only modification to methods in the 2015 survey was that whole cores (5-20cm depending on site substrate type) were obtained rather than splitting into top and bottom horizons as in previous years. Also, the number of environmental variables measured was reduced and only incorporated water chemistry (salinity, dissolved oxygen, oxygen saturation, pH and temperature), and sediment size and organic matter which may be analysed at a later date.

Patterns of change in benthic macroinvertebrates within the Murray Mouth and Coorong from 2010-2015

Based on abundances, percent contributions, and species richness and diversity of benthic macroinvertebrates there were multiple patterns of change between the years 2010 to 2015 (Figures A1.2 to A1.11). Within each year there were also multiple patterns of small-scale temporal variation and succession of various taxa, indicative of seasonal recruitment. Across the five years of surveys, sites within the three separate regions showed different patterns from each other, most notably in the North Lagoon with increasing distance away from the barrages and water release outflows. The following sections will discuss in detail those patterns of change in benthic macroinvertebrate abundances, percent contributions, and species richness and diversity during the 2010-2015 survey periods from the intertidal and subtidal sampling.

Data analysis

To test for differences in the total abundance of macroinvertebrates in all survey years, data were fourth root transformed before calculating a Euclidean distance matrix (as single variable) used with a PERMANOVA four-factor design including year (2010/11, 2011/12, 2012/13, 2013/14, 2015) and region (Murray Mouth, North Lagoon, South Lagoon) as fixed factors, with sites nested in regions and months nested in years.

Patterns of change in the Murray Mouth and Coorong – intertidal macroinvertebrate abundances

Any patterns of change for intertidal macrofaunal abundances across years and regions were not consistent across all taxonomic groups. In the Murray Mouth the polychaete species *Simplisetia aequisetis* contributed most to polychaete and annelid abundances in all years (Figure A1.2). Significant differences in *S. aequisetis* abundances were identified for all four factors across all years and pairs of regions across the years, which were between the Murray Mouth and South Lagoon from 2012-2015 and the Murray Mouth and North Lagoon in 2015 (Region x Year interaction, Pseudo-F = 2.20, $P_{(PERM)}$= 0.017). *Simplisetia aequisetis* also contributed most to polychaete and annelid abundances at Mark Point in the North Lagoon during 2011/12 and 2012/13. Capitellids contributed most to polychaete and annelid abundances in all of the other North Lagoon sites in all years (Figure A1.2). The abundances of capitellids were significantly different between some regions and sites across all years and between some sites in particular months and years (Year x Site (Region) interaction, Pseudo-F = 2.0, $P_{(PERM)}$= 0.02; Month (Year) x Site (Region) interaction, Pseudo-F = 20.1, $P_{(PERM)}$= 0.0001) In comparison oligochaetes had very low abundances across all years and regions with only some small scale spatial and temporal differences identified (Month (Year) x Site (Month) interaction, Pseudo-F = 10.35, $P_{(PERM)}$= 0.0001).

Amphipods contributed most to crustacean abundances at all sites where they were present, with ostracods and decapods contributing very little in comparison (Figure A1.2). Amphipod abundances were significantly different between regions, months and sites across all years and between particular months for some sites and regions (Region x Month interaction, Pseudo-F = 2.25, $P_{(PERM)}$= 0.01; Month (Year) x Site (Region) interaction, Pseudo-F = 24.9, $P_{(PERM)}$= 0.0001). Gastropods of the family Hydrobiidae were very low in abundance throughout all years and only found in the Murray Mouth Region (Figure A1.2). Hydrobiid abundances were significantly different between some regions within years, which were specifically between the Murray Mouth and South Lagoon from 2012-2015 and the Murray Mouth and North Lagoon from 2013-2015 (Region x Year interaction, Pseudo-F = 7.49, $P_{(PERM)}$= 0.0001). The bivalve *Arthritica helmsi* was very abundant in 2013/14 at Tauwitcherie in the Murray Mouth (Figure A1.2). After returning to the Murray Mouth and Coorong in 2013/14, *A. helmsi* had much greater abundances at all Murray Mouth sites and Mulbin-Yerrok in the North Lagoon during 2014/15. There were significant differences in A. helmsi abundances between the South Lagoon with both the other two regions in 2013/14 and between the Murray Mouth and both of the other two regions in 2015 (Region x Year interaction, Pseudo-F = 7.91, $P_{(PERM)}$= 0.0001). In 2010/11 Diptera were most abundant at Parnka Point North in the North Lagoon and Jacks Point in the South Lagoon (Figure A1.2). Diptera were more abundant at more sites in the Murray Mouth and North Lagoon during 2012/13 and also abundant at Mundoo Channel in 2013/14. In 2015, Diptera had very low abundances at most sites along the Murray Mouth and Coorong, except at Monument Road and Mundoo Channel (Figure A1.2). There were significant differences in abundances of Diptera between regions in particular years (Region x Year interaction, Pseudo-F = 2.64, $P_{(PERM)}$= 0.005). Those differences were between the Murray Mouth and South Lagoon (2010/11, 2013/14 and 2014/15), all paired combinations of regions (2012/13), and the Murray Mouth and North Lagoon (2011/12).

Patterns of change in the Murray Mouth and Coorong – intertidal macroinvertebrate percent contributions

After the initial water release in 2010 amphipods and Diptera contributed most to intertidal benthic faunal communities, except at Monument Road which also had high percentages of polychaetes (Figure A1.3). In 2011/12 the percent contribution of polychaetes had decreased, particularly at Monument Road. The 2012/13 surveys had an increase in polychaete percent contributions in the later months of the survey period at Monument Road and Tauwitcherie. In 2012/2013 oligochaetes increased in percent contributions at Ewe Island and Pelican Point in the earlier months of the survey period (Figure A1.3). The 2012/2013 survey also had bivalves increase in percent contribution at Tauwitcherie, which were virtually absent from the Murray Mouth Region in previous years. Some of the largest patterns of change began in the 2013/2014 survey period. The high percent contribution of amphipods to benthic communities at most sites, except Tauwitcherie which instead had the highest contribution of bivalves, soon changed in the following survey months to increased percent contributions of polychaetes (Figure A1.3). This change also coincided with the arrival of bivalves at Hunters Creek, Ewe Island and Pelican Point, and gastropods at Monument Road. The 2014/15 had very large changes in patterns at most sites, except Monument Road which saw a return to community structure observed in previous years but with the additional presence of bivalves and gastropods (Figure A1.3). In 2014/2015 bivalves arrived at Monument Road and gastropods were still present but amphipods and polychaetes contributed most to percent contributions at that site (Figure A1.3). During the 2014/2015 survey, the sites of Hunters Creek, Mundoo Channel, Ewe Island and Pelican Point were similar with bivalves, amphipods and polychaetes contributing most to percent contributions.

The patterns of change for macroinvertebrates were more complicated across the sampling years and percent contributions were not consistent between sites throughout the North Lagoon (Figure A1.4). From 2010 to 2013/14 the most northern site of Mark Point had unique percent contributions and was not similar to any other site in the North Lagoon (Figure A1.4). In 2010/11 Mark Point had decapods, Diptera and polychaetes and amphipods contributing most to percent contributions of benthic faunal communities but this varied between months (Figure A1.4). From 2011 to 2012/13 at Mark Point amphipods, oligochaetes and polychaetes had the highest percent contributions and the arrival of bivalves contributed to percent contributions in later months. Those patterns changed to higher percent contributions of Diptera and bivalves in 2013/14 at Mark Point. The percent contributions at Mulbin-Yerrok and Long Point were similar from 2010 to 2011 and in 2013/14 with highest contributions from polychaetes, oligochaetes and amphipods (Figure A1.4). In 2012/13 Long Point had faunal structure more similar to Noonameena with the highest contributions from polychaetes, amphipods and Diptera. In comparison, Mulbin-Yerrok had oligochaetes contributing most to percentages at that site during 2012/13. Noonameena was similar to Parnka Point North during 2010/11 with the highest percent contribution from Diptera (Figure A1.4). Other than the two years of similar percent contributions for Noonameena with Mulbin-Yerrok and Noonameena and Parnka Point South, the latter sites had their own unique percent contributions of macrofauna. Noonameena had highest percent contributions of polychaetes and amphipods in 2011 – 2012/13, then polychaetes and Diptera in 2013/14 and mostly polychaetes in 2014/15 (Figure A1.4). Parnka Point South had highest percent contributions from ostracods, amphipods and Diptera in 2011/12, then lower percent contribution of amphipods in 2012/13, an increase in percent contributions of polychaetes and Coleoptera in 2013/14 and only Diptera present in 2014/15.

In the South Lagoon, Diptera generally contributed most to the intertidal benthic faunal composition at most sites in the years from 2010 to 2015 (Figure A1.5). Amphipods had higher percent contributions compared to the previous year at Villa de Yumpa, Jacks Point and Loop Road. Parnka Point South had some polychaetes with high percent contributions in later months of 2012/13. The largest change to percent contributions was at Parnka Point South during 2013/14 with the dominance of ostracods (Figure A1.5). Also, in 2013/14, amphipods and polychaetes were contributing more to percentages at Jacks Point and Loop Road. The major change in 2015 was at Loop Road, which had 100 percent contributions from polychaetes.

Patterns of change in the Murray Mouth and Coorong – intertidal macroinvertebrate species richness

At most sites in the Murray Mouth the species numbers of intertidal macroinvertebrates generally increased between the years 2010 to 2013/14 and then decreased again in 2015 (Figure A1.6). Some exceptions were the decrease in macroinvertebrate numbers in 2011/12 and 2013/14 at Tauwitcherie and at Pelican Point in 2015 compared to the previous sampled year. Species numbers at Mundoo Channel were very similar across all years and did not change much at all (Figure A6). Macroinvertebrate species diversities (H') were high at most sites with consideration to species numbers in the Murray Mouth during 2010/11 (Figure A1.6). In 2011/12, 2012/13 and 2013/14 macroinvertebrate diversities were low at most sites. The pattern changed in 2015 where macroinvertebrate diversities were high at all Murray Mouth sites, with consideration to species numbers for each of those sites (Figure A1.6).

In the North Lagoon of the Coorong, intertidal Macroinvertebrate species numbers increased in 2011/12 and 2012/13 at most sites with species numbers at Long Point and Noonameena decreasing or staying the same respectively (Figure A1.6). In 2013/14 macroinvertebrate species numbers in the North Lagoon decreased or stayed similar to species numbers found in the previous sampling year. There was a pattern shift with a decrease of macroinvertebrate species numbersin the North Lagoon in 2015 where numbers returned back to those similarly found in the 2010/11 sampling year (Figure A1.6).In 2010/11, macroinvertebrate species diversities (H') in the North Lagoon were high at Mark Point and Mulbin Yerrok and low at Long Point relative to species numbers (Figure A1.6). Macroinvertebrate species diversities in 2011/12 were generally low at all sites relative to species numbers with the exception of higher diversity at Noonameena. In 2012/13, macroinvertebrate species diversities were consistent with species numbers indicating more even distributions of all species at each site. In comparison, macroinvertebrate species diversities were very low at two sites (Noonameena and Parnka Point North) and particularly high at Mulbin-Yerrok in 2015.

In the South Lagoon of the Coorong intertidal macroinvertebrate species numbers were similar at most sites from 2010 to 2012/13, with the exception of a slight decrease in the number of species in 2012/13 at Jacks Point and Loop Road (Figure A1.6). In 2013/14 most sites increased in macroinvertebrate species numbers compared to previous years, with the exception of Villa de Yumpa. In contrast, species numbers were very low at all sites in the South Lagoon in 2015 compared to previous years (Figure A1.6). Throughout the years from 2010 to 2013/14 macroinvertebrate species diversities were generally high relative to species numbers found at each site, with a few exceptions (Jacks Point 2010/11, Villa de Yumpa 2012/13 and Parnka Point South 2013/14; Figure A1.6). In the South Lagoon in 2015, macroinvertebrate species diversities were only high relative to species numbers at Jacks Point (Figure A1.6).

Patterns of change in the Murray Mouth and Coorong – subtidal macroinvertebrate abundances

The largest changes in subtidal abundances for most taxa occurred in the 2012/13 and 2013/14 sampling years, where abundances increased dramatically to those found in previous years (Figure A1.7). In the Murray Mouth the polychaete species *Simplisetia aequisetis* and contributed most to polychaete and annelid abundances in most years (Figure A1.7). Similar patterns of change in *S. aequisetis* abundance were also found in the North Lagoon at Mark Point and Long Point (Figure A1.7). Abundances of *S. aequisetis* were significantly different between some sites in particular months and years (Year x Site (Region) interaction, Pseudo-F = 3.62, $P_{(PERM)}$= 0.0002; Month (Year) x Site (Region) interaction, Pseudo-F = 10.6, $P_{(PERM)}$= 0.0001). In 2012/13 and 2013/14 sampling years the polychaete species *Boccardiella limnicola* also contributed to the increase in polychaete and annelid abundances at Monument Road and Hunters Creek. There were significant differences in *B. limnicola* abundances between some sites in particular months and years (Year x Site (Region) interaction, Pseudo-F = 19.03, $P_{(PERM)}$= 0.0001; Month (Year) x Site (Region) interaction, Pseudo-F = 8.85, $P_{(PERM)}$= 0.0001). Capitellids were had the highest abundances during 2012/13 and 2013/14 and only at the two NorthLagoon sites of Long Point and Noonameena. Capitellid abundances at those two sites contributed to significant differences between the Murray Mouth and North Lagoon in 2011/12 and 2013/14 (Region x Year interaction, Pseudo-F = 3.20, $P_{(PERM)}$= 0.009). In comparison, there were no differences in capitellid abundances between the Murray Mouth and North Lagoon in 2012/13, which is likely due to the patchiness in samples during that year at Long Point and Noonameena (Figure A1.7).Oligochaetes contributed very little to annelid abundances but were highest in abundance in the Murray Mouth at Ewe Island and in the North Lagoon at Noonameena during the 2013/14 and 2011/12 sampling years, respectively (Figure A1.7).

Ostracods were found in highest abundances at Parnka Point North and Villa de Yumpa in 2013/14 (Figure A1.7). The higher ostracod abundances at Villa de Yumpa in 2013/14 is what contributed to the significant differences between the South Lagoon and Murray Mouth for that taxon (Region x Year interaction, Pseudo-F = 7.46, $P_{(PERM)}$= 0.007). Amphipods contributed most to crustacean abundances in the Murray Mouth and North Lagoon throughout all years except at Parnka Point North (Figure A1.7). The highest abundances of amphipods were found in 2013/14 at most sites, except at Hunters Creek in the Murray Mouth and Long Point in the North Lagoon where highest abundances for those sites were similar in 2012/13 and 2013/14 (Figure A1.7). Also, at Noonameena amphipod abundances were highest in 2012/13. Amphipod abundances were significantly different at some sites in particular years and months within years (Year x Site (Region) interaction, Pseudo-F = 1.98, $P_{(PERM)}$= 0.03; Month (Year) x Site (Region) interaction, Pseudo-F = 22.02, $P_{(PERM)}$= 0.0001). The bivalve *Arthritica helmsi* contributed most to bivalves and molluscs at Tauwitcherie in the Murray Mouth and Mark Point in the North Lagoon in 2012/13 and the much higher abundances found at those two sites in 2013/14. Significant differences of *A. helmsi* were only identified at some sites in particular years and months within years (Year x Site (Region) interaction, Pseudo-F = 43.97, $P_{(PERM)}$= 0.0001; Month (Year) x Site (Region) interaction, Pseudo-F = 2.38, $P_{(PERM)}$= 0.0001). Hydrobiid snails contributed most to the higher abundances at Monument Road and Hunters Creek in 2013/14, where they were also highest overall at the latter site across all years of sampling (Figure A1.7). Same as with *A. helmsi*, hydrobiids were significantly different at certain sites between particular years and months within years (Year x Site (Region) interaction, Pseudo-F = 2.76, $P_{(PERM)}$= 0.0001; Month (Year) x Site (Region) interaction, Pseudo-F = 11.98, $P_{(PERM)}$= 0.0001). Insects mainly consisted of dipterans and were found in the highest abundances at Parnka Point North in the North Lagoon during 2013/14, and Parnka Point South and Villa de Yumpa in 2012/13 and 2013/14, respectively (Figure A1.7).Significant differences in dipterans were found at some sites between particular years and months within years(Region) interaction, Pseudo-F = 2.16, $P_{(PERM)}$= 0.02; Month (Year) x Site (Region) interaction, Pseudo-F = 15.52, $P_{(PERM)}$= 0.0001).

Patterns of change in the Murray Mouth and Coorong - subtidal macroinvertebrate percent contributions

The percent contributions of subtidal macrobenthic taxa at the two sites of Monument Road and Hunters Creek in the Murray Mouth followed a similar pattern across sampling years with a dominance of amphipods, polychaetes and some dipterans (Figure A1.8). At Ewe Island and Tauwitcherie in the Murray Mouth amphipods, dipterans and polychaetes contributed most to the macrobenthos at those sites in 2010/11 and 2012/13, and had an increase in percent contributions by oligochaetes in 2011/12. In 2013/14 all sites in the Murray Mouth had highest percent contributions by amphipods with the return of gastropods at Hunters Creek and bivalves at Ewe Island and Tauwitcherie but they only contributed a small amount to percentages (Figure A1.8).

Percent contributions of subtidal macrobenthos in the North Lagoon varied considerably from site to site throughout the sampling years. At Mark Point amphipods were the main contributor to percentages across all years but also consisted of diptera, oligochaetes and polychaetes in 2010/11, polychaetes in all other subsequent years and the arrival of bivalves in 2013/14 (Figure A1.9).Percent contributions at Long Point had amphipods as the largest contributor to percentages in 2011/12 and 2012/13 followed by polychaetes and oligocheates in particular months. In 2013/14 percent contributions were mainly made up by amphipods and polychaetes (Figure A1.9). At Noonameema percent contributions varied considerably between months in 2011/12 which changed from polychaetes, to polychaetes and diptera and polychaetes, oligochaetes and amphipods in later months (Figure A1.9). In 2012/13 and 2013/14 percent contributions at Noonameena were mainly made up of polychaetes and amphipods. Parnka Point South was very different in all years compared to all of the other North Lagoon sites with percent contributions mainly consisting of diptera, and ostracods and polychaetes in some months (Figure A1.9).

In the South Lagoon, percent contributions were consistently dominated by diptera at both sites. Villa de Yumpa had more taxa contributing to percent contributions in particular months of certain years, which included amphipods in 2011/12, polychaetes in 2012/13 and ostracods in 2013/14 (Figure A1.9).

Patterns of change in the Murray Mouth and Coorong - subtidal macroinvertebrate species richness

Species richness of subtidal macrobenthos was similar at all sites from all regions sampled in 2011/12 with a range of five to nine species found (Figure A1.10). In 2011/12 the number of species found increased slightly since the previous year at Monument Road, Ewe Island and Tauwitcherie in the Murray Mouth. There was also a slight decrease in species richness at Sugars Beach and Hunters Creek in the Murray Mouth and Mark Point in the North Lagoon in 2011/12 (Figure A1.10).In comparison, species richness was very low at Parnka Point North in the North Lagoon and Parnka Point South in the South Lagoon during 2011/12. Species richness in 2012/13 was similarly high at most sites in the Murray Mouth and North Lagoon (Figure A1.10). Compared to species richness values in 2011/12, there were increases in 2012/13 at Monument Road, Hunters Creek and Ewe Island in the Murray Mouth and Mark Point and Long Point in the North Lagoon. In comparison, species richness was very low at Parnka Point North in the North Lagoon and Parnka Point South and Villa de Yumpa in the South Lagoon (Figure A1.10). During the 2013/14 sampling year, species richness decreased at most sites in the Murray Mouth and North Lagoon compared to the previous year, except at Ewe Island and Parnka Point North which both had slight increases in species richness. The only site sampled in the South Lagoon during 2013/14 at Villa de Yumpa, had a slight increase in species richness compared to the 2012/13 year (Figure A1.10).

During the 2010/11 survey, species diversity of subtidal macrobenthos was large at Monument Road and Pelican Point and very low at Hunters Creek and Ewe Island with consideration to species richness at those sites (Figure A1.10). In 2011/12 species diversity values were much lower than species richness values at most sites except Noonameena in the North Lagoon and Villa de Yumpa in the South Lagoon. Similarly in 2012/13, species diversities were low at nearly all sites but more even with species richness values at Noonameena (Figure A1.10). In 2013/14, species diversities were high at Hunters Creek in the Murray Mouth and Mark Point, Long Point and Parnka Point North in the North Lagoon.

Scenarios of reducing taxonomic resolution based on benthic macroinvertebrate data from 2010-2015.

Taxonomic resolution was compared from the 2010 to 2015 macroinvertebrate data to identify the possibilities of refining future macroinvertebrate monitoring programs. Community data were summed across taxonomic levels for each sample to create total abundances for each group for each sample.

This was done on two levels – firstly, data were summed across species/taxa to Class level, creating 12 groups (Polychaeta, Oligochaeta, Amphipoda, Decapoda, Ostracoda, Ispoda, Bivalvia, Gastropoda, Coleoptera, Diptera, Tricoptera and Other Insecta) from the original 37 species/taxa. This process was then repeated for species/taxa to Phylum/Subphylum level, this time creating just 4 groups (Annelida, Crustacea, Mollusca and Hexapoda). These data were then used for PERMANOVA running the same 4 factor nested design tested on the original data set, to determine if the reduced taxonomic distinction altered or weakened observed significant differences in community structure. Lastly, a similar process was undertaken to create trajectory plots for community structure over time at two sites (Ewe Island and Mark Point), by summing the original data across taxonomic groups as described above, and across replicates for each sampling event. PCO was then run on each data set with trajectory overlay for the order of sampling events, resulting in three plots for each site, the first on the data using the original taxonomic levels and again on the Class and Phylum/Subphylum levels for comparison.

Reducing taxonomic distinction did alter the results of PERMANOVAs testing for significant differences in community structure among levels and interaction terms in the design. There was a reduction in the strength of the significant differences in community structure among years with reduced taxonomic distinction from highly significant (*P*(perm) = 0.0001) to just significant (*P*(perm) = 0.048), although no change in the overall result (*i.e.* all these *P*(perm) values are significant at the α = 0.05 level) (Table A1.3). More importantly however, the significance of several of the interaction terms was changed, with the interaction between Years and Sites (nested in Regions) changing from non-significant to significant, and the interaction between months (nested in Years) and Sites (nested in Regions) changing from significant to non-significant when taxonomic distinction was decreased (Table A1.3). This latter difference changes the overall interpretation of the table and differences in community structure over space and time in the system. The original output indicates that there are significant small-scale spatial and temporal variation (significant Month x Site interaction) and regional differences within and/or between months (significant Month x Region interaction), and, most importantly, inter-annual differences between regions (significant Year x Region) (Table A1.3). These results could be further investigated using multiple *post-hoc* pairwise tests to investigate which region/year combinations differed significantly from others to determine if there is any trend for recovery in the different regions over time. However, the outputs of tests on data sets with reduced taxonomic distinction indicate that there are significant inter-annual differences among sites (significant Year x Site interaction) but not between Month x Region pairs. This indicates that the inter-annual differences in community structure among sites overrides any inter-annual differences among regions in terms of recovery (i.e. what is happening at the site level is more important than what is happening among regions) when taxonomic distinction is reduced (i.e. species/taxa are driving differences among regions, not Classes or Phyla).

PCO trajectory plots showed no extreme deviations from the patterns observed when reduced taxonomic distinction was used compared to the full data set (Figure A1.11). Increases in the percentage of total variation explained by each axis on these plots as taxonomic distinction decreases are an artefact of summing data into fewer groups for each analyses, a process which reduces the total variation in the data set. Although the overall trends in trajectories do not change, the distinction between communities at the different time steps does decrease (i.e. data points representing the community at each time become closer together), an observation that is especially clear for the first and last sampling occasions at Mark Point (Figure A1.11).

2.2 Recovery

What are the responses of estuarine macroinvertebrates to the reinstated water regimes and what are the processes which give rise to these responses?

<u>*Hypotheses regarding response to flow restoration*</u>

Macroinvertebrate responses to continued flow over the barrages into the Murray Mouth and Coorong Lagoons have been assessed via a long-term (5-year) benthic monitoring program beginning when flows resumed in 2010/2011 (Dittmann et al. 2014b). These data can be used to assess various hypotheses relating to community and species responses to continued freshwater flows into the system.

Thus far, hypotheses relating to changes in the benthos due to continued freshwater flows over the barrage have been focused on community level responses (i.e. changes to total abundance, diversity and community structure of macroinvertebrates), as well as some species-specific responses for key taxa (changes in distribution range, changes in species densities etc.) over time and space, and the sampling regime used has been designed to gather data to test these. Further hypotheses, relating to the biological or physical mechanisms behind the observed species-specific responses to continued environmental flows can also be assessed more generally, but these have not yet been formally tested by manipulative experiments.

It is hypothesised that continued environmental freshwater flows over the barrages into the Murray Mouth and Coorong Lagoons will result in changes in benthic macroinvertebrate communities, specifically, that continued flow over the barrages will lead to:

1. Increases in benthic macroinvertebrate diversity and abundances;
2. Extended distribution ranges of benthic macroinvertebrates, with occurrences reaching in to the South Lagoon; and
3. Changes in the macroinvertebrate community, increasingly dominated by species larger in size and dwelling deeper in the sediment.

The mechanisms driving the hypothesised changes in macroinvertebrate communities have not been formally tested with manipulative experiments, but can be generally assessed for feasibility by investigation of species-specific traits known from the literature. Species-specific traits may affect the individual ability of each species to recolonise mudflats and form viable populations at locations where they had previously been lost during the Millennium Drought. Generally, it is expected that;

Species-specific responses of macroinvertebrates to continued flow may be determined by:

4. Life-history (e.g. dispersal potential, reproduction, larval development, etc.)
5. Habitat suitability affecting recolonization i.e. (water and sediment quality)
6. Species interactions (e.g. predation, competition, bioturbation)

Responses of macroinvertebrate communities to continued flows

Abundance and species numbers

The response of macroinvertebrate communities (in terms of changes in total abundance and abundance of key taxa, species diversity and community structure) to continued freshwater flows over the barrages, has been assessed as part of the water release response monitoring program (CLLMM) and presented for individual years with comparisons to previous years, in a series of annual reports (Dittmann *et al*. 2011; 2013; 2014; Keuning *et al.* 2012). The detailed results presented in these reports will not be repeated here; however, the key observations can be summarised to investigate the changes that have occurred spatially and temporally since flows were restored.

Continued flows across the barrages have resulted in a general increase in abundance and species numbers of benthic macroinvertebrates in the Murray Mouth region from when flows recommenced (2010/11) to 2013/14 (see MR to EI in Figures A2.1, A2.2). This general increase in abundance and species number is not seen as clearly in the North Lagoon, and is not seen at all for the South Lagoon (Figures A2.1, A2.2). This is reflected in the PERMANOVA analysis for total abundance for both depths, and for species number in the intertidal zone, as a significant interaction between regions and years, indicating that there is a significant difference in abundance across the five years of surveys, but that it is not consistent across regions (Table A2.1). For species number in the subtidal, there is a significant interaction between regions and months, indicating that there are significant differences in species numbers within years across regions (Table 2.1). For both variables, there was also significant small-scale spatial and temporal variation for both intertidal and subtidal communities (significant month and site interaction; Table A2.1).

Overall community structure (in terms of species composition and relative abundance) for both intertidal and subtidal habitats exhibited significant small-scale spatial and temporal variation (site and month interaction), and significant inter-annual variation between sites (year and site interaction; Table A2.1). Importantly, there were also significant differences among regions between years (year and region interaction) for both intertidal and subtidal habitats, indicating differences in community structure shifts among the three regions across time (Table A2.1). Multidimensional scaling (MDS) plots for data averaged by regions and years indicate that there is an increasing divergence of communities in the three regions over time at both depths (intertidal and subtidal), with points from each year for the three years moving further apart from each other over subsequent years (i.e. benthic macroinvertebrate communities in each region become increasingly different in structure to each other as flows continue), but with the South Lagoon following a different trajectory to communities in the Murray Mouth and North Lagoon (Figure A2.3, A2.4). Initially, during 2010/11, communities in all three regions were quite similar to one another (points plotted closely together on

MDS plot; Figure A2.3, A2.4). During subsequent monitoring years, communities in the Murray Mouth and North Lagoon become increasingly dissimilar to those in the South Lagoon, and eventually also to each other, but, until 2015, there is not a great distinction in communities from the South Lagoon (Figure A2.3).

Increase in abundance have not been general across all species, however, with decline in the abundance and distribution ranges of some species which thrived under disturbed conditions during the drought (e.g. *Capitella*) being matched by increases in others which have recovered in numbers and recolonised sites as flows continued and conditions improved (e.g. *Arthritica helmsi*). This can be seen clearly (and is described) in the statistical and graphical analysis for patterns of change in the Murray Mouth and Coorong for both intertidal and subtidal communities (Stocktake of Monitoring; Section 2.1, this report), as an inconsistency in patterns for change in abundance and percent contributions to communities across the different species and taxa in the system.

Distribution ranges of key species

The distribution ranges of five key species/taxa were looked at in intertidal and subtidal habitats across the study region and the different years of the monitoring study. Species selected were the polychaetes *Simplisetia aequisetis* and *Capitella spp.*, the Amphipoda, the bivalve *Arthritica helmsi* and the Diptera (flies; both larvae and pupae stages combined). In all cases, the relative abundances of species during 2010/11 was low (*i.e.* too low to appear on distribution maps), with the exceptions of *Capitella spp.* at Long Point Intertidal and Diptera at intertidal sites at Parnka Point North, Jacks Point and Villa dei Yumpa (Figure A2.5-A2.9).

The polychaete *Simplisetia aequisetis* was initially low in abundance during 2010/11, with a population centred in the Murray Mouth region (Figure A2.5). As flows continued, this species expanded its distribution range as far south as Noonameena during 2012/13, when abundances also peaked for this species, with average densities of 17,288 ind.m^{-2} observed at Mark Point (Figure A2.5a). During this same year, and also in 2013/14, increased abundances of this species were observed in the subtidal at sites in the Murray Mouth, especially Monument Road and Ewe Island, and these increases were mirrored in the intertidal populations during 2013/14 and 2015 for each site (Figure A2.5a,b), indicating a recolonisation of intertidal mudflats from recovering subtidal populations.

The polychaete species complex, *Capitella spp.*, persistently maintained a population in the subtidal at Long Point and Noonameena, which steadily increased in abundance at both sites as freshwater flows continued into the system (Figure A2.6b). As flows continued into 2012/13 and 2013/14 this species extended its distribution range in the subtidal southward to include Parnka Point North, and also, although in much lower abundances, Villa dei Yumpa in the South Lagoon (Figure A2.6b). Populations of this species on intertidal mudflats were also most abundant in the North Lagoon during early monitoring years (2010/11 – 2011/12), and were centred at first around Long Point and Noonameena, but then extended northwards as flows into the system continued, becoming abundant at Mulbin-Yerrok in 2013/14 and 2015, and extending as far north as Ewe Island during late summer sampling in February 2015 (Figure A2.6a).

Although Amphipoda were ubiquitous in distribution throughout the system in most years, relatively abundant populations of these species were only observed in the Murray Mouth and North Lagoon regions for both intertidal mudflats and subtidal habitats (Figure A2.7). Amphipoda were not recorded in samples south of Mark Point in 2010/2011, but as flows continued these species were recorded in low abundances at intertidal sites as far south as Loop Road in both 2011/12 and 2013/14 (Figure A2.7a) and in the subtidal at Villa dei Yumpa after 2011/12 (subtidal sites were not sampled at Jacks Point and Loop Road) (Figure A2.7b). Species of amphipods were not distinguished in this monitoring program, and it is likely that multiple species are represented throughout the system, each probably able to tolerate different ranges of salinity, resulting in multiple 'peaks' in abundance across the salinity gradient in the system from North to South. Subtidal populations of amphipods increased steadily in abundance from 2010/11 to 2013/14; however, distribution ranges remained unchanged (Figure A2.7b). Intertidal populations were initially restricted to the Murray Mouth and northern part of the North Lagoon in 2010/11, but as flows continued amphipods extended their distribution range southwards to include all sites sampled in 2013/14, but were not observed in high numbers south of Mulbin-Yerrok during the single February sampling event in 2015 (Figure A2.7a). This may have been due to the late timing of the sampling event, having missed the time before arrival of foraging shorebirds, when abundance and distribution of this species may have been greater (*i.e.* before predation).

The small bivalve *Arthritica helmsi* was only recorded as one-off individuals during early monitoring years (2010/11-2011/12) in both intertidal and subtidal habitats (Figure A2.8). During 2012/13, small populations of this species were recorded in the subtidal for the first time at both Tauwitcherie and Mark Point, and a number of individuals were found in samples from intertidal sites between Hunters Creek and Long Point (Figure A2.8). The following year, subtidal populations at Tauwitcherie and Mark Point increased over 20-fold (Figure A2.8b), going from a few hundred individuals per square metre to nearly 10,000 ind.m^{-2}. During this same year, very high abundances (over 70,000 ind.m^{-2}) of this species were also recorded in the intertidal at Tauwitchere (Figure A2.8a), with this species also being recorded throughout the Murray Mouth and northern North Lagoon between Hunters Creek and Long Point. During the most recent monitoring event in 2015, such extremely high abundances were not recorded for this species (note however that Tauwitcherie was not included in sampling during 2015), but abundance of this species had increased at all sites sampled in the Murray Mouth and North Lagoon from a few hundred to a thousand individuals per square metre during 2013/14 to tens of thousands of individuals per square metre during 2015 at most sites where it occurred previously (Figure A2.8a), with a small population also recorded at Monument Road for the first time since flows were restored during 2010. This species appears to have recovered populations first in the subtidal, then recolonised intertidal mudflats as flows into the system continued before expanding its distribution range to include all sites sampled in the Murray Mouth and as far south as Mulbin-Yerrok and Long Point in the North Lagoon.

Diptera (larvae and pupae), like Amphipoda, are ubiquitously distributed throughout the system, and include a number of salt-tolerant species like Chironomidae and Ephydridae, enabling them to persist in the South Lagoon even when conditions in that region were poor following the Millennium Drought. These species have not increased their distribution range but have increased in abundance as flows continued, with peak abundances recorded for these species at the intertidal site at Pelican Point during 2012/13 (Figure A2.9a), and have subsequently decreased in abundance, especially in the Murray Mouth region, having returned in 2015 to similar abundances as were recorded during 2011/12 monitoring. Subtidal populations of these species increased substantially during 2013/14 (Figure A2.9b), but as subtidal monitoring was discontinued for 2015, it is unknown if these populations have declined in the same way as for intertidal populations, or continued to grow and expand.

Distribution ranges in general

The index of occurrence was used to look at whether there had been a general increase in distribution range in the system for all species (references). The index is calculated for each species as the number of sites that species was found in a particular year out of the total number of sites sampled, as a percentage. These indexes for each species are then tallied into distribution range categories for each sampling year to calculate percentage species occurrence, that is, the percentage of species that were widely distributed (*e.g.* occurred at more than 80% of sites sampled), through to species that were only observed at one or two locations each year. For these calculations, species that were only observed at one site at one time were removed from the data set.

Although there were some changes in distribution ranges for key species in intertidal habitats, on the whole species distribution ranges in general have not changed greatly since flows were restored in 2010 (Figure A2.10a). There was an increase in distribution ranges for many species during 2012/13, but this was not seen to continue into 2013/14 and by 2015 overall distribution ranges had reverted to similar patterns as were seen in the first year of monitoring (2010/11; Figure A2.10a). Part of this may be an artefact from the single round of sampling undertaken during 2015, late in the season, which may have missed wider distribution ranges of species prior to arrival of migratory shorebirds. Shorebirds may have reduced populations of some species via predation over the summer months before sampling during February.

In the subtidal there is a pattern for more species increasing their distribution ranges, with fewer species observed to occur at only one or two sites, and more species being found at around half the sites sampled by 2013/14 (Figure A2.10b). As subtidal sampling was not undertaken during 2015, it is impossible to know whether this pattern has continued or if there has also been a return to distribution ranges observed in early monitoring years.

Community structure and species compositions

Changes in macroinvertebrate community structure across time since flows commenced until the most recent sampling in 2015 are clear in each region. In the Murray Mouth Region there is little distinction between macroinvertebrate communities at different sites for any individual sampling year (*i.e.* all the points for each site in each year are close to each other), but a general trend over time for change in community structure (Figure A2.11a). This change is apparent first as a shift from left to right across the x-axis of the plot during the first three years of flow (2010-2013), then as a vertical shift during the last two years of monitoring (2013/14-2015) (Figure A2.11a). Overall, this temporal shift explains 75.4% of the overall variation in the data. Spearman correlation vector overlays indicate that changes in macroinvertebrate community structure over time are due to a succession of species at the sites, as the large polychaete, *Nephtys australiensis*, became increasingly less common and eventually absent from samples during the last monitoring event (possibly linked to the scaling back and eventual exclusion of subtidal monitoring) but increases in abundances of Chironomid larvae and Amphipoda, both groups that inhabit the top surface layer of sediments (Figure A2.11a). During the two most recent years of monitoring, other species which generally inhabit the top 5 cm of sediments increase in abundance, including the polychaetes *Boccardiella limnicola* and *Simplisetia aequisetis*, as well as the molluscs *Arthritica helmsi* and Hydrobidae snails (Figure A2.11a). Although there is a clear succession of species in this region over time as flows into the system continue up to 2015, as yet the larger, deeper dwelling species such as *Nephtys australiensis*, *Australonereius ehlersi* and the large bivalves *Soletellina alba* and *Notospisula* are yet to recolonise intertidal sediments in significant numbers, indicating that recovery, even in the Murray Mouth region, is not yet complete.

In the Northern Coorong Region, the two sites sampled (Mark Point and Mulbin-Yerrok) during the first year of monitoring (2010/11) (and also Mulbin-Yerrok in 2012/13) are distinguished from other sites by the reduced abundances of Amphipoda, *Simplisetia aequisetis*, *Arthritica helmsi*, *Soletellina alba* and *Capitella spp.* in samples, with this split explaining 42.5% of the total variation in the data (Figure A2.11b). This region represents a transitional zone between the Murray Mouth Region and the Southern Coorong, where conditions remained hyper-haline throughout the monitoring period (see Annual Trends section A2.3, this report), and this is evident in the remaining monitoring years, with no clear distinction between sites in this region within years, and no apparent pattern of recovery over years (close and overlain data points for each site indicating similar community structures at each site; Figure A2.11b).

The Southern Coorong represents a hyper-haline region in the system, with a consistently distinct community structure over the monitoring years, driven by high salinities in the region (see Annual Trends section A2.3, this report). Noonameena is distinguished from other sites in the region in most sampling years, with the exception of the very first year of monitoring (2010/11), by the higher abundance of a range of estuarine and marine species in samples (Figure A2.11c). This one site shows a temporal transition from 2010/11 to 2015, moving initially from a depauperate community in 2010/11 to one containing increasing abundances of the polychaetes *Australonereis ehlersi*, *Capitella spp.* and *Simplisetia aequisetis*, as well as mysid shrimp, oligochaete worms and the bivalve *Notospisula* (Figure A2.11c). Overall, this representation of distinctions in communities among sites in the region only explained 51.2% of the total variation in the data (Figure A2.11c), most likely owing to the stable hyper-haline condition in this region over the past five years and depauperate macrofaunal communities.

Species-specific responses to continued flows

Re-establishment of populations – recruitment from other populations

The re-establishment of populations of species that have been lost at some or all sites under drought conditions may be dependent on species-specific life-history patterns, particularly the species ability to recolonise sediments from populations in other locations. Generally, species with planktonic larvae are best able to recolonise sediments, because the parent populations can be at some distance from the recolonised site (Grantham et al. 2003). Species with larvae that spend a longer time in the plankton generally are able to disperse across a greater distance than those with short-lived planktonic larval stages, and species that have no planktonic larval stage (i.e. direct developers), have the most limited capacity of all to recolonise distant sites, even after environmental conditions become favourable following recovery from disturbance (Grantham et al. 2003).

Unfortunately, the life-history and reproductive biology for many benthic macroinvertebrate species inhabiting the Coorong is not known. Of the polychaete species recorded in the study region, most have planktonic larvae of unknown duration (Table A2.2), and should have a reasonable capacity to recolonise sediments as environmental conditions improve, allowing larval settlement, survival and growth of juveniles. This can be seen for *Capitella spp.*, a k-selected species with short lifespan and high fecundity in addition to a planktonic larval stage (Table A2.2), which allows this species to recover and recolonise habitats quickly (Tsutsumi 1987, Mendez et al. 1997). This can be seen in the recolonisation of subtidal sediments at Parnka Point within three years of flow restoration to the region from subtidal populations up to 20 km away at Long Point and Noonameena (Figure A2.6).

Another polychaete species, the Nereid *Simplisetia aequisetis*, displays a very different life-history strategy, with adults brooding clutches of eggs in tubes in the sediments and the juveniles hatching and recruiting directly into the parent population (*i.e.* direct development; Table A2.2) (Dorsey 1981). This species has been much slower to expand its distribution range, with substantial increases in population abundances observed over the five years following the reinstatement of environmental flows into the Murray Mouth and Coorong Lagoons, rather than a large increase in distribution range (Figure A2.5).

Suitability of habitat – species tolerances to environmental conditions

Many of the species inhabiting the Murray Mouth and Coorong Lagoons are tolerant of a wide range of water and sediment conditions, a trait which is typical of estuarine species which are adapted to life in a highly variable environment (Table A2.2). Some species are particularly tolerant, such as *Capitella spp.*, which is known as an indicator of marine pollution (especially organic enrichment) or environmental disturbance (Table A2.2) (Rolston 2010). It is not surprising, then, that this species was able to persist in relatively high abundances in the system during the Millennium Drought, when environmental conditions deteriorated throughout the system. Since flows have been restored, this species has persisted in the system, but its distribution range is being reduced as *Capitella sp.* is pushed further south towards Noonameena, especially in the subtidal habitat (Figure A2.6b), as conditions in the Murray Mouth and northern North Lagoon continue to improve.

The small bivalve, *Arthritica helmsi*, was present in the system in very low numbers at both intertidal and subtidal sites around the Murray Mouth when flows were restored in 2010/11. This species was not able to recover even to form small populations at these sites until the third year of continued flows, and since then abundances of this species have increased rapidly in the fourth and fifth years of flow, including an expansion of distribution range into the northern North Lagoon (Figure A2.8). Little is known of the environmental tolerances of this species, but it does seem that some threshold in environmental or biological conditions has been reached to allow the species to re-establish populations quickly throughout its distribution range. *Arthritica helmsi* does display a wide tolerance of salinity conditions (Table A2.2) but has a preference for polyhaline conditions (see Conceptual Models section 2.5; this report), which were not seen during the drought in the region when conditions were closer to euhaline (marine), or immediately following flow restorations, when salinity dropped to oligohaline (near freshwater) around the Murray Mouth.

Colonisation of sediments – species interactions allowing or affecting re-colonisation

Once environmental conditions improve following disturbance, if species are able to arrive at new sites via larval or adult dispersal, species interactions, such as predation, bioturbation and competition may all affect whether or not those newly arrived individuals are able to form viable populations. Most benthic macroinvertebrates encountered in the Murray Mouth and Coorong Lagoons are deposit feeders, that is, they are either selective or non-selective feeders on benthic sediments and microbenthos (Table 2.2). Some closely related species, such as the two Nereids, *Simplisetia aequisetis* and *Australonereis ehlersi* are believed to undergo resource partitioning where populations of these species overlap, so as not to directly compete with one another for access to food or other resources (Dorsey 1981). Species are also not likely to be competing for space, with the mudflat providing a three-dimensional habitat allowing species to inhabit the surface of sediments (e.g. amphipods and insect larvae), top layers (e.g. smaller polychaetes and bivalves) or deeper layers (e.g. large bivalves and polychaetes).

Some species make important changes to habitats that allow other species to recolonise sediments. These species are known as ecosystem engineers, and may create habitat structure (e.g. reef or tube forming species), aerate sediments (e.g. tube builders and burrowing species) or stabilise or destabilise sediments (Coleman and Williams 2002). Because some species require the structure or alterations made by these engineer species in order to recolonise habitats themselves, often a progression of species can be seen as habitats recovery from disturbance, with first recolonisation by k-selected species like *Capitella spp.* and species with highly mobile adults like Amphipoda and Diptera (flies). These species can then change the habitat further via processes such as bioturbation. This process involves individuals digging into the surface sediments, adding oxygen and organic matter, which can make conditions more favourable for other species (Coleman and Williams 2002), such as smaller polychaetes like *Simplisetia aequisetis* and *Boccardiella limnicola*, and small bivalves such as *Arthritica helmsi*. This is the process which has been observed in the Murray Mouth since flows resumed in 2010/11. Following restoration of flows, early years saw increase in abundance of these bioturbating species, specifically Amphipoda and larvae of the Chironomid fly inhabiting the very surface of sediments in the Murray Mouth region (Figure 2.11a). As flows continued into 2013/14 and 2015, species which inhabit the top layers of sediment were able to recolonise, including *Simplisetia aequisetis*, *Boccardiella limnicola*, Hydrobiid snails and the small bivalve *Arthritica helmsi*, possibly at least in part because bioturbating species such as amphipods had softened surface layers to the point that larvae of subsequent species were able to settle and survive. The next progression of this process may involve further ecosystem engineering, especially by the tube building species *S. aequisetis* which will increase oxygenation of deeper sediments, and the sediment stabilising species *Boccardiella limnicola*, which will help consolidate surface sediments (Table 2.2). This in turn may assist the recolonisation of mudflats by deeper dwelling species, such as the large bivalves *Notospisula trigonella* and *Soletellina alba*, and the large, predatory polychaete *Nephtys australiensis*, which are still uncommon in mudflat samples even in the Murray Mouth. Without continued water release and benthic macroinvertebrate monitoring of this system, we will not know whether this further progression takes place in this system.

2.3 Annual Trends

Can insight or explanations be gained regarding the inter-annual trajectories?

Defining regions within the system

Previously, the study area has been divided into three regions, the Murray Mouth, the North and the South Lagoon, based on geographical boundaries. Pelican Point has been considered the southern-most site in the Murray Mouth region, with a transition between the North and South Lagoons presumed to occur at Hells Gate at Parnka Point, between Parnka Point North and South sites. However, there is no a priori reason to expect that such geographic boundaries imposed by map-makers, managers and scientists should actually represent the true spatial divisions in this system. To investigate where these spatial divisions may truly lie, LinkTREE (+SIMPROF: minimum grouping size = 5; P(perm) = 1%) was used to group sites across space and time that exhibited similar biological assemblages and salinity conditions (as other environmental variables were missing data for many sites/sampling occasions), in order to define true boundaries between regions within the system.

In order to create matched environmental and biological assemblage data for the LinkTREE (+ SIMPROF), salinity data and macroinvertebrate community (species and abundance) data were averaged to obtain a value for each variable (either salinity or macroinvertebrate species) for each depth (intertidal or subtidal) for each sampling occasion for the period starting when monitoring began in 2010/11 to the most recent event in 2015. Prior to all analysis, salinity data was used to construct a Euclidian distance-based similarity matrix on the normalised, untransformed data (as advised in Clarke and Gorley 2006). Biological assemblage (community) data were 4th-root transformed to reduce the influence of dominant species prior to analysis. Selected samples were used to construct a zero-adjusted Bray-Curtis Dissimilarity matrix (dummy variable = 1). LinkTREE was run on the paired salinity and biological assemblage data sets using minimum group size of 5, minimum split size of 10 and a minimum split R value of 0, with the SIMPROF test option selected (significance level reduced to 1% to limit the number of group splits to only those that were highly significant). A mean of 1000 permutations and 999 simulations were used. These tests were all run using Primer v6.

There was a clear separation of sites from the southern region of the Coorong Lagoons in all years, with sites in the South Lagoon (Parnka Point South, Villa dei Yumpa, Jacks Point and Loop Road separating from other sites consistently within and across years (except during September 2012), as well as Noonameena and Parnka Point North during most sampling occasions (Figure A3.1). These sites were characterised by having depauperate biological assemblages containing sparse numbers of halophilic invertebrates (Chironomid larvae + pupae, Amphipoda, Capitella and Ephydridae pupae; defined by SIMPER analysis on data from all years based on groups defined by LinkTREE +SIMPROF) and high salinities (salinity > 50.1 ppt). This group is consistently separate from all other groupings within and between years, and likely represents an extreme hyperhaline southern region in the Coorong Lagoons that is distinct from all other regions.

After this the transition points become more variable, as the northern Coorong and Murray Mouth sites presumably go through a series of seasonal changes within-years and recovery/transition stages over years since flows recommenced in 2010 (Figure A3.1). Within years there is a seasonal change at most sites from spring/early summer communities and lower salinity conditions to late summer/early autumn communities and increased salinity conditions. During 2011/12 and 2012/13, when sampling was the most intensive both spatially and temporally, it is possible to see an initial change in community structure and salinity in the Murray Mouth region as freshwater flows into the system decline, followed by a second shift back to fresher water communities as flows increase again in April and May 2012 (Figure A3.1). These effects are even seen as far south into the southern region of the Coorong as Villa dei Yumpa during September 2012, when flows continue to be high (Figure A3.1). After this point however, there is a steady change to higher salinity communities over 2012/13 at all sites as flow volumes also decrease (Figure A3.1). Without further data it is impossible to determine whether the seasonal community shifts observed are related to changes in salinity as freshwater flows into the Coorong vary over the summer or whether foraging pressure from migratory waders results in community structure over time, or even a combination of both effects.

Oligohaline (freshwater/low salinity) communities (with salinities between 0 and 6 ppt) were persistent in the Murray Mouth region between Monument Road and Tauwitchere/Pelican Point, especially during the early monitoring years (2010/11 and 2011/12), and for each survey year, particularly during early summer 2012/13 and 2013/14 (Figure A3.1). Because monitoring was only undertaken during February during 2015, it is unknown whether the Murray Mouth region again returned to oligohaline conditions during early summer in 2014/15, or if reduced flows are causing an increasing tendency towards meso- and polyhaline conditions in this region. Oligohaline conditions and communities were observed as far south into the North Lagoon as Mark Point and Long Point when barrage flows were high over winter 2012 (Figure A3.1). Analysis suggests that Mark Point may sometimes fall into similar community and salinity states as sites in the Murray Mouth Region, and that the transition point between the Murray Mouth and Coorong fluctuates between Pelican Point and Mulbin-Yerrok, where the influence of barrage flows on salinity and community structure apparently declines, except during periods of high continuous flows (i.e. winter 2012; Figure A3.1). The transition most often occurs between Pelican Point and Mark Point, the traditional boundary used in previous years to separate these regions. These communities are characterised by the presence of the omnipresent Amphipoda and Chironomidae larvae, and relatively high abundances of the polychaete worm *Simplisetia aequisetis*, with two additional polychaetes, *Boccardiella limnicola* and *Nephtys australiensis* also occurring in small numbers when salinities ranged between 3-6 ppt (group 7, dark orange shading in Figure A3.1; Table A3.1). This last community type (salinity 3 – 6 ppt) is generally only observed at sites in the Murray Mouth region during December of each monitoring year (2011/12 – 2013/14), and appears to represent part of the transition of sites in this region between freshwater and estuarine communities over the summer months as salinities increase (Figure A3.1). Over years, as flows continue over the barrages, there is a gradual change in the groupings of oligohaline communities in the Murray Mouth region. The very low salinity grouping (group 4, Figure A3.1) which is observed throughout the Murray Mouth during 2010/11 monitoring is seen less frequently in subsequent years, as other oligohaline groups (especially groups 7 and 8; Figure A3.1) are observed in the region instead. Although these groupings represent distinct communities of macroinvertebrates, species compositions generally remain the same, but relative abundances of the defining species change (Table A3.1). Initially, abundances are dominated by amphipods and chironomid larvae (group 4), but over time, other species, especially *S. aequisetis* recover in numbers as flows are continued, resulting in very different communities, even though salinity changes are negligible (Figure A3.1; Table A3.1).

Estuarine conditions and communities are represented by meso- and polyhaline states, and are generally observed in the northern section of the North Lagoon (Mark Point, Mulbin-Yerrok and occasionally Long Point), and seasonally extend into the Murray Mouth region, especially during late summer/autumn (see particularly 2012/13, 2013/14 and 2015; Figure A3.1). These communities represent a transition between freshwater and marine communities, and are comprised of a mix of typically freshwater and marine species (Table A3.1). Besides the omnipresent Amphipoda and Chironomidae larvae, the polychaete worm *Simplisetia aequisetis* becomes quite typical of these estuarine communities, particularly when salinities are around 15 - 16 ppt (Group 16; Figure A3.1; Table A3.1). At this same salinity, the bivalve *Arthritica helmsi* also characterises communities, while snails from Hydrobiidae family as well as the polychaete *Boccardiella limnicola* are also observed (Table A3.1).

Marine salinity communities are not often observed in the system, appearing sporadically at sites sampled in the North Lagoon during 2011/12 and consistently at sites in the Murray Mouth and North Lagoon in late summer during 2012/13 and 2013/14 (Figure A3.1). Rarely is there are clear transition from fresh to estuarine and then marine conditions, with the boundary between estuarine and hyperhaline conditions (presumably containing the euhaline/marine conditions) often falling somewhere at locations not sampled in the mid-North Lagoon, between Long Point and Noonameena

(Figure A3.1). These euhaline/marine communities are characterised by many of the species observed in estuarine conditions, with the addition of the salt-tolerant polychaete worm *Capitella spp.* (Table A3.1).

A hyperhaline region exists with salinities between 38 – 50 ppt, generally including sites previously considered to be in the southern North Lagoon, such as Long Point, Noonameena and on one occasion (Sept 2012), even Parnka Point North and Villa dei Yumpa. These sites are characterised by high abundances of salt-tolerant species, including *Capitella spp.* and Amphipoda, as well as the presence of larval and pupal stages of the chironomid fly, oligochaetes and occasionally the polychaete worm, *Simplisetia aequisetis* (Table A3.1).

Overall, regional divisions in the Murray Mouth and Coorong Lagoons are difficult to definitively define, with seasonal and inter-annual shifts in environmental conditions and community structure making divisions in the study area highly variable within and between years (Figure A3.1). In general, a defined region exists within any particular sampling event throughout the Murray Mouth, sometimes extending into the North Lagoon to include Mark Point (Figure A3.1). This region is typically oligohaline, but over the years, as flows across the barrages decrease during 2012/13 and 2013/14, persistent oligohaline conditions that were observed in the Murray Mouth region during early monitoring years (2010/11 and 2011/12) change to seasonal shifts towards mesohaline, polyhaline and eventually euhaline (approximating marine) conditions during late summer/autumn 2013/2014, with each state represented by different macroinvertebrate communities (transition from groups 7 – 12; Figure A3.1; Table A3.1). Likewise, there is a persistent division of sites in the Coorong Lagoons south of (and including) Noonameena, to create a southern region where hyperhaline conditions and communities dominate, and groupings 1 and 2 persist within and across years (Figure A3.1; Table A3.1). Between these two is a transitional region, between Mark Point and Long Point (including the Long Point Peninsula site), where salinity conditions are highly variable and communities fluctuate between oligohaline and hypermarine types over the study period, transitioning from groups 11 to 10 as salinity increases (Figure A3.1).

Community change over years in response to flow restoration

Changes in benthic macroinvertebrate communities over years since flows were restored in 2010 have been monitored as part of the benthic invertebrate monitoring program beginning in 2010/11. These data can be used to investigate inter-annual trajectories of change for benthic macroinvertebrate communities and make insights or inferences on the processes that may be responsible for changes in these communities as they recover after the Millennium Drought.

Averaged community data were fourth-root transformed and a zero-adjusted Bray-Curtis similarity matrix was calculated separately for each analysis (done separately by regions and also by each depth in each region). Regions were based on the new splits between sites determined by the LinkTREE analysis (Figure A3.1). Non-metric multidimensional scaling (nMDS) plots were generated using Primer v.6 on community data (species and relative abundances) averaged for each region and year of the monitoring program, and also separately for each habitat (i.e. intertidal and subtidal). This was not possible for the South Lagoon subtidal data set, because there were too few monitoring years in which subtidal sampling was undertaken (two years only; see Stocktake of Monitoring section 2.1, this report). Cluster analysis was then used to generate dendrograms for each data set to determine in which years benthic invertebrate communities were more or less similar to one another for each grouping (i.e. for each region, for each region/depth). Trajectory overlays were put on MDS plots to track the change in benthic macroinvertebrate communities over consecutive years of the monitoring program, and cluster overlays (based on the results of the cluster analysis dendrogram for each data set) were used to create ellipses around years that were over 70 % similar in macroinvertebrate community structure.

SIMPER analysis was then undertaken on each regional overall (intertidal and subtidal combined) data set with groups based on years that were grouped by the cluster analysis. Species that contributed highly to average similarity within years were identified as those species that characterised communities for those year groupings in each region.

In each region and each region by depth there was a clear change over time in benthic macroinvertebrate community structure, with a general progression over years from 2010/11 to the most recent monitoring event in 2015 (Figure A3.2). Generally, overall and in intertidal communities, there was a distinction in community structure between the first year of monitoring (immediately following restoration of flows into the system in 2010/11) which grouped separately, the intermediate years (2011/12 to 2013/14) which grouped as either one or two groups, and the final, most recent monitoring event in 2015 which also grouped separately (Figure A3.2). A similar pattern was seen in the subtidal for the Murray Mouth and Northern Coorong (Figure A3.2). The clear distinction of communities in 2015 from recent monitoring years most likely represents the fact that these communities were only sampled once, during February, when salinities were estuarine in the Murray Mouth, marine in the Northern Coorong and hyper-haline in the Southern Coorong, in addition to continued recovery in the system with restored flows. However, because sampling was only a once-off, the transitional states that generally occur over summer as salinities increase in each region (Figure A3.1) were missed, and so the averaged community represented in these trajectory plots for 2015 is really only that for late summer, not over the whole summer period. Nonetheless, although salinities were relatively high in each region at the time of sampling (Figure A3.1), communities were diverse and abundant (abundance/diversity plots), unlike what has been seen during late summer in other monitoring years, indicating continued recovery of benthic macroinvertebrate communities.

SIMPER analysis of year groupings indicated a change in species composition, as well as average abundances of each species, over time as flows continued into the system (Table A3.2). In the Murray Mouth region, benthic macroinvertebrate communities in the first year following restoration of flows into the system (group '2010/11') were dominated by amphipods and chironomid fly larvae and pupae, which together explained over 60 % of the average similarity in community structure across samples in the region (Table A3.2). These ubiquitous taxa are highly tolerant of variable conditions and inhabit the surface of mudflat sediments, and were the first species to be seen to recolonise sediments as habitats recovered following the Millennium Drought (see Recovery section A2.2, this report). In addition, the annelids Simplisetia aequisetis, Nephtys australiensis and Oligochaete worms contributed a further 33 % to average similarity, but exhibited relatively low average abundances (Table A3.2). As flows continued into the system, the intermediate monitoring years (group '2011/12 to 2013/14') saw an increased average abundance of all species that were observed in benthic macroinvertebrate communities in the region during 2010/11, with the exception of *N. australiensis* (Table A3.2). Again, amphipods, chironomid fly larvae and pupae and the polychaete *S. aequisetis* contributed highly to average similarity among samples, together contributing over 76 % to average similarity (Table A3.2). Four additional species, including three species that did not contribute highly to average similarity in community structure during 2010/11, added a further 18 % to average similarity during 2011/12 – 2013/14 (Table A3.2). In the most recent monitoring year (2015), average similarity of samples across the Murray Mouth region increased greatly (79.6 % compared to 63.2 and 65.3 % in the first and second year groupings; Table A3.2), but this may only be an artefact of the reduced sampling effort in 2015. There is also the addition of new species to the list of contributing taxa, including the molluscs *Arthritica helmsi* and hydrobiid snails, an increase in the abundance of species that inhabit top layers of sediments such as *S. aequisetis* and *Boccardiella limnicola,* and decrease in the dominance of taxa like amphipods and chironomids that were highly abundant in earlier monitoring years (Table A3.2). Five species in total contributed highly to average similarity among samples in the region, with a combined contribution of over 87 %, with a sixth species adding only another 2 % overall (Table A3.2). Despite continued community structure shifts towards a more diverse and abundance community of benthic macroinvertebrates in this region, the return of larger, deeper dwelling invertebrates, such as the predatory polychaete *N. australiensis*, and the large bivalves *Soletellina alba* and *Notospisula trigonella* has not yet been observed, and these communities still appear to be in a transition to recovery following the Millennium Drought.

Benthic macroinvertebrate communities in the Northern Coorong in the first year following restoration of flows into the system were characterised by relatively low abundances of oligochaetes, *Capitella spp.*, chironomid fly larvae and pupae and an unidentified mysid shrimp (Table A3.3). Together these four species contributed to all (100 %) of the similarity among samples for the Northern Coorong during 2010/11 (Table A3.3). The following year saw another community structure in the Northern Coorong, characterised by an increase in abundance of amphipods, oligochaetes, *Capitella sp.* and chironomid fly larvae and pupae, with these four species together contributing over 80 % to average similarity among samples from the region during 2011/12 (Table 3.3). In addition, two polychaete worm species, *Simplisetia aequisetis* and *Australonereis ehlersi*, which were not characteristic species during 2010/11 were also observed, with these two species contributing a further 12 % to average similarity among samples (Table 3.3). Communities remained similar in the Northern Coorong between 2012/13 and 2013/14, and were characterised by high abundances of amphipods and the polychaete species *Capitella spp.* and *S. aequisetis* (Table 3.3). Together, these three species contributed nearly 70 % to average similarity among samples for those two monitoring years, with a further three species, the bivalve *Arthritica helmsi*, chironomid fly larvae and pupae and oligochaete worms contributed a further 20 % (Table 3.3). Only one site, Mulbin-Yerrok, was sampled in this region during 2015 monitoring, and SIMPER analysis was not possible for this single site grouping. However, relative abundances could still be calculated for this site, and indicate that the benthic macroinvertebrate community at this site during 2015 differed from previous years by increased abundance of *Capitella spp.*, *A. helmsi*, and to a lesser extent, *S. aequisetis*, and a decrease in abundance in amphipods (Table 3.3).

Macroinvertebrate communities in the Southern Coorong were dominated by insect larvae, amphipods and in some years, also the polychaete *Capitella spp.* (Table 3.4). There are less obvious changes in community structure, in terms of both abundances and species compositions, in the Southern Coorong, which is not surprising given benthic macroinvertebrate communities in the Southern Coorong are typically highly variable in composition, depauperate in species and abundances and sparse in distribution. The second and third years of flow are distinguished from other years by an increased diversity of insect larvae in samples, with three fly families represented (Chironomidae, Ceratopogonidae and Ephydridae), but only the Chironomidae were characteristic (i.e. contributed highly to average similarity; Table 3.4). The final year of monitoring is separated from earlier years by a decrease in the average abundance of Chironomidae, which was the only characteristic species (contributing over 93 % to average similarity) for the Southern Coorong during 2015 (Table 3.4).

What evidence is available to link the inter-annual trajectories of benthic communities to those for plankton and water quality?

The benthic macroinvertebrate communities found in the Murray Mouth and Coorong were influenced by changes to flows through the barrages and subsequent salinity reductions during the 2010-2015 monitoring years (Figure A3.1). Those changes to macroinvertebrate communities were regions specific with the Murray Mouth showing increasing signs of recovery to a more estuarine/marine macroinvertebrate community structure by 2015. Changes towards recovery of macroinvertebrate communities in the North Lagoon were more site specific with a shifting transition zone across the years of macroinvertebrate communities more similar to either the Murray Mouth or the South Lagoon depending on the year sampled (Figure A3.1). In the South Lagoon, the macroinvertebrate community structure did not shift towards recovery but stayed within the hyperhaline range with the presence of only opportunistic species that have high salinity tolerances (Figure A3.1, Table A3.4).

In comparison, water temperature and salinities across the Coorong were identified as the main environmental influence on changes to phytoplankton communities with changes in flow from 2010 to 2013 compared to drought conditions before 2010 (Leterme et al. 2015). The dominance of cyanobacteria and chlorophytes in the Murray Mouth and South Lagoon respectively during 2011/12 changed to higher diversity of taxa in the northern Coorong in 2013/14 (Oliver et al. 2014, Leterme et al. 2015, Table A3.5). The pattern of change away from dominance of particular taxa to a more complex mix of phytoplankton in 2013/14 does follow a similar pattern to macroinvertebrate taxa, particularly in the Murray Mouth region (Table A3.5).

Zooplankton community structure also changed in similar ways to phytoplankton and macroinvertebrates with higher species diversities and increasing complexities in community structure from 2010 to 2012/13 (Oliver et al. 2014, Table A3.5). The authors suggest that environmental flows were associated with changes to community structure through time, particularly in the northern Coorong (Oliver et al. 2014). However, further investigations need to investigate the association of zooplankton with the environmental variables such as salinity and temperature, and flow regimes more generally, to determine if there is a similar pattern to those changes identified for phytoplankton and zooplankton communities.

Integration of other service providers findings.

Changes in freshwater flows through the barrages and subsequent water quality during the water release monitoring period of 2010-2015 did appear to have some influence on all aspects of the food web (Table A3.5). The large increase in freshwater flows through the barrages during 2010/11 in the Murray Mouth and Coorong resulted in dominance of opportunistic, short lived macroinvertebrates and dominance of particular species or groups of phytoplankton and zooplankton (Table A3.5). Those large freshwater flows in the first year of water release also resulted in large numbers of freshwater fishes in the northern Coorong and low species diversity overall (Bice and Zampatti 2014, Table 3.5). Bird species were declining from 2010 to 2011/12 due to large freshwater flows resulting in flooded tidal that reduced the preferred area for foraging along the intertidal zone (Paton and Bailey 2014, Table A3.5). In 2012/13 the community compositions of zooplankton, macroinvertebrates, fish and migratory shorebirds increased in species diversity and there was an increase in fish recruitment during the same year (Table A3.5). The reduction in freshwater flows through the barrages in 2013/14 resulted in little improvement of zooplankton and macroinvertebrate communities compared to 2011/12 and there were lower abundances of indicator fish species such as sandy sprat (Bice and Zampatti 2014). In comparison, phytoplankton and fish communities were more species diverse, fish recruitment improved for some species and bird numbers increased during 2013/14 (Table A3.5) The reduced but consistent flows in 2015 resulted in increased abundances of larger, longer lived, deeper burrowing macroinvertebrates (i.e. akin to a more typical estuarine state) with higher species diversity compared to previous years (Table A3.5).

Overall there were very similar responses for all taxonomic groups with the initial large volume freshwater flows through the barrages into the Coorong during 2010/11. Complex responses were identified across all taxonomic groups with fluctuations in freshwater flows in subsequent years to large reduction in flow volumes during 2013/14, then still consistent but low flow volume flows through to 2015. The large reduction in flow during 2013/14 only appeared to impact the recovery of zooplankton, macroinvertebrates and some fish species. In 2015 the responses of macroinvertebrates had improved again with consistent but low volume freshwater flows through the barrages into the Coorong. Further investigation and comparison of data for all of the other taxonomic groups from 2015 is needed and may indicate if they too have responded favourably to the same flow regime in the last year.

2.4 Conceptual Models

What are the typical inhabitants of the benthos?

<u>*Species in the CLLMM system:*</u>

In total, 40 taxa were recorded from the Murray Mouth and Coorong Lagoons over the 5 year monitoring program (Table A4.1). These included eight species of polychaete worms as well as worms from the Class Oligochaeta (Table A4.1). Three species of bivalves were identified, including the small-bodied *Arthritica helmsi* and larger, deeper dwelling taxa, *Spisula trigonella* and *Soletellina alba* as well as eight species of gastropods, including six species of hydrobid snails (Table A4.1). Crustacea were generally identified to class level, and were represented by Ostracoda, Isopoda, Amphioda and Mysidacea as well as three species of decapod crabs and the brine shrimp *Paratemia sp.* (Table A4.1). Insects (Hexapods) were identified to family level where possible, and were represented by the larval and pupae stages of eight dipteran families and four coleopteran families (Table A4.1).

In general, over the monitoring period fewer taxa were recorded from the South Lagoon (16 taxa) compared to the Murray Mouth (26 taxa) and the North Lagoon (30 taxa; Table A4.1). In the Murray Mouth and North Lagoon, more taxa were recorded during intermediate years (e.g. 2012/13) than the most recent survey (i.e. 2015; Table A4.1); however, this may simply reflect the reduced sampling effort and timing of the 2015 monitoring event (i.e. only one sampling event and only the intertidal zone sampled during February 2015).

Meta analysis of study findings.

<u>*Environmental tolerances of macroinvertebrate species*</u>

Nine key species/taxa were chosen to investigate their tolerances for environmental conditions. To be selected, species/taxa had to be relatively common and consistent in samples (occurring at most sites and/or in most years) and relatively abundant when it occurred. Where abundances were low (fewer than 1000 ind.10m^{-2}, i.e. fewer than 100 ind. m^{-2}, or approx. less than one individual per core taken) that species/taxa was considered to be out of its distribution range, and so environmental conditions experienced by that species at that site/time were not included in the calculation of environmental tolerances. The species/taxa that fit the criteria included 5 annelids (the taxa oligochaeta and four species (or species complexes) of polychaetes: *Simplisetia aequisetis*, *Capitella spp.*, *Nephtys australiensis* and *Boccardiella limnicola*), two molluscs (the bivalve species *Arthritica helmsi* and the gastropod family (taxa) Hydrobiidae), the crustacean order (taxa) Amphipoda and the dipteran family (most likely a single species) Chironomidae (larvae and pupae combined). Five environmental variables were considered; two water quality variables (salinity and dissolved oxygen percentage), two sediment characteristics (organic matter content and median grain size) and chlorophyll-*a* content (in mg.m^{-2}). For each of these species/taxa, a set of descriptive statistics were calculated for each environmental variable, including minimum and maximum values it was observed at (in relatively high abundances, see above), the range in values, and the average, median (or middle value) and mode (the most commonly observed value). This process was also undertaken to obtain the full range of environmental conditions observed (across all sites/sampling occasions, even when sites had no or very few invertebrates in cores), and for the subset of samples with very low abundances (total abundance < 100 ind. m^{-2}, approx. one individual per core) or very high abundances (total abundance > 1,000 ind.m^{-2}, approx. 800 individuals per core).

In general, most species were able to tolerate a wide range of environmental conditions, especially the Chironomidae, which were found across the full range of conditions experienced for each of the measured environmental variables (Table A4.2). Amphipoda were also tolerant of a wide range of conditions, but were not common when organic matter content of sediments were above 10% (Table A4.2). This taxa (Amphipoda) is likely represented by a number of species, and the specific tolerances of each species are not known. Most species/taxa tolerated a wide range in salinities (Table A4.2), which is not unexpected for estuarine invertebrates. Extreme hyperhaline conditions (salinity > 40 ppt) were not tolerated by four key species/taxa, two polychaetes *N. australiensis* and *B. limnicola* and both *A. helmsi* and species in the family Hydrobiidae (Table A4.2). Likewise, a wide range of dissolved oxygen concentrations was tolerated by all key species/taxa (Table A4.2), from levels below recommended lower limit thresholds (DO% < 80%) for estuaries in southern Australia (ANZEC guidelines Table 3.3.8) to oxygen oversaturation (max. DO % observed = 236.53 %; tolerated by Chironomidae). Many key species/taxa showed preferences for certain sediment conditions, with few tolerating very high organic matter concentrations (i.e. > 10%; tolerated only by Chironomidae), and some not tolerating very fine silts (*N. australiensis* and Hydrobiidae) or very coarse sands (*N. australiensis*, *B. limnicola* and Hydrobiidae) (Table A4.2). Some key species/taxa did not tolerate conditions of high (*Capitella spp.*, *B. limnicola* and *A. helmsi*) or very high (Oligochaeta, *S. aequisetis* and *N. australiensis*) sediment chlorophyll-a concentrations (Table A4.2). The tolerances of at least one key species/taxa were within the full range of environmental conditions observed in the Murray Mouth and Coorong Lagoons (Table A4.2), except in the case of the lowest level of dissolved oxygen concentrations observed (DO = 49.80%), which was recorded at the intertidal site at Hunters Creek in December 2010, at which site and time no invertebrates were collected in any core.

Overall, very low (including zero) abundances for macroinvertebrate communities were observed across the full range of environmental variables (Table A4.2), including the full range of salinity conditions from oligohaline (salinity = 0.19 ppt) to hyperhaline (salinity = 104.33ppt) levels and a wide range of oxygen saturation levels (DO % range 49.8 – 132.8 %). Very low abundances were not observed when sediments were very coarse (> 645.27 µm) or when sediment organic matter or chlorophyll content were high (> 4.24 % and > 2.19 %, respectively) (Table A4.2). Very high abundances were not observed when salinity exceeded that typical of seawater (salinity > 35.93 ppt) or when oxygen saturation levels were extremely low (DO % < 73.77 %) (Table A4.2). Very high abundances were also restricted to quite muddy sediments (Table A4.2), ranging from silts to fine sands (median grain size range 29.6 – 305.2 µm). Like very low abundances, very highly abundance communities were observed across a similar range of sediment organic matter and chlorophyll-*a* content (Table A4.2), and so it would seem that these environmental variables are less important in determining tolerance ranges for invertebrate communities in the Murray Mouth and Coorong Lagoons.

What do we understand of the characteristics of the species inhabiting the benthos in the system?

Species attributes

Of these 40 taxa, 17 were selected for further investigation of species attributes. These 17 taxa were the same selected for the biological traits analysis (see Biological Traits section below). These taxa included eight annelids (oligochaetes as a taxa and all polychaete species except *Euchone variabilis*), three crustaceans (amphipods, ostracods and the decapod crab *Paragrapsis gaimardii*), all three bivalve species as well as the gastropods *Salinator fragilis* and the Hydrodidae snails (all 6 species combined), and the (combined) larvae and pupae stages of the Chironomid fly.

Unsurprisingly for taxa living in a highly dynamic and changeable ecosystem, many taxa of the Murray Mouth and Coorong generally displayed either highly adaptable biology or relatively wide tolerances for environmental conditions, or both (Table A4.3), and so preferences were determined for each species, so as to narrow down wide ranges to single categories.

Annelids all had relatively large body sizes (generally larger than 20 mm long), and most species/taxa had a medium to long life span (Table A4.3). Most annelid taxa recorded in the system exhibit sexual reproduction and either brood or shed their eggs, with most species/taxa also having a pelagic larval stage (Table A4.3). Most were also burrowers or tube dwellers that live in the deeper layers of the sediment, and perform an important role in bio-irrigating (or deep mixing) of sediments. Shallow living species, such as oligochaetes, *Capitella*, *Phyllodoce novaehollandiae* and *Boccardiella limnicola* also play important roles as bioturbators, as modifiers of surficial sediments (Table A4.3). *Boccardiella limnicola*, for example, performs an important role in the stabilisation of surface sediments (see Recovery section; this report). Another species, *Ficopomatus enigmaticus* performs no role as a bioturbator of sediments, but is still considered to be an ecosystem engineer due to the tube reefs colonies of this species produces (see Recovery section; this report). Annelids in the system displayed a range of feeding habits, from filter/suspension feeders such as *F. enigmaticus* to a number of predatory polychaete species (Table A4.3). Higher abundances of these predatory species were generally only found in the Murray Mouth region (Figure A4.1), even though the species were also distributed in the North Lagoon (Table A4.1). Almost all species/taxa of Annelida displayed multiple feeding modes, with many generally being surface or sub-surface deposition feeders that would also predate on other species whenever possible (Table A4.3). The environmental tolerances of these species/taxa were broad (see Table A4.2), but most species displayed a preference (interpreted from a greater occurrence of taxa) for Oligohaline (salinity 0 – 6 ppt) conditions and very fine sands (125 – 250 µm). Some species, such as *Capitella* preferred a very wide range of salinities, being common when salinities ranged from Polyhaline (18 – 30 ppt) right through to Hyperhaline (50+ ppt) conditions (Table A4.3).

Polychaetes were generally less abundant in the Coorong Lagoons than they were in the Murray Mouth region with the exception of *Capitella*, which was most abundant in the North Lagoon (see Figure A4.1). *Capitella* is considered an opportunistic species which thrives under poor environmental conditions. This species is able to respond quickly to changes in environmental condition due to its short life span, multiple spawning events and pelagic larval stage (Table A4.3; see also Recovery section; this report). The opportunistic nature of this species would be well suited to the highly dynamic conditions observed in the North Lagoon over the monitoring period. Another widely distributed species, *Simplisetia aequisetis* is also known to be tolerant of poor environmental conditions, particularly low oxygen concentrations and organically enriched sediments (see in Recovery section; this report). *Australonereis ehlersi*, on the other hand, is intolerant of low oxygen concentrations and poor environmental conditions (see Recovery section; this report), but was most abundant in the North Lagoon during 2011/12 to 2013/14, with a peak in abundance in this region of 220.2 ind./m^2 during 2012/13 (Figure A4.1). This species is known to have a wide salinity tolerance and preference for soft, fine sandy sediments (see Recovery section; this report) (Adams and Stauber 2008, King et al. 2004) and so the increased abundance of this particular species in the North Lagoon during 2012/13 indicates that environmental conditions and water quality in that region at the time were likely to have been good.

Arthritica helmsi is quite different in some attributes to other bivalves that were recorded in the system (Table A4.3). This species is very small compared to *Spisula trigonella* and *Soletellina alba,* and exhibits a very different life history to these two species. *A. helmsi* broods its eggs, carries them rather than depositing them into the environment and is a benthic brooder of larvae, as opposed to the larger species which both shed their eggs to the pelagic environment and have planktonic larval stages (Table A4.3) (Glasby 2000). These traits make recolonisation of sediments more difficult for *A. helmsi* than other bivalves in the system. Without a pelagic larval stage, the capacity of this species to disperse and recolonise habitats away from the adult population is very limited, and may be the reason behind this species slow recolonisation of sediments in the system following the re-establishment of environmental flows in 2010 (Figure A4.1g,h). However, once sediments are recolonised by *A. helmsi* it seems this species has the capacity for rapid population growth (Figure A4.1g,h).

The amphipod taxa recorded in the system most likely represented a number of species, rather than a single species. Previous work in the system had identified at least 10 species of amphipods in the system (Dittmann *et al.*2006). Amphipods displayed a number of peaks in abundance throughout the system (see Stocktake of Monitoring section; this report), most likely representing a number of different species each with its own salinity tolerances. Therefore it was difficult to define specific tolerances and attributes for amphipods in the system. Different species of amphipods display a range of feeding modes, including filter/suspension feeders, deposit feeders, omnivores and predatory species (Table A4.3; also see Recovery section; this report). Amphipods are generally free-living on the surface or build shallow burrows into surface sediments (Table A4.3) and are known to be modifiers of surface sediments (Table A4.3), playing an important role as a bioturbator in sediment destabilisation (see Recovery section; this report) (Rysgaard et al. 1995). Although tolerant of a range of salinity and sediment grain-size conditions observed in the Murray Mouth and Coorong Lagoons (Table A4.2), amphipods in the system displayed a preference for Oligohaline conditions and fine to medium sands (Table A4.3).

Chironomid larvae and pupae recorded in the Murray Mouth and Coorong Lagoons most likely represented a single species with a wide tolerance to environmental conditions experienced in the system (Table A4.2), but without identifying the adult specimen, it is not certain that the larvae observed truly represented a single species. Chironomidae in general are small-bodied and have a short life-cycle, generally completed within a year (Table A4.3) (Oliver 1971). The time spent as a larvae or pupae (as they exist in the macrobenthos) is even shorter. This family deposits eggs on the benthos and has either a pelagic or benthic larval stage (Table A4.3), however, dispersion of this species is enhanced by the mobility of the winged adult fly (Oliver 1971). Like amphipods, as larvae this taxa is either free-living or creates shallow burrows into surface sediments, and is also a modifier of surface sediments (Table A4.3) (Oliver 1971).

Historical and current communities

For longer term comparisons, only qualitative data on the presence of species in the Coorong are available, taken during a 16 month period of no flow over the barrages between December 1981 to March 1983 (Geddes and Butler 1984) and a following period of above average flow over the barrages between March 1983 and March 1985 (Geddes 1987), but no historic data on macroinvertebrates exist for the Murray Mouth region.

The amount of water released over the barrages during the 1983-1985 release was of a similar magnitude to the recent release event in 2010-2015, but followed a much shorter period of no-flow (16 months only) compared to the Millennium Drought of 2005 – 2010n (Geddes and Butler 1984, Geddes 1987, Dittmann et al. 2015).

Four community types were identified by Geddes and Butler (1984) and Geddes (1987). A freshwater community was observed (for salinities 0 – 2 ppt) where *Simplisetia aequisetis*, *Nephtys australiensis* and *Capitella* were not recorded, and *Australonereis ehlersi* and *Spisula trigonella* were rare. Under estuarine conditions (salinity 5 – 30 ppt), *S. aequisetis*, *Ficopomatus enigmaticus*, Hydrobid snails and amphipods were abundant, with *A. ehlersi* and *N. australiensis* also being present, as well as *Arthritica helmsi* and *S. trigonella*. When conditions became hypermarine (salinity 35 – 50 ppt) only amphipods were abundant, with *Capitella*, Hydrobid snails, *Salinator fragilis* and larvae of the Chironomid and Ephydrid flies being present also. Finally, under hypersaline conditions (salinity > 50 ppt) only halophylic species of ostracods, isopods and the salt-tolerant larvae of Chironomid and Ephydrid flies were found (Geddes and Butler 1984; Geddes 1987; Table A4.4). These community types were compared to those recorded during the 2010 – 2015 monitoring, based on the SIMPER output from the LinkTREE analysis of community types under different salinity conditions (see Annual Trends section; this report).

Lowest salinity conditions (comparable to ‘Freshwater’ communities of Geddes 1984; Geddes and Butler 1987; Table A4.4) were observed in the Murray Mouth region in the first year of water release (i.e. 2010/11) when salinities in the region were very low (between 0 and 1 ppt), and communities were classified as type 4 and 5 (see Annual Trends section; this report). These community types were characterised by the presence of amphipods and chironomid fly larvae, as well as very low abundances of *Simplisetia aequisetis* (Table A4.4). This indicates that *S. aequisetis* is able to tolerate these very low salinities, even though previous records had indicated they were absent from the system when salinities were lower than 2 ppt (Geddes 1984; Geddes and Butler 1987; Table A4.4). When salinities were between 1 – 2 ppt (types 3 and 8), which was observed at Monument Road and Sugars Beach during December 2011 and even in the North Lagoon during March and May 2012 and even some sites in the Murray Mouth region during 2012/13 monitoring (see Annual Trends section, this report), *S. aequisetis* was still present in communities (TableA4.4).

Estuarine conditions (salinities 5 – 30 ppt) were represented by community types 9 – 12 in the LinkTREE analysis and covered Oligohaline to Polyhaline conditions (Table A4.4). These conditions were experienced in the Murray Mouth and North Lagoon throughout the monitoring period (Figure 3.1; Annual Trends), with types 9 (2 – 3 ppt) and 6 (6.5 – 9 ppt) only being observed during the second monitoring year (i.e. 2011/12) in the Murray Mouth region as salinities in the region increased from initial freshwater levels observed during 2010/11 (see Annual Trends section, this report). These community types (i.e. 9 and 6) appear to have been a transitional stage for the Murray Mouth, and were generally replaced by the type 7 community (3 – 6 ppt) in early summer transitioning to a type 15 or 12 community type in the region in late summer when flows reduced in 2012/13 and 2013/14, respectively (see Annual Trends section, this report). By February 2015 the whole Murray Mouth was characterised by a type 16 community (see Annual Trends section, this report). Type 12, 15 and 16 communities were also observed in the North Lagoon as far south as Long Point during early summer in 2012/13 and 2013/14 monitoring, before transitioning to Euhaline-type communities (see Annual Trends section, this report). All of these communities (types 9 – 12; Table A4.4) were characterised by similar species, with *S. aequisetis* being at first rare then either present or abundant, amphipods being either present or abundant, and, during more recent monitoring years (i.e. types 12 and 16), by *Arthritica helmsi* also being at first rare and then abundant (Table A4.4). These last transitional stages for this community (i.e. Types 12 and 16) are starting to approximate the Estuarine community observed in the Coorong by Geddes (1984) and Geddes and Butler (1987), except that larger bodied species such as *Spisula trigonella*, *Australonereis ehlersi* and *Nephtys australiensis* have still not re-established into the community (Table A4.4).

A marine community type that was not observed in the 1980’s studies was often observed in the Murray Mouth and North Lagoon during late summer of more recent monitoring years (i.e. 2012/13 – 2013/14; see Annual Trends section, this report). This community was characterised by high abundance of *Simplisetia aequisetis*, the presence of *Arthritica helmsi*, amphipods and chironomid larvae and low abundances of *Capitella* (Table A4.4). In the Murray Mouth, these communities transitioned to type 10 in late summer, with a reduction in the abundance of *S. aequisetis* but no increase in the abundance of *Capitella*, and to type 2 communities in the North Lagoon, again with a reduction in *S. aequisetis*, but increase in abundance of *Capitella* (Table A4.4). This latter community type observed in the North Lagoon only (Type 2) approximates the hypermarine community observed in the 1980s in the Coorong (Table A4.4), and was observed in the Coorong frequently between Mulbin Yerrok and Villa dei Yumpa between 2011/12 and 2015 monitoring (see Annual Trends section, this report).

An extreme salinity community (type 1; salinities greater than 50 ppt) was observed consistently in the South Lagoon (except in September 2012) and in the southern part of the North Lagoon on most sampling occasions. This community was characterised by depauperate fauna, with only chironomid larvae being consistently present in communities (Table A4.4). This community is similar to the Hypersaline community observed in the Coorong in the 1980s (Table A4.4).

Species trends over time

Although most taxa were distributed across at least the Murray Mouth and North Lagoon at some stage during the monitoring period, with some taxa even being recorded throughout the system (such as amphipods, chironomids, *Simplisetia aequisetis* and oligochaetes; Table A4.1), the abundances of these widely distributed taxa in different regions was not consistent. Most taxa exhibited their highest abundances in the Murray Mouth region during the most recent monitoring years (Figure A4.1a,d,g), presumably reflecting recovery of populations of these taxa from the effects of the Millennium Drought, as freshwater flows into the system continued from 2010 onwards. Species and taxa such as *Simplisetia aequisetis*, amphipods and *Arthritica helmsi* all had highest abundances in the Murray Mouth region, especially *S. aequisetis* and *A. helmsi* during the 2015 monitoring event (Figure A4.1a,g). Amphipod abundances peaked in the Murray Mouth region during 2012/13 monitoring, and have exhibited a steady decline since (Figure A4.1d). The North Lagoon represents a transition zone between the estuarine Murray Mouth region and the hyperhaline South Lagoon (see Annual Trends section; this report). This region had many taxa in common with the Murray Mouth region, but these taxa were generally lower in abundance in the North Lagoon compared to the Murray Mouth (Figure A4.1b,e,h). The exception to this trend was the polychaete species complex, *Capitella*. This species peaked in abundance in the North Lagoon during the most recent monitoring event (2015), after a steady increase in abundance since flows resumed during 2010/11 (Figure A4.1b). This increase appears to be plateauing during the 2015 event (Figure A4.1b). Abundances of taxa in the South Lagoon were always much lower than those in either the Murray Mouth or North Lagoon, which can be clearly seen in the different scale needed for the y-axes on these plots (Figure A4.1c,f,i). Any increases in abundance of particular taxa in the South Lagoon are short lived, generally one-off events (e.g. for ostracods; Figure A4.1f) or represent collections of just one individual at one site on one occasion (e.g. for *A. helmsi*; Figure A4.1i). A small increase in *Capitella* abundance was observed in the South Lagoon during 2012/13 and 2013/14, but did not continue into 2015 (Figure A4.1c).

Biological traits

Biological traits methods

Literature reviews of biological trait analysis conducted in estuarine ecosystems globally were undertaken to establish a set of categories and sub sets of associated biological traits. Information on categories and traits were also obtained from The Biological Traits Information Catalogue (BIOTIC) which was established through The Marine Life Information Network (MarLIN) in the United Kingdom in the mid-2000s (MarLIN 2006). From those literature reviews and the BIOTIC network, 10 categories and 38 biological traits were selected as the most appropriate for estuarine macrobenthos in the Murray Mouth and Coorong.

Abundance data of all macrobenthic taxa found in the Murray Mouth and Coorong during sampling events from 2010 to 2015 were collated into a multi-species dataset. Species that were only found on single occasions were removed from the dataset as they have very little influence on the outcomes from biological trait analysis. Extensive literature reviews were conducted on the remaining 17 taxa to obtain biological trait information of morphological, life history and living habits categories. Most taxa and associated biological trait information were obtained at the species level, with few individual taxa at the genus or family level. Two categories of preferred environmental conditions (salinity and sediment grain size) were also established from data obtained in monitoring surveys of the Coorong from 2004-2015. To obtain preferred salinity and sediment grain size ranges, zero-removed abundance data of each of the 17 taxa were plotted against each environmental category in separate 2d Kernel Density plots in OriginPro 2015. The non-parametric Kernel Density plots are calculated with a probability density function which is a smoothed density plot of the average trend of standard scatterplots. The result is a Kernel Density plot with coloured regions of the highest densities of abundances at particular salinity and sediment grain size ranges. The ranges of both environmental variables were based on well-established categorical ranges, which were used as biological traits ranging from very fine to medium sand grain sizes (Blott and Pye 2001) and oligohaline to hyperhaline salinities (Whitfield et al. 2012).

Within each of the 10 biological trait categories, the 17 macrobenthic taxa were assigned fuzzy coding scores with increasing importance from 0 to 1 for each biological trait within each category (Chevenet et al. 1994, Hewitt et al. 2008, Berthelsen et al. 2015). If individual taxa had one biological trait in a particular category, then a value of one was assigned to that trait. Some taxa also showed two or three traits per category, which would then require the fuzzy code value to be split amongst those traits evenly (e.g. 0.5 and 0.33 respectively) so that when summed they equalled a total of one for that category. The abundance values from the intertidal macrobenthos of each taxa, per replicate, per site in each sampling event from 2010-2015 were multiplied by the fuzzy code value for all 38 biological traits. Those abundance-weighted values were then summed across all taxa per replicate, which resulted in frequency values for each biological trait (Berthelsen et al. 2015). The data matrix with biological trait frequency values was fourth –root transformed due to the large range of values before a Bray-Curtis similarity matrix was calculated. Data were then plotted using the boostrap MDS method, which resulted in a cluster of multiple bootstrapped averages according to each region and year for the intertidal macrobenthos. Bootstrapped MDS plots of the intertidal macrobenthos were also conducted on the combined biological trait values for the Murray Mouth and North Lagoon regions for ease of interpretation and with the South Lagoon region removed as that particular region had very different macrobenthic structure in all years. Separate boostrap MDS plots were conducted on the four matching intertidal and subtidal sites (so that comparisons could be made between macrobenthic biological traits across all years. Following the bootstrap MDS procedure, SIMPER analysis was conducted on Bray Curtis matrices to identify the biological traits that contributed most to regions within each year. All analyses were conducted using the PRIMER 7/PERMANOVA+ software package (Clarke and Gorley 2015).

Biological traits of the intertidal benthos

Species inhabiting the system were identified and their distribution throughout the system (Table A4.1), environmental tolerances (Table A4.2) and attributes (Table A4.3) have been detailed in a series of annotated tables and discussed. Historical communities were detailed for the Coorong in an annotated table and compared to current communities in the system (Table A4.4). Species trends over time were investigated using line graphs of average abundance for key species/taxa for each region across years (Figure A4.1).

Biological traits analysis was completed for the key species/taxa across regions. Results from SIMPER analysis showed that the major contributing biological traits in the Murray Mouth diversified in every year through to 2015 (Figure A4.2,, Table A4.5). Diversification in benthic reproductive strategies and the arrival of longer lived taxa started in the Murray Mouth during 2011/12 and 2012/13. During 2013/14 larger taxa, predatory feeding habits and deeper bioturbation started in the Murray Mouth. In 2015 biological traits such as filter feeding, benthic larvae and taxa with preference for euhaline (30-40 ppt) salinity conditions were more important in the Murray Mouth (Table A4.5, Figure A4.2).

In the North Lagoon the biological traits that changed from 2011/12 to 2012/13 were smaller taxa, pelagic planktonic larvae and preference for medium sized sand grain sizes (Table A4.5). There were no more changes to biological traits in subsequent years for the North Lagoon with mainly short lived, surficial sediment modification, and sediment surface and bentho-pelagic habits (Table A4.5, Figure A4.2). In 2010/11 and 2013/14 the biological traits in the North Lagoon were too inconsistent for reliable interpretation of the data (Table A4.5).

During 2010/11 and 2011/12 the South Lagoon had biological traits that mainly consisted of small-bodied, short lived, opportunistic, free living, pelagic or benthic larvae and only surficial sediment modification (Table A4.5). In 2010/11, and 2012 to 2015 the biological traits in the South Lagoon were too inconsistent for reliable interpretation of the data (Table A4.5).

Comparison of biological traits between intertidal and subtidal macrobenthos

The biological traits of the intertidal and subtidal macrobenthos from four of the sites that were consistently sampled at both tidal levels (Monument Road, Hunters Creek, Ewe Island and Mark

Point) were dissimilar in 2010/11 (Figure A4.3). From 2011 to the start of 2013 the biological traits at both tidal levels were more similar to each other. However the reduced flow through the barrages in 2013/14 resulted in a shift of biological traits of the intertidal macrobenthos away from the subtidal macrobenthos. In 2015, the biological traits of the intertidal macrobenthos were more similar to subtidal macrobenthic traits identified in 2013/14. The patterns observed between the intertidal and subtidal biological traits suggest that the subtidal macrobenthos is more resilient and less affected by changes to flow regimes. The more similar biological traits between the intertidal and subtidal trhough time (with exception to 2013/14) indicates that the subtidal may also be a resource pool for re-colonisation into the intertidal macrobenthos, particularly for the Murray Mouth region.

The current (2015) biological functioning of the macrobenthos varies between the Murray Mouth and the North Lagoon (Figure A4.4). In the Murray Mouth, there is deep bioturbation, benthic-pelagic coupling is increasing and the food web is diversifying compared to earlier years. For the North Lagoon, there is only surficial bioturbation, benthic-pelagic coupling is only beginning and the food web is rather simple in comparison to the Murray Mouth (Figure A4.4).

Subtidal habitats as benign refugia

Conceptual models were developed in Inkscape version 0.91 using the Integration and Application Network (IAN) symbols developed and available via their website (*www.ian.umces.edu*). A key to macroinvertebrates used in these models is available in Figure A4.5.

Subtidal habitats in the Murray Mouth and Coorong Lagoons generally represent areas where environmental conditions are more stable relative to the dynamic intertidal zone. As such, species that may not be able to persist in the intertidal during extreme conditions of increased (i.e. drought scenario) or decreased (i.e. flood scenario) salinity are able to persist in subtidal habitats and later recolonise intertidal sediments once conditions improve.

During drought conditions, limited or no freshwater flows over the barrages may combine with closure of the mouth of the River Murray resulting in increased salinity in the Murray Mouth and Coorong Lagoons (Figure A4.6a). At this time, salinities in the shallow water overlying mudflats of intertidal zones increase and estuarine species become restricted to deeper water subtidal areas (Figure A4.6a). Some species may reduce in abundance with continued adverse conditions, and others may not be able to persist at all, thus disappearing from the system at that site (Figure A4.6a). Species typical of marine and hyperhaline conditions, such as *Capitella spp.*, may also occupy the intertidal zone (Figure A4.6a).

When water flows over the barrages in flood conditions (i.e. large water release events, such as the one that ended the Millennium Drought in 2010) salinity in the Murray Mouth region decreases to near freshwater levels (Figure A4.6b). Species that cannot tolerate freshwater conditions, such as *Capitella spp.* will be lost from intertidal sediments, and the abundance of species that are just able to tolerate these conditions, such as *Simplisetia aequisetis* will be reduced (Figure A4.6b). Slightly higher salinities may be observed in subtidal habitats, allowing estuarine species to persist and later recolonise intertidal sediments as conditions stabilise (Figure A4.6b).

Under healthy conditions, i.e. with continued freshwater releases over the barrages and exchange with the open ocean via an open River Murray mouth, estuarine conditions are observed in the Murray Mouth and Northern Coorong (Figure A4.6c). When these conditions are persistent and stable, species that are at other times restricted to the subtidal zone are able to colonise the intertidal mudflats, including the small bivalve *Arthritica helmsi*, and large, deep-dwelling bivalve species such as *Soletellina alba* and predatory polychaetes such as *Australonereis ehlersi* (Figure A4.6c). Under these conditions mudflats are healthier, owing to the operation of bioturbation and aeration of sediments by macroinvertebrates – resulting in deepening the layer of oxygenated sediments, and there is a larger range of prey species available to foraging shorebirds and fish.

Which environmental conditions influence the distribution and abundance of macroinvertebrates?

Analysis presented in this report (see Recovery section 2.2, this report) indicated that the salinity of waters overlying mudflats is the main environmental condition that influences the distribution and abundance of macroinvertebrates in the Murray Mouth and Coorong Lagoons.

A salinity gradient is generally observed in this system from fresh/estuarine conditions at the Murray Mouth to estuarine/hypermarine conditions observed further south. This gradient is dynamic, and the transition points between fresh, estuarine, marine and hypermarine conditions change as flows over the barrages increase and decrease in response to climatic conditions (i.e. drought and flood)and tidal conditions depending on the changes to the Murray Mouth opening. During the monitoring period for the environmental water releases over the barrages, the system passed through several disruptions in salinity state and recovery stages (see Recovery section 2.2, this report). During early monitoring, water releases had a freshening effect on the system, with salinities in the Murray Mouth region being close to freshwater, and communities were dominated by amphipods, insect larvae and low abundances of the polychaete *Simplisetia aequisetis* (Figure A4.7). As freshwater flows continued and estuarine conditions were observed in the Murray Mouth region, estuarine species were able to recolonise intertidal mudflats, with increases in the abundance of *S. aequisetis*, and recolonisation by the polychaetes *Boccardiella limnicola* and *Australonereis ehlersi*, and also oligochaete worms (Figure A4.7). As mesohaline conditions became established in the Murray Mouth and North Lagoon regions, abundance of typically estuarine species such as *S. aequisetis* increased, and small molluscs such as *Arthritica helmsi* and hydrobiid snails were able to recolonise mudflats (Figure A4.7). Further south, in the southern North Lagoon, polyhaline and euhaline conditions are generally observed, and communities become dominated by species that can tolerate the higher salinity conditions, such as *Capitella spp.* (Figure A4.7). Other species, such as *S. aequisetis*, *A. helmsi* and even *B. limnicola* are able to persist in these conditions in small numbers, but are generally not abundant (Figure A4.7). Surrounding the junction of the North Lagoon and the South Lagoon, hyperhaline conditions are generally observed, with little or no freshwater flows over the barrages influencing communities in this region. There, communities are dominated by halophilic species, such as amphipods, insect larvae and *Capitella spp.*, with only occasional records of estuarine species such as *S. aequisetis* when monitoring data has indicated salinities towards the lower end of the hyperhaline range (Figure A4.7).

As transition points for these salinity conditions move in space and time, macroinvertebrate species are constantly challenged to respond to these conditions, making macroinvertebrate communities in the system potentially highly dynamic in space and time.

Species-specific conceptual models - Polychaetes

Species-specific conceptual models have been developed for the five key species of polychaete worms recorded in the system.

Capitella spp.

Capitella spp. (*Capitella capitata* or *Capitella* species complex) is a comparatively small species that is tolerant of adverse environmental conditions, such as high salinities (Tsutsumi 1987, Mendez et al. 1997), and was thus able to colonise large areas of the system during the Millennium Drought – owing to the extirpation of less tolerant macrobenthos from those habitats (Figure A4.8). As at February 2015, this species is restricted to mesohaline - euhaline regions of the Coorong, and is generally only abundant in the North Lagoon (see Recovery section 2.2, this report).

Capitella spp. is a shallow-burrowing species that consumes detritus and is consumed by fish and short-billed shorebirds foraging on surface sediments. Thus, this species is an important food source for bird and fish predators in times when other species are prevented from reaching high abundances owing to poor water quality conditions, such as high salinities.

This species is widely known to have a short lifespan and is able to reproduce rapidly when conditions are favourable (Tsutsumi 1987, Mendez et al. 1997). Multiple spawning events are possible in one year and eggs are brooded by adults in the benthic environment (Tsutsumi 1987, Mendez et al. 1997). Larvae are able to disperse via a pelagic free-swimming larval stage and, as a result, readily colonise areas away from the adult population (Qian and Chia 1992).

Whilst *Capitella spp.* are considered an indicator species for poor environmental conditions under some circumstances, they are also known to play a role in stabilising surface sediments - through constructing mucus-lined tubes that hold sediments together and provide some aeration of sediments (Tsutsumi 1987). Such attributes make this species an important modifier of surficial sediments and their importance to colonise mudflats is greatly increased in areas where other species are absent.

Simplisetia aequisetis

Simplisetia aequisetis is tolerant of a wide range of environmental conditions (Table A4.2) and has often been quite widely distributed throughout the system from oligohaline to hyperhaline conditions (Figure A4.9).

S. aequisetis is a medium-sized polychaete worm with a life-span of one to three years. Individuals generally occupy the surface layers of sediments, with burrows sometimes extending more than 5 cm deep into the sediment (De Roach 2006).

This species is an omnivore, consuming detritus and algae as well as microinvertebrates. In turn, *S. aequisetis* is consumed by fish and short to medium billed shorebirds, as it generally dwells in the top few centimetres of sediment. Being a highly abundant species on intertidal mudflats under environmental conditions, this species is an important food source for migratory wading shorebirds and fish when conditions are favorable.

This polychaete has relatively limited ability to disperse and to colonise new areas. *S. aequisetis* utilises direct development reproduction, and broods eggs in burrows and juveniles of this species are benthic, with no pelagic larval stage to assist their spatial dispersion (De Roach 2006).

S. aequisetis is an important ecosystem engineer, building small narrow burrows that can reach quite deep into the sediment (greater than 5 cm) promoting aeration and bioturbation of deep sediments.

<u>*Boccardiella limnicola*</u>

Boccardiella limnicola is a small to medium-sized polychaete that is generally observed on mudflats when conditions are oligohaline to polyhaline (Figure A4.10).

This species has a life-span of between one and three years and occupies the surface layers of sediments, to approximately 5 cm depth (Dorsey 1981).

B. limnicola is an omnivore that consumes detritus and benthic algae, and may also filter feed from the water column (Dorsey 1981). This species in turn is also consumed by fish and short to medium-billed shorebirds.

This species also broods eggs in the benthic environment, but has a pelagic larval stage, allowing juveniles to settle in new areas distant from adult populations and effect the recolonisation of defaunated sediments (Dorsey 1981).

Although this species does not construct burrows, it does aid in the stabilisation of surface sediments by producing mucus that helps to bind loose sediments together (Dorsey 1981).

<u>*Australonereis ehlersi*</u>

Australonereis ehlersi is a large-bodied polychaete worm that dwells deep in the sediment, generally at depths greater than 5 cm. It has a medium life-span of between one and three years (Figure A4.11) (Glasby 2000, King et al. 2004, De Roach 2006). This species has only been recorded in low abundances in recent years from 2010 onwards, but – as it is tolerant of a wide range of environmental conditions (Table A4.2) - it may increase in abundance and disperse further throughout the system if estuarine conditions persist.

This species is an omnivore and consumes detritus and algae from sediment deposits, as well as predating on other polychaetes (Glasby 2000, King et al. 2004, De Roach 2006). This species is consumed by fish and medium to long-billed shorebird species and due to its large size is a valuable prey item but it is rarely as abundant as other benthic polychaetes such as *Capitella spp.* or *Simplisetia aequisetis*.

A. ehlersi broods eggs in the sediments but has a pelagic larval stage that allows juveniles to settle in new environments away from adult populations and hence recolonise sediments (Glasby 2000, King et al. 2004, De Roach 2006).

This species builds burrows that go deep (up to 40cm) into the sediment, helping to aerate and irrigate deep sediments (Glasby et al. 2000). This species, as well as other large-bodied, deep dwelling polychaetes such as *Nephtys australiensis* and bivalves such as *Spisula trigonella* and *Soletellina alba* are important species for improving sediment conditions in the system by bioturbating and irrigating deep sediments, leading to lowering of the depth of the anoxic layer of sediments.

This species is also known to be intolerant of poor environmental conditions (Dorsey 1981), and may be useful as an indicator species (where populations of this species have a stable abundance and distribution throughout a habitat) for positive environmental health in the Murray Mouth and Coorong Lagoons.

Nephtys australiensis

Nephtys australiensis is also a large-bodied, deep dwelling species that has been low in abundance and limited in distribution throughout the system since the Millennium Drought (Figure A4.12). This species has a wide range of environmental tolerances (Table A4.2) and should continue to establish new populations, increasing in abundance and distribution throughout the system if estuarine conditions persist with continued water releases. This species has a medium to long life-span of 3 to 10 years (Glasby 2000).

This species is an omnivore that consumes detritus and predates other polychaetes (Glasby 2000). This species is in turn consumed by fish and long-billed shorebird species. Like *A. ehlersi*, this species is a valuable food item for migratory shorebirds due to its large body size.

This species has both pelagic eggs and larvae, allowing wide dispersion of juveniles away from the adult population, and will aid it to recolonise mudflats when environmental conditions become favourable for juveniles and adults.

N. australiensis builds burrows into deep sediments, allowing aeration and irrigation of deeper sediments and provides an important role in improving the condition of sediments in mudflats (Glasby 2000, Adams and Stauber 2008).

Species-specific conceptual models – Bivalves

Arthritica helmsi

Arthritica helmsi is a small-bodied bivalve that inhabits the surface layers of sediments in mudflats. This species has recently dramatically increased in abundance in the Murray Mouth and Northern Coorong regions (see Stocktake of Monitoring section 2.1, this report) as estuarine conditions have established and persisted with continued freshwater releases over the barrages.

As a bivalve, this species is a filter-feeder of planktonic algae from the water column (Figure A4.13) (Beesley et al. 1998). In turn, *A. helmsi* is consumed by fish and short-billed foraging shorebirds. Although small, this species can be highly abundant, and is an important prey item for migratory shorebirds in the Coorong.

This species has limited dispersion potential. *A. helmsi* is a direct developer, which broods eggs in the benthos and has a benthic larval stage (Beesley et al. 1998). This habit limits the species ability to distribute and recolonise mudflats away from adult populations, which may be one reason why it took a number of years before the abundance and distribution of this species increased in the system (see Stocktake of Monitoring section 2.1, this report).

This species constructs small, shallow tubes in the benthos, and plays a role in the modification and irrigation of surface sediments in mudflats (Beesley et al. 1998).

Species-specific conceptual models – macroinvertebrates as prey for shorebirds

Mudflats are three-dimensional habitats with benthic macroinvertebrate species able to occupy different depths within the sediment, responding to potential interspecies competition for space and resources when communities are highly abundant. Thus, the species of macroinvertebrates that are utilised as prey by different species of shorebirds in the Murray Mouth and Coorong depends on the bill-length and hence foraging depth and behaviour of the shorebird species concerned (Figure A4.14).

Short-billed species, such as *Pluvialis fulva* (Pacific Golden Plover, pictured), dotterels, plovers, stints and lapwings, and species that only forage in the top layer of sediments, such as *Recurvirostra novaehollandiae* (Red-necked Avocet, pictured), consume infaunal macroinvertebrates that inhabit the surface sediments, such as amphipods, insect larvae, small worms such as *Capitella spp.* and small bivalves such as *Arthritica helmsi* (Figure A4.14) (Keuning 2011)

Medium-billed species, such as *Calidris ferruginea* (Curlew Sandpiper, pictured), *C. canutus* (Red Knot), *Himantopus himantopus* (Black-winged Stilt, pictured), *Cladorhynchus leucocephalus* (Banded Stilt) and *Tringa nebularia* (Greenshank) are able to access prey that dwell in approximately the top five centimetres of sediments, including the small bivalve *Arthritica helmsi*, and medium-sized polychaetes such as *Simplisetia aequisetis* and *Boccardiella limnicola* (Figure A4.14) (Keuning 2011).

Long-billed species, such as *Numenius madagascariensis* (Eastern Curlew), *Limosa lapponica* (Bar-tailed Godwit), *L. limosa* (Black-tailed Godwit) and *Haematopus longirostris* (Pied Oystercatcher, pictured) are able to access prey that dwell deep in the sediments, including large-bodied polychaetes such as *Nephtys australiensis* and *Australonereius ehlersi*, and large bivalves such as *Soletellina alba* and *Spisula trigonella* (Figure A4.14) (Keuning 2011).

3. Preliminary response to Key Question "Quantitative or Qualitative Changes in Benthic Macroinvertebrates since listing (1985)?"

3.1 Macroinvertebrate communities at the time of listing (1981 – 1985) – species and distribution in the system

Information on macroinvertebrates around the time of listing is only available from studies by Mike Geddes (Geddes and Butler 1984, Geddes 2007). These studies focussed on the Coorong, and data of macroinvertebrates at the times of listing are not available for the Murray Mouth. It is also important for the flow and salinity conditions to be known and put into context before considering the macroinvertebrate data in this wetland.

Community types were qualitatively described for the Coorong Lagoons during a period of drought and then flow over the barrages between 1981 and 1985 (Geddes and Butler 1984; Geddes 1987). These community types are summarised in Table A5.1 and A4.4 (see Conceptual Models; this report), and include: a freshwater community in which estuarine polychaete worms and molluscs were either rare or absent; an estuarine community, when these species were present and even abundant in communities; a hypermarine community dominated by amphipods, *Capitella* sp. and larvae of salt-tolerant dipterans, and finally, a hypersaline community, where only isopods, ostracods and salt-tolerant dipteran larvae were present (Geddes and Butler 1984; Geddes 1987).

Only sites in the Coorong were sampled during the 1981 – 1985 monitoring period (Geddes and Butler 1984; Geddes 1987). In total, 14 sites were sampled by Geddes and Butler (1984) and Geddes (1987) (Table A5.1) and some sites were the same or nearby to sites used in the current monitoring program. The following summary of the description of macroinvertebrate communities has been adapted from qualitative descriptions in Geddes (1987) for communities at the end of the 1981 – 1985 monitoring period (ending approximately around 1984 – 1985); at the time when the site received Ramsar listing.

Conditions in the Coorong Lagoons had freshened with the resumption of freshwater releases over the barrages after a 16 month period of no water release between 1981 and 1983. Estuarine conditions were recorded from just south of Pelican Point to Dodd Point (north of Noonameena), with hyperhaline conditions dominating south of the area around Noonameena (Table A5.1). Communities in the northern part of the North Lagoon, approximately between Pelican Point and Dodd Point were dominated by the polychaete worms *Ficopomatus enigmaticus*, *Capitella capitata*, *Nephtys* *australiensis* and *Simplisetia aequisetis*. During the same period, when conditions became estuarine, *Boccardiella limnicola* and *Australonereis ehlersi* were present at relatively low abundances (Table A5.1). Amphipods, the bivalves *Arthritica helmsi* and *Spisula trigonella*, and hydrobid snails were abundant, with *Soletellina alba* and *Salinator fragilis* present in lower abundances (Table A5.1). Decapods and insect larvae were also commonly found in samples (Table A5.1). Around Robs Point (south of Noonameena) to The Needles just north of Parnka Point, most polychaetes dropped out of communities as conditions were marine to hyperhaline, with only *F. enigmaticus*, *C. capitata* and *S. aequisetis* remaining at times when salinities were lower (Table A5.1). The large bivalve, *S. alba* also dropped out of communities at this transition point (Table A5.1). When salinities at those Northern Coorong sites increased above 50 ppt, only *C. capitata*, salt-tolerant dipteran larvae, hydrobiid snails and *S. fragilis* remained (Table A5.1). South of (and including) Parnka Point, conditions were hyperhaline and only salt-tolerant species of isopods, ostracods and insect larvae were able to tolerate the high salinities present (Table A5.1).

3.2 Current macroinvertebrate communities: 2013/14 - 2015

During the most recent monitoring years, salinity conditions in the Murray Mouth region, including all sites between Monument Road and Pelican Point, have typically been oligohaline in early summer and risen to polyhaline conditions by late summer, but the region could generally be considered to be estuarine overall (Table A5.1). Macroinvertebrate communities in this region have been dominated by the polychaete worm *Simplisetia aequisetis*, chironomid larvae and amphipods, with *Arthritica helmsi* becoming more common in samples in the most recent monitoring events (see Annual Trends section; this report).

Arthritica helmsi abundances started to recover in 2013 from very low abundances in the Murray Mouth region during the Millennium Drought (Figure A5.1). *Capitella capitata* was mostly confined to the North Lagoon since flows resumed in 2010, yet occurred at Ewe Island in 2015, possibly because of macroalgal mats seen at the site (Table A5.2). Amphipods were more abundant at sites in the Murray Mouth when conditions were freshest (Table A5.2) at the start of summer. *Simplisetia aequisetis* generally increased in abundance as conditions became more polyhaline in the Murray Mouth, towards late summer (Table A5.2). Many interactions could have resulted in the pattern of a decline in amphipod abundances and increases in *S. aequisetis* abundances over summer months. It is likely that abiotic interactions (e.g. salinity increase over summer months) in combination with biotic interactions (such as competition or predation) are influencing the abundance and structure of benthic communities.

Sites in the northern North Lagoon (hereafter Northern Coorong), between Mark Point and Long Point, act as a highly dynamic transition zone from estuarine conditions in the Murray Mouth to hyperhaline conditions in the South Lagoon (Table A5.1). Salinity conditions range from mesohaline to euhaline, and communities were numerically dominated by *Capitella capitata*, amphipods and, also *Arthritica helmsi* during very recent sampling occasions (Tables A5.1, A5.2). The polychaete, *Simplisetia aequisetis* was also common in samples (Table A5.1), but did not reach the same high abundances in the Northern Coorong as were observed in the Murray Mouth (Table A5.2). Abundances of these species over the summer months were highly variable and showed no clear pattern for increase or decrease (Table A5.2), and likely reflect a response to the highly dynamic salinity conditions observed in this region.

Sites in the southern North Lagoon and South Lagoon (hereafter Southern Coorong), south of (and including) Noonameena were consistently hyperhaline, and macroinvertebrate communities in this region were generally depauperate (Table A5.1). Only larvae and pupae of the salt-tolerant dipteran families Chironomidae and Ephydridae were consistently present across sampling occasions and sites (Table A5.2). Ostracods, isopods and amphipods were sometimes present in samples, and on rare occasions individuals of *Simplisetia aequisetis*, *Arthritica helmsi* and even *Australonereis ehlersi* were found but it cannot be ruled out that some individuals could be introduced from sieving equipment between sites *(*Table A5.2). The polychaete *Capitella capitata* was consistently present in samples from Noonameena, but only rarely observed further south (Table A5.1, A5.2).

3.3 Have macroinvertebrate communities changed since listing, and if so, how?

Comparisons between the two monitoring periods (1985 and current 2013-2015 surveys) are difficult to draw because of the purely qualitative nature of the data available from the 1980's surveys (Geddes 1987). Overall, the taxa recorded in the system at the time of listing are generally still found in the Coorong, and areas with similar salinity ranges are still represented by similar suites of species/taxa as were observed at the time of listing. Between the times of 1985 and 2013-2015, two taxa - the polychaete *Ficopomatus enigmaticus* and decapod crustaceans - appear (from more recent monitoring) to be now less widely distributed throughout the system (Table A5.1). Sampling methods used for the more recent monitoring in 2013-2015 did not target these invertebrates well. For example, *F. enigmaticus* build reefs which were not included when collecting mudflat core samples. Yet, observations were made during field trips and presence of live tubeworms recorded qualitatively, showing their presence in the North Lagoon to Noonameena. Decapods (represented in the 1980's surveys by a single crab species) are highly mobile and not likely to be collected by coring into the muddy substrate. The more common distribution of decapods in the early Geddes (1987) study may be due to the use of handnets and epibenthic trawls. Yet we qualitatively recorded sightings of crabs during field work, and noted the presence of several species of decapod crabs, mostly in the Murray Mouth and northern North Lagoon. Also, there is evidence from previous studies that yellow-eyed mullet (*Aldrichetta forsteri*) feed on mysid shrimp and green back flounder (*Rhombosolea tapirina*) feed on both mysid shrimp and *Paragrapsus gaimardii* in the Murray Mouth and Coorong (Giatas 2012, Earl 2014).

Over time there appears to have been a shift in salinity conditions and macroinvertebrate distribution towards the Murray Mouth, with salinity conditions and fauna observed in the Northern Coorong at the time of listing now occurring in the Murray Mouth. Some of the large-bodied, deep burrowing species such as *Australonereis ehlersi*, *Nephtys australiensis* and *Spisula trigonella* are relatively rare in samples and only recorded at some sites, months or only in relatively low abundances (Table A5.1, A5.2). With only qualitative data available from the 1980's surveys, it is not known if the relative abundances of these species has declined, remained stable or even increased. However, recolonisation of the sediment by those large-bodied, deep burrowing species is likely to be the beginning of the last successional steps in the recovery of this system following disturbance during the prolonged period of no freshwater flows during the Millennium Drought (see section 2.5 of this report). Therefore, the larger-bodied, deep burrowing species may not become common in communities unless conditions continue to remain estuarine in the Murray Mouth into the future.

Many species previously recorded in the Northern Coorong region were not observed or rare during the most recent monitoring, particularly polychaete worms such as *Nephtys australiensis*, *Boccardiella limnicola* and *Australonereis ehlersi*, gastropod species and the large, deep dwelling bivalve species *Spisula trigonella* and *Soletellina alba* (Table A5.1). This may simply reflect the current position of the highly dynamic boundary between the Murray Mouth and Northern Coorong regions, with some of those species previously absent from sites once salinities increased to marine and hypermarine levels (Table A5.1). Salinity conditions in the southern part of the North Lagoon at Noonameena are similar to those observed at Robs Point and The Needles in the past, but none of the mollusc species previously observed in this region have been recorded during recent monitoring which may yet be a sign of their slow, delayed recolonisation (Table A5.1). Across the Northern Lagoon, most mollusc species recorded at the time of listing have not been recorded during recent monitoring, even though they can tolerate the higher salinities that are currently observed in the region (Table A5.1, see also section 2.5 of this report).

There has been no apparent shift in the boundary of the Southern Coorong hyperhaline region (Table A5.1). In the hyperhaline Southern Coorong region, species compositions are largely unchanged, with communities still dominated by salt-tolerant dipteran larvae, isopods and ostracods, with some amphipods also found during recent monitoring (Table A5.1). *Capitella capitata* were sometimes observed in the Southern Coorong, particularly during December at Parnka Point, suggesting that populations of this species may not persist (Table A5.2).

Overall, it seems that many of the larger-bodied, deeper dwelling species of polychaetes and bivalves are still recovering with regard to both distributional ranges and population abundances in the system following the prolonged Millennium Drought of 2005 – 2010. Whether these species continue to recover and recolonise the sites at which they were previously distributed at the time of Ramsar listing will depend on future environmental conditions and freshwater flows into the system to maintain estuarine conditions.

3.4 Were these change(s) beyond the bounds of normal seasonal (within years) or inter-annual (between years) and/or exceeded specified limits of environmentally acceptable change?

The most notable change in the system since listing has been the reduction in occurrence and spatial distribution of large-bodied, deep dwelling species such as *Australonereis ehlersi*, *Nephtys australiensis*, *Soletellina alba* and *Spisula trigonella*, especially from the Northern Coorong. Without a detailed understanding of the nature of the Coorong prior to installation of barrages and flow regulations across the whole Murray-Darling system, or even quantitative data from the time of listing, it is difficult to say whether these changes are beyond the bounds of natural seasonal and inter-annual variation for these species.

Unfortunately there is no quantitative or qualitative evidence indicating what macroinvertebrate communities were like prior to flow regulations in the Murray Mouth and Coorong Lagoons. The cultural knowledge of the Ngarrindjeri people tells us that the system once received freshwater inputs from both the River Murray in the north and the South East in the south, and that salinity changed seasonally from freshwater to marine conditions as freshwater flows varied across the year (Phillips and Muller 2006). After the installation of flow regulators (barrages and weirs) into the Murray Darling system during the 1940s, salinities rose noticeably in the 1970s and the ecological condition of the system began to decline (Phillips and Muller 2006). Freshwater flows that previously flushed the system from Salt Creek in the South Lagoon ceased (Phillips and Muller 2006), and it is likely that salinity increases in the Southern Coorong led to a decline in macroinvertebrate communities as conditions became increasingly hyperhaline. Thus it is highly unlikely that the macroinvertebrate community currently observed in the Southern Coorong, or that which was observed at the time of Ramsar listing, is natural to the region. It is more likely that the community currently observed in the Murray Mouth and previously observed in the Northern Coorong in the 1980s once extended across the whole Murray Mouth and Coorong.

Early macroinvertebrate surveys were qualitative (Geddes and Butler 1984; Geddes 1987), and there is no information on the levels of natural variation in species or communities at the time of Ramsar listing. Anecdotal evidence suggests that the system had in fact been declining in health for 30 years prior to listing, and that declines observed since listing were the result of changes that had been occurring since flow regulation began (Phillips and Muller 2006). Since flow regulations began, the system has been subject to periods of no-flow (drought), small flows and some large flows over the barrages, with fewer periods of continuous flows of different durations. It is likely that macroinvertebrate communities have been responding to changing salinity conditions throughout the system over different temporal scales from long term (across the 75 years since flow regulations began), to decadal, inter-annual and also seasonal changes.

There are currently no specified limits of environmentally acceptable change for benthic macroinvertebrates in the system (Phillips and Muller 2006). However, given the importance of these species as a food source for many fish and bird species, as well as the roles many of the macroinvertebrates play in habitat stabilisation and ecosystem engineering, limits of acceptable environmental change for this group should be developed. Without a baseline, we will trial multivariate control charts (Anderson and Thompson 2004) to find trigger values for unacceptable change.

3.5 Were these changes adverse and, if so, were they human induced?

The reduced abundance and distribution of large-bodied, deep dwelling species from the system is an adverse change. These species are often long-lived and serve important roles in bio-irrigation of deep sediments by oxygenating deeper layers of the sediment.

These changes appear to be the result of flow regulation in the Murray Darling system and in the South East region over the last 75 years, and, more recently, the Millennium Drought between 2005 and 2010. Whilst periods of drought and flow were probably typical of this system even prior to flow regulations, climate change is a recognised human-induced phenomenon that is affecting rainfall patterns across Australia resulting in periods of extremely low rainfall (Murphy and Timball 2008). Data from the monitoring period 2010 – 2015 indicate that any reductions in flow have negative effects on macroinvertebrates in the Murray Mouth and Coorong, and consistent flows, even at lower volumes, are better than no flow at all (Dittmann et al. 2015).

Does the site still meet the Ramsar nomination criteria for which the site was listed?

This site was not listed on any criteria based on macroinvertebrate communities or species populations within the system *per se*, although macroinvertebrate communities are an important food source for many of the fish and migratory shorebird species that are listed under the nomination criteria. Further works are required with comparison to other Ramsar listed wetlands to determine if the site still meets Ramsar nomination.

References

Adams M.S., Stauber J.L. (2008). Marine whole sediment toxicity tests for use in temperate and tropical Australian Environments: Current Status, *Australasian Journal of Ecotoxicology*, 14, 1550167.

Anderson M.J., Thompson A.A. (2004). Multivariate control charts for ecological and environmental monitoring*. Ecological Applications*, 14, 1921-1935.

Beesley P.L., Ross G.J.B., Wells A (1998). Mollusca: The Southern Synthesis. Fauna of Australia. Vol. 5. CSIRO Publishing, Melbourne. Part A & B,pp.1234.

Berthelsen A.K., Hewitt J.E., Taylor R.B. (2015). Biological traits and taxonomic composition of invertebrate assemblages associated with coralline turf along an environmental gradient. *Marine Ecology Progress Series*, 530,150-27.

Bice C.M., Zampatti B.P. (2014). Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes in 2013/14. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Publication No. F2011/000186-4. SARDI Research Report Series No. 800.

Blott S.J., Pye K. (2001). Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms*, 26, 1237-1248.

Chevenet F., Doledec S., Chessel D. (1994) A fuzzy coding approach for the analysis of long-term ecological data, *Freshwater Biology*, 31, 295-309.

Clarke K.R., Gorley R.N. (2015). PRIMER V7: User Manual/Tutorial. PRIMER-E Ltd. Plymouth Marine Laboratory, United Kingdom.

Coleman F.C., Williams S.L.(2002). Overexploiting marine ecosystem engineers: potential consequences for biodiversity. *TRENDS in Ecology and Evolution*, 17, 40-44.

De Roach R.J. (2006). The polychaetes *Australonereis ehlersi* (Augener) and *Simplisetia aequisetis* (Augener) within the eutrophic Swan River Estuary, Western Australia: Life history, population structureand effects on sedimentary microbial nitrogen cycling. PhD thesis, University of Western Australia.

Dittmann, S. & Nelson, M. (2006). Macrobenthic survey 2006: Murray Mouth, Coorong and Lower Lakes Ramsar site. Report for the Department for Environment and Heritage. Adelaide. Flinders University.

Dittmann S., Baggalley S., Brown E., Drew M., Keuning J. (2011) Benthic macroinvertebrate monitoring for the Goolwa Channel Water Level Management Project, year two, and Barrage Release within the Coorong, Lower Lakes and Murray mouth region. Report for the Department of Environment, Water and Natural Resources. Adelaide, Flinders University.

Dittmann, S., Ramsdale, T., Keuning, J., Navong, N. and Baggalley, S. (2013) Benthic Macroinvertebrate Response Monitoring in the Coorong and Murray Mouth, 2012/13. Report for the Department of Environment, Water and Natural Resources, Adelaide, Flinders University,

Dittmann S., Navong N., Ramsdale T.,McGuire A.(2014) Benthic macroinvertebrate survey 2013-2014: Lower lakes, Coorong and Murray Mouth Icon Site. Report for the Department of Environment, Water and Natural Resources and the Murray-Darling Basin Authority, Flinders University.

Dittmann S., Ramsdale T., Navong N., McGuire A. (2014) Benthic macroinvertebrate response monitoring in the Coorong and Murray Mouth, 2013/14. Report for the Department of Environment, Water and Natural Resources, Adelaide, Flinders University.

Dittmann S., Baring R., Baggalley S., Cantin A., Earl J., Gannon R., Keuning J., Mayo A., Navong N., Nelson M., Noble W., Ramsdale T. (2015) Drought and flood effects on macrobenthic communities in the estuary of Australia's largest river system. *Estuarine, Coastal and Shelf Science*, 165, 36-51.

Dorsey J.H. (1981) The ecology of *Australonereis ehlersi* (Augener, 1913) and *Ceratonereis erythraeensis* Fauvel, 1919 (Polychaeta, nereidae) living offshore from the Werribee sewage-treatment farm, Port Phillip Bay, Victoria, Australia. PhD thesis, Department of Zoology, The University of Melbourne.

Earl J. (2014). Population biology and ecology of the greenback flounder (*Rhombosolea tapirina*) in the Coorong estuary, South Australia, PhD thesis, Flinders University, Adelaide.

Geddes M.C. (1987) Changes in salinity and in the distribution of macrophytes, macrobenthos and fish in the Coorong Lagoons, South Australia, following a period of River Murray flow. *Transactions of the Royal Society of South Australia,* 111, 173–181.

Geddes M.C., Butler A.J. (1984) Physicochemical and biological studies on the Coorong Lagoons, South Australia, and the effect of salinity on the distribution of the macronbenthos.*Transactions of the Royal Society of South Australia*, 108, 51-62.

Giatas G. (2012). Diet of the Yellow-eye mullet (*Aldrichetta forsteri*) in the River Murray estuary and Coorong Laggoon, South Australia, Honours thesis, Flinders University, Adelaide.

Glasby C.J. (1986) Population structure and reproductive biology of Ceratonereis limnetica (Polychaeta: Nereididae) at Lower Portland, Hawkesbury River, Australia. *Marine Biology*, 90, 589-595.

Glasby CJ, Hutchings PA, Fauchald K, Paxton H, Rouse GW, Watson-Russell C and Wilson RS. 2000. Class Polychaete (chapter 1). In *Polychaetes and Their Allies: the Southern Synthesis.*

Fauna of Pogonophora, Echiura, Sipuncula. Beesley PL, Ross CJB, Glasby CJ (Eds). CSIRO Publishing, Melbourne, Australia, pp. 1–296.

Grantham B.A., Eckert G.L., Shanks A.L. (2003). Dispersal potential of marine invertebrates in diverse habitats, *Ecological Applications*, 13, s108-s116.

Hewitt J.E., Thrush S.F., Dayton P.D. (2008). Habitat variation, species diversity and ecological functioning in a marine system. *Journal of Experimental Marine Biology and Ecology*, 366, 116-122.

Keuning J. (2011). Food availability and foraging behaviour of shorebirds in the modified Murray River estuary. PhD thesis, Flinders Univeristy, Adelaide.

Keuning J., Brown E., Navong N., Beyer K., Baggalley S., Dittmann S. (2012) Benthic macroinvertebrate response monitoring in the Murray Mouth and Coorong 2011/12. Report for the Department of Environment, Water and Natural Resources, Adelaide, Flinders University.

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

Leblanc M., Tweed S., Van Dijk A., Timbal B. (2012). A review of historic and future hydrological changes in the Murray-Darling Basin. *Global and Planetary Change*, 80-81, 226-246.

Leterme S.C., Allais L., Jendyk J., Hemraj D.A., Newton K., Mitchell J., Shanafield M. (2015) Drought conditions and recovery in the Coorong wetland, south Australia in 1997-2013. *Estuarine, Coastal and Shelf Science*, 163, 175-184.

Livore J.P., Ye Q., Bucater L., Short D. (2013) Fish response to flows in the Coorong during 2012/13. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Publication No. F2013/000486-1. SARDI Research Report Series No. 732.

MarLIN, 2006. *BIOTIC - Biological Traits Information Catalogue.* Marine Life Information Network. Plymouth: Marine Biological Association of the United Kingdom. [01/06/2014] Available from www.marlin.ac.uk/biotic.

Mendez N., Romero J., Flos J. (1997) Population dynamics and production of the polychaete Capitella capitate in the littoral zone of Barcelona (Spain, NW Mediterranean). *Journal of Experimental Marine Biology and Ecology*, 218, 263-284.

Murphy B.F., Timbal B. (2008). A review of recent climate variability and climate change in southeastern Australia. *International Journal of Climatology*, 28, 859-879.

Oliver D.R. (1971) Life history of the Chironimidae. *Annual Review in Entomology*, 16, 211-230.

Oliver R., Lorenz Z., Nielsen D., Shiel R. (2014). Multivariate Analyses of the Microalgae, Zooplankton and Water Quality Monitoring Data from the Coorong, Lower Lakes and Murray Mouth Analysing Environmental Perturbations in a Connected River, Lake and Estuarine System. CSIRO, Land and Water Flagship, Australia.

Rolston A., Gannon R., Green D., Beaumont K., Dittmann S. (2010) microbenthic invertberates of the Coorong, Lower Lakes and Murraqy Mouth Ramsar Site: A literature Review of responses to changing environmental conditions. Report to the Department for Environment and Heritage, Adelaide, Flinders University.

Paton D.C., Bailey C.P. (2012) Condition Monitoring of the Lower Lakes, Coorong and Murray Mouth Icon Site: Waterbirds using the Coorong and Murray Estuary 2012. Report for the Department of Environment, Water and Natural Resources and the Murray-Darling Basin Authority, University of Adelaide.

Phillips W., Muller K. (2006). Ecological character of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance. Department for Environment and Heritage, Adelaide.

Qian P.Y., Chia F.S. (1992). Effects of diet type on the demographics of Capitella sp. (Annelida: Polychaeta): lecithotrophic development vs. planktotrophic development. *Journal of Experimental Marine biology and Ecology*, 157, 159-179.

Rysgaard S., Christensen P.B., Nielsen L.P. (1995). Seasonal variation in nitrification and dentrification in estuarine sediment colonised by benthic microalgae and bioturbating infauna. *Marine Ecology Progress Series*, 126, 111-121.

Tsutsumi H. (1987) Population dynamics of *Capitella capitata* (Polychaeta; Capitellidae) in an organically polluted cove. *Marine Ecology Progress Series*, 36, 139-149.

Whitfield A.K., Elliott M., Basset A., Blaber S.J.M., West R.J. (2012) Paradigms in estuarine ecology – A review of the Remane diagram with suggested revised model for estuaries. *Estuarine, Coastal and Shelf Science*, 97, 78-90.

A. Appendix

A1. Stocktake of Monitoring to Date

Table A1.1: Surveys and sampling site periodicities for benthic macroinvertebrate communities from 2010-2015. Note abbreviated month names as D, December; J, January; J/F, January-February; F, February; M March; A/My, April-May; My, May; S, September; O, October; N/D, November-December, followed by abbreviated year sampled. TLM=The Living Murray program; WR=Water release monitoring

		2010-2011					2011-2012					2012-2013				2013-2014			2015
Region	Site	D10	J11	F11	M11	A/My11	O11	D11	J/F12	M12	My12	S12	D12	F13	M13	N/D13	F14	M14	F15
MM	Monument Rd	I,S	I	S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I	I	I
	1/2 Way Beach	I,S	I,S	x	I,S	I,S	x	x	x	x	x	x	x	x	x	x	x	x	x
	Sugars Beach	I,S	I,S	x	I,S	I,S	I,S	I,S	I,S	I,S	I,S	x	x	x	x	x	x	x	x
	Hunters Ck	I,S	I,S	x	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I	I	I
	Boundary Ck	I,S	x	I,S	I,S	I,S	x	x	x	x	x	x	x	x	x	x	x	x	x
	Mundoo Channel	I	x	x	x	x	x	I	x	x	x	x	I	x	x	I	x	x	I
	Ewe Is.	I,S	I	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I	I	I
	Pelican Point	x	I,S	I,S	I,S	I,S	I	I	I	I	I	I	I	I	I	I	I	I	I
	Tauwitcherie	I,S	x	I,S	I,S	I,S	I,S	x	x	x	x	I,S	x	I,S	I,S	I,S	x	x	x
NL	Mark Point	x	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I	I	x
	Mulbin-Yerrok	x	I	x	x	x	x	I	x	x	x	x	I	x	x	I	x	x	I
	Long Point	x	I	x	x	x	I,S	I,S	I,S	I,S	I,S	I,S,P	I,S	I,S	I,S,P	I,S,P	I	I	x
	Noonameena	x	I	x	x	x	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I,S	I	I	I
	Parnka Point North	x	I	x	x	x	x	I	x	I,S	x	I,S	I,S	I,S	I,S	I,S	I	I	I
SL	Parnka Point South	x	x	x	x	x	I,S	x	x	x	x	x	I	I,S	I,S	I	I	I	x
	Villa de Yumpa	x	I	x	x	x	I,S	I	x	I,S	x	I,S	I,S	I,S	I,S	I,S	I	I	I
	Jacks Point	x	I	x	x	x	x	I	x	x	x	x	I	x	x	I	x	x	I
	Loop Road	x	I	x	x	x	x	I	x	x	x	x	I	x	x	I	x	x	I

Key:				
	x	Site not sampled	I =	Intertidal
	(green)	TLM only sites/data	S =	Subtidal
	(orange)	TLM/WR overlap sites & dates	P =	Peninsula
	(white)	WR only sites		

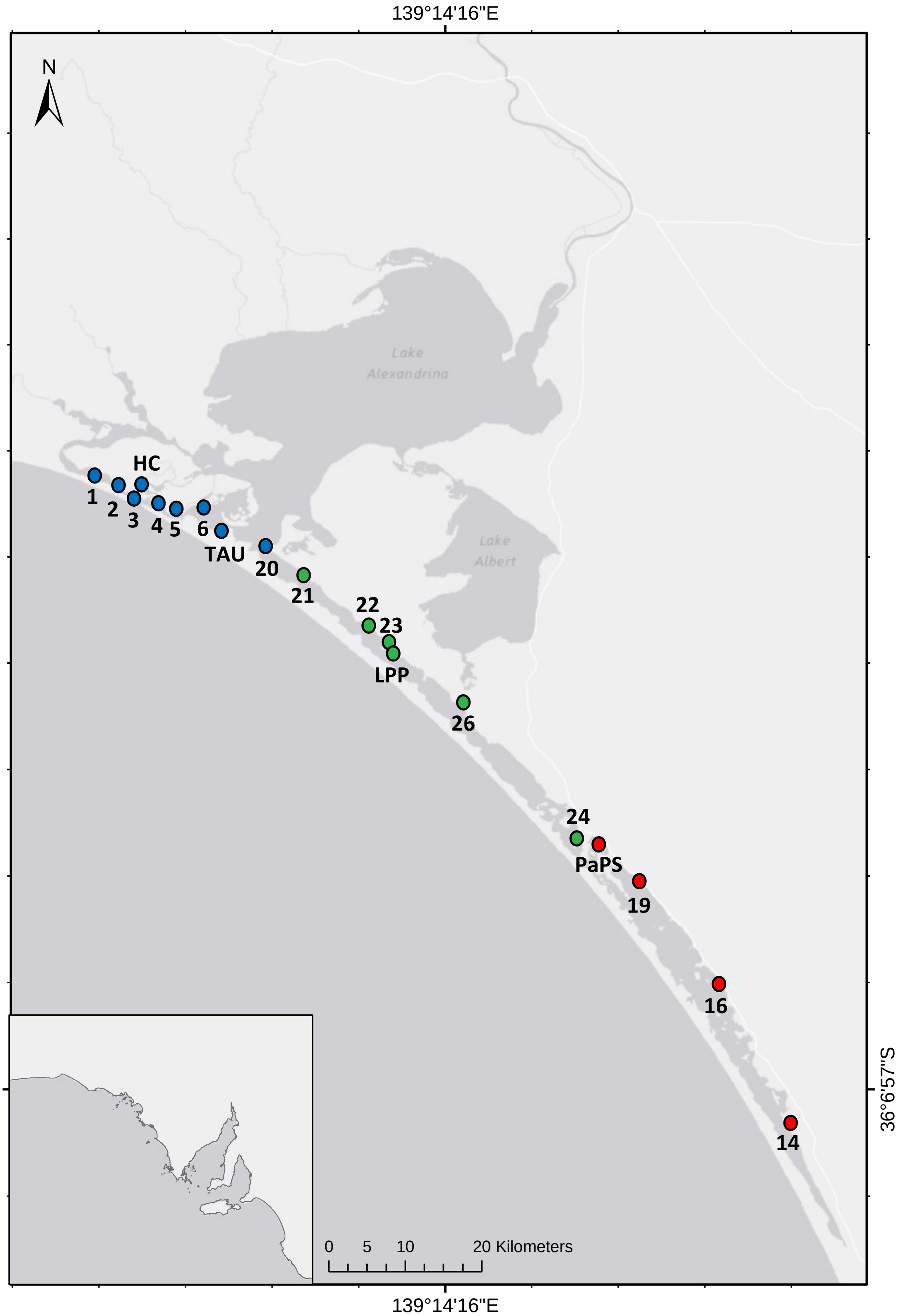


Figure A1.1: Sites sampled during benthic macroinvertebrate program from 2010 to 2015. Coloured circles represent the Murray Mouth, North and South Lagoons as listed in Table A2.

Table A1.2: Sites and code number with GPS location for intertidal and subtidal sampling locations for benthic macroinvertebrate sampling from 2010 to 2015.

Site	Number	Region	Intertidal		Subtidal	
			Lat.	Long.	Lat.	Long.
Monument Road	1	MM	138 49.745	35 31.519	138 49.764	35 31.586
½ Way	2		138 51.266	35 32.139	138 51.186	35 32.360
Sugars Beach	3		138 52.685	35 32.940	138 52.656	35 32.966
Hunters Creek	HC		138 53.412	35 32.200	138 53.413	35 32.200
Mundoo Channel	4		138 54.084	35 32.264		
Boundary Creek	5		138 55.135	35 33.780	138 55.241	35 33.840
Ewe Island	6		138 57.302	35 33.579	138 57.599	35 33.785
Tauwitcherie	TAU		138 57.627	35 34.545	139 00.746	35 35.633
Pelican Point	20		139 01.275	35 35.676	139 01.613	35 35.935
Mark Point	21	NL	139 04.319	35 37.901	139 04.764	35 37.806
Mulbin-Yerrok	22		139 08.340	35 40.150		
Long Point	23		139 09.828	35 41.640	139 09.816	35 41.569
Long Point Peninsula	LPP		139 09.286	35 41.928		
Noonameena	26		139 15.653	35 45.507	139 15.521	35 45.522
Parnka Point North	24		139 23.992	35 53.829	139 23.860	35 54.011
Parnka Point South	PaPS	SL	139 23.996	35 54.124	139 23.873	35 54.159
Villa dei Yumpa	19		139 27.214	35 54.722	139 27.117	35 54.662
Jacks Point	16		139 34.398	36 01.398		
Loop Road	14		139 33.910	36 10.069		

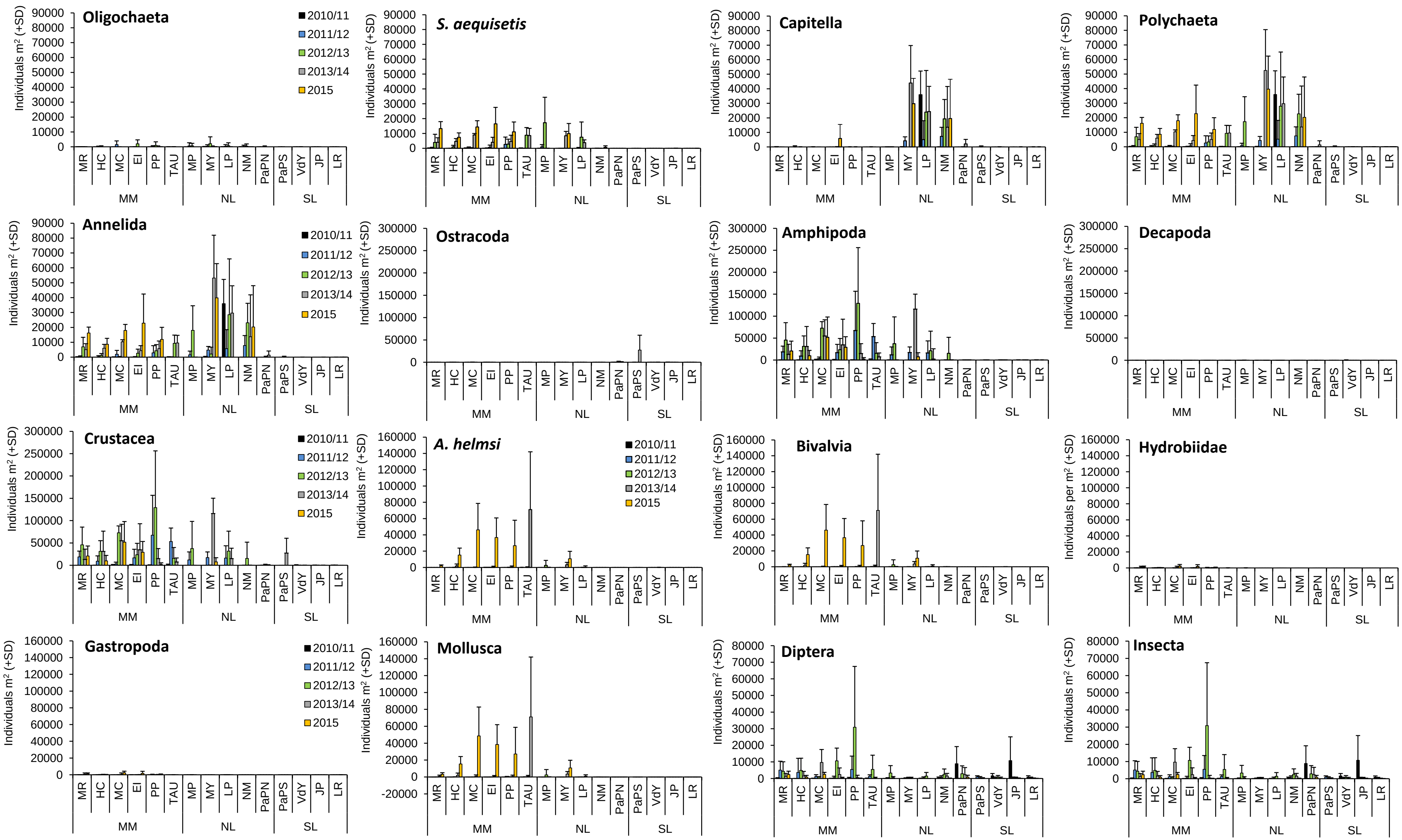


Figure A1.2: Abundances of key intertidal macrobenthic taxa sampled in the Murray Mouth and Coorong from 2010/11 to 2015. Note different y-axis scales.

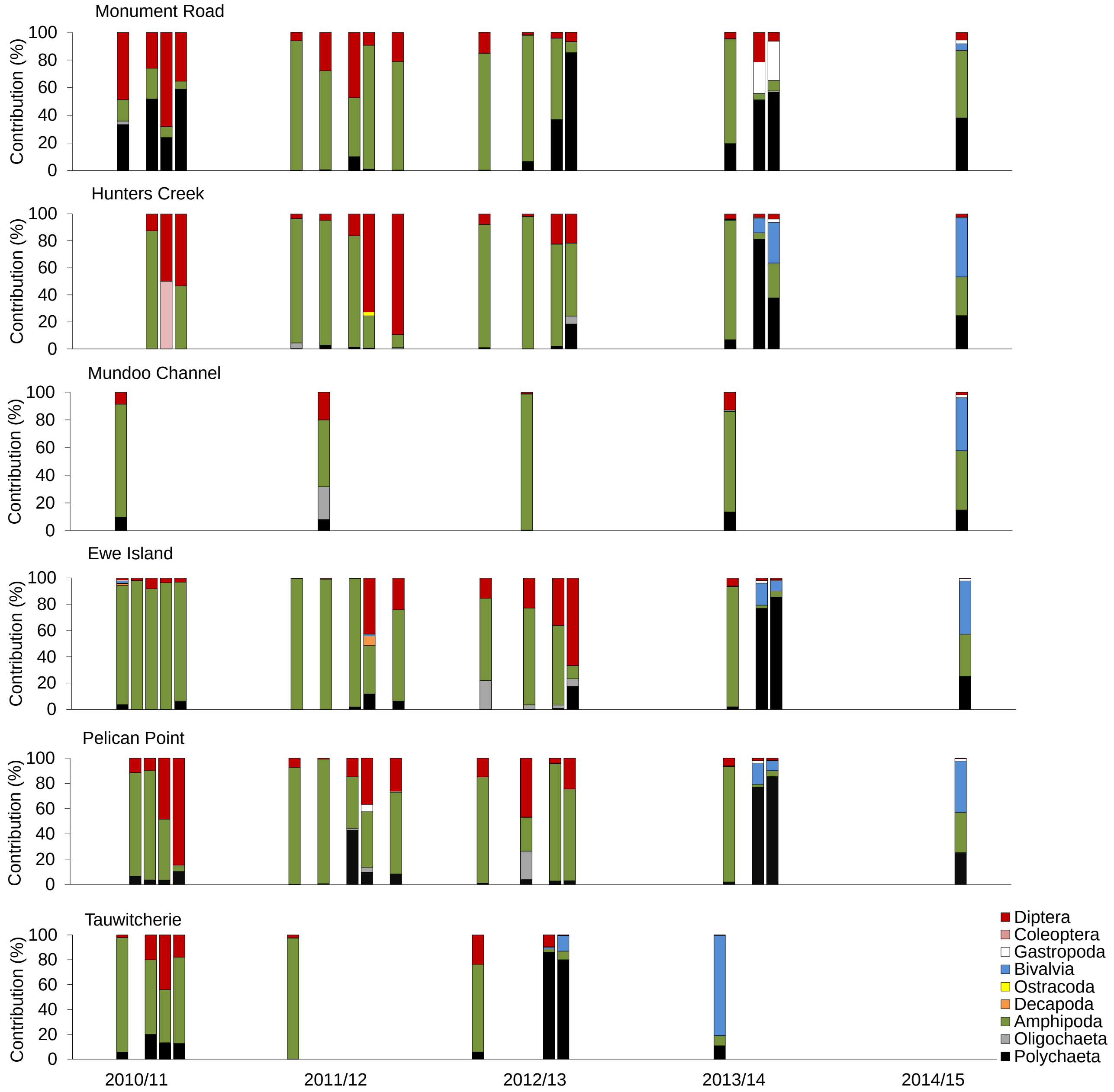


Figure A1.3: Percent contributions of benthic macroinvertebrates sampled at intertidal sites in the Murray Mouth during multiple seasons within years from 2010 to 2015

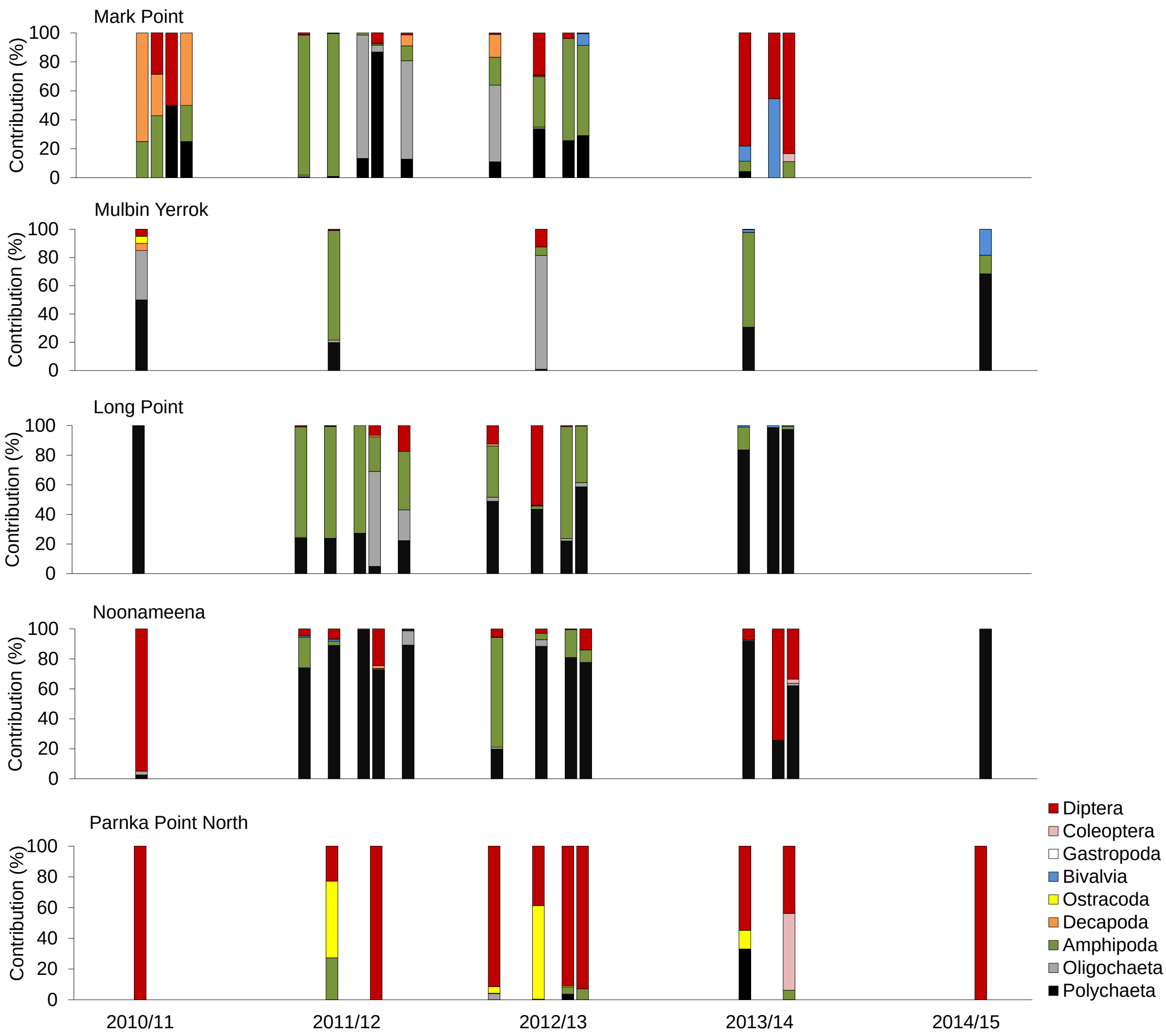


Figure A1.4: Percent contributions of benthic macroinvertebrates sampled at intertidal sites in the North Lagoon during multiple seasons within years from 2010 to 2015.

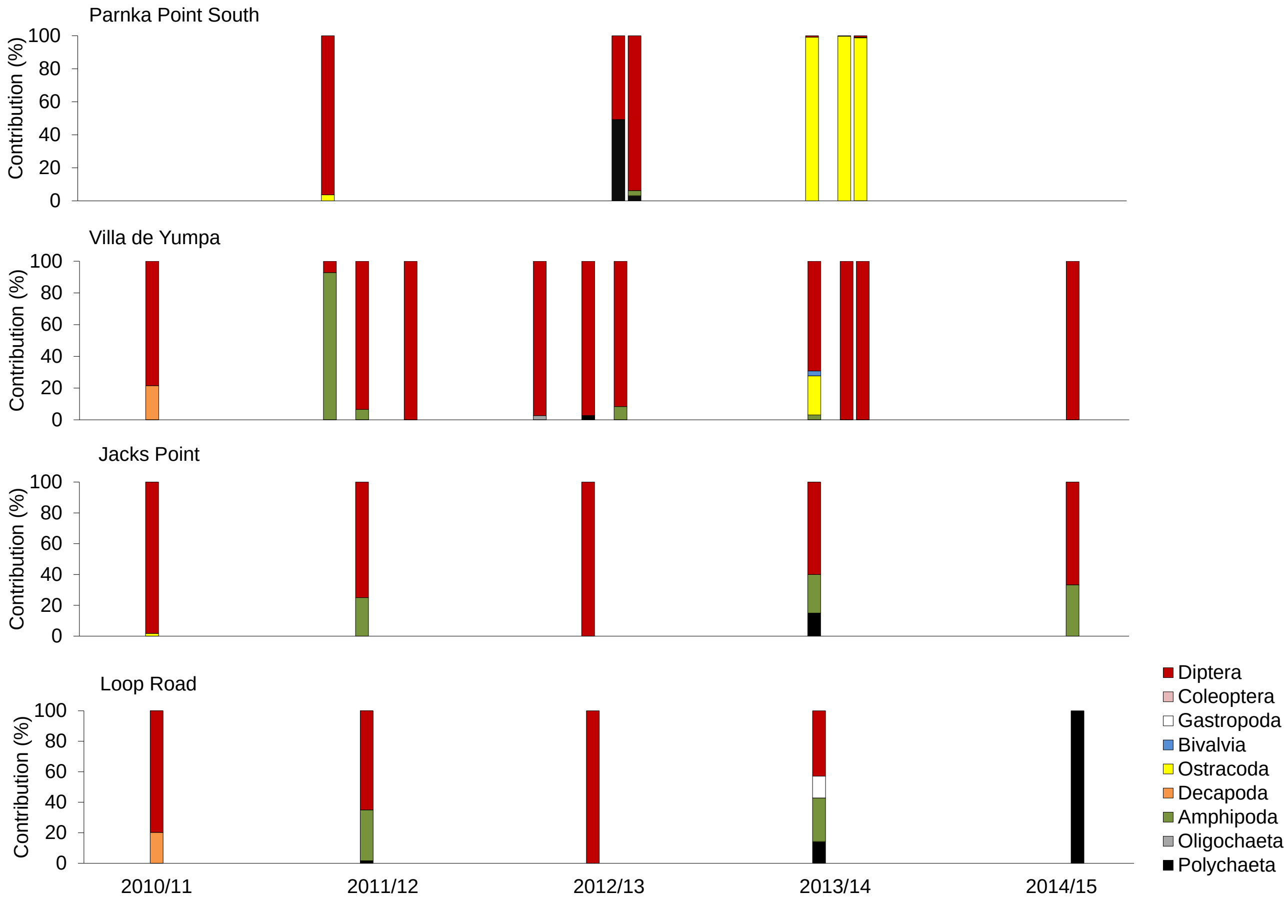


Figure A1.5: Percent contributions of benthic macroinvertebrates sampled at intertidal sites in the South Lagoon during multiple seasons within years from 2010 to 2015.

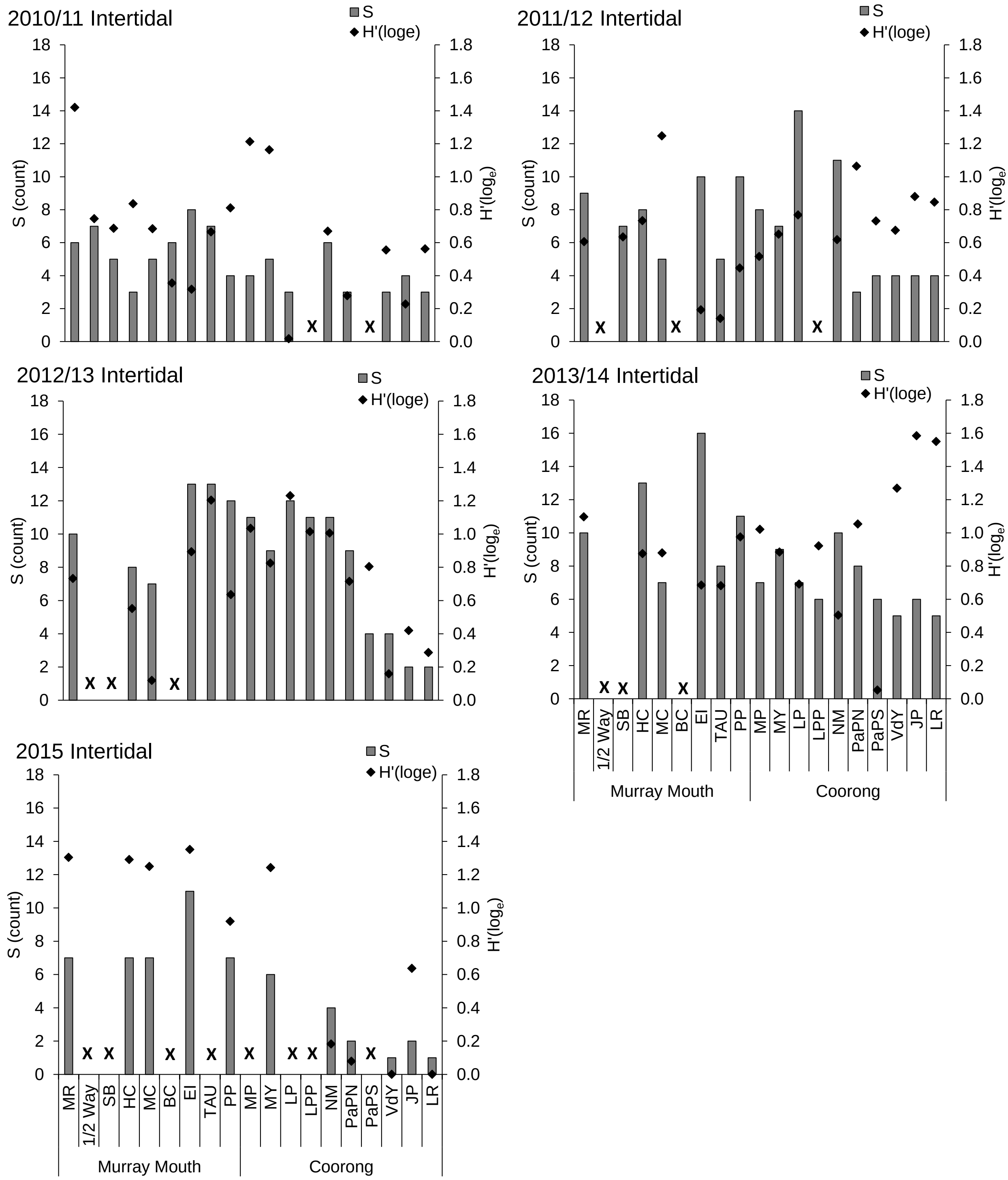


Figure A1.6: Species richness (S) and Shannon-Wiener diversity (H') of benthic macroinvertebrates sampled at intertidal sites in the Murray Mouth and Coorong across all years from 2010/11 to 2015.

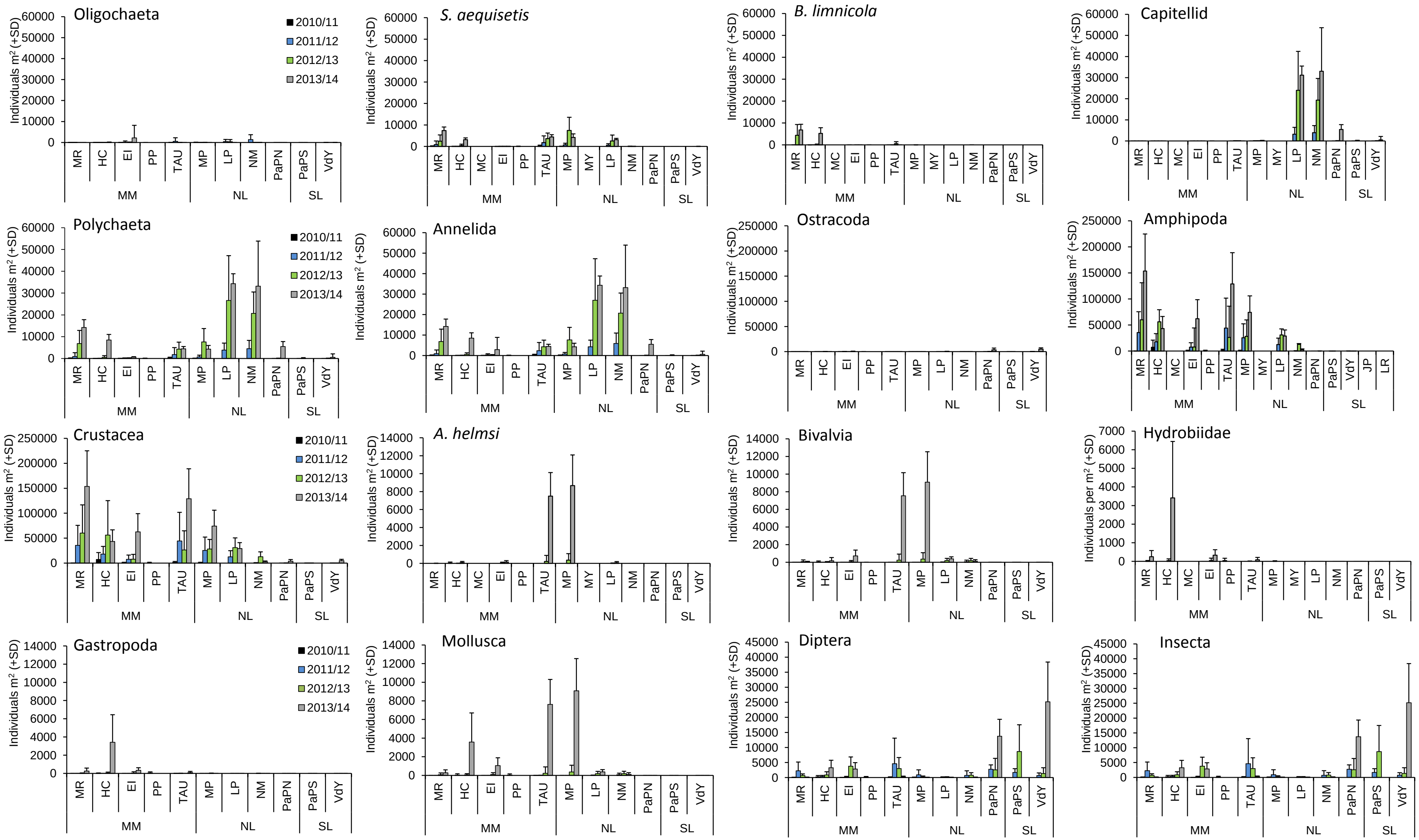


Figure A1.7: Abundances of key macrobenthic taxa sampled at subtidal sites in the Murray Mouth and Coorong from 2010/11 to 2015.

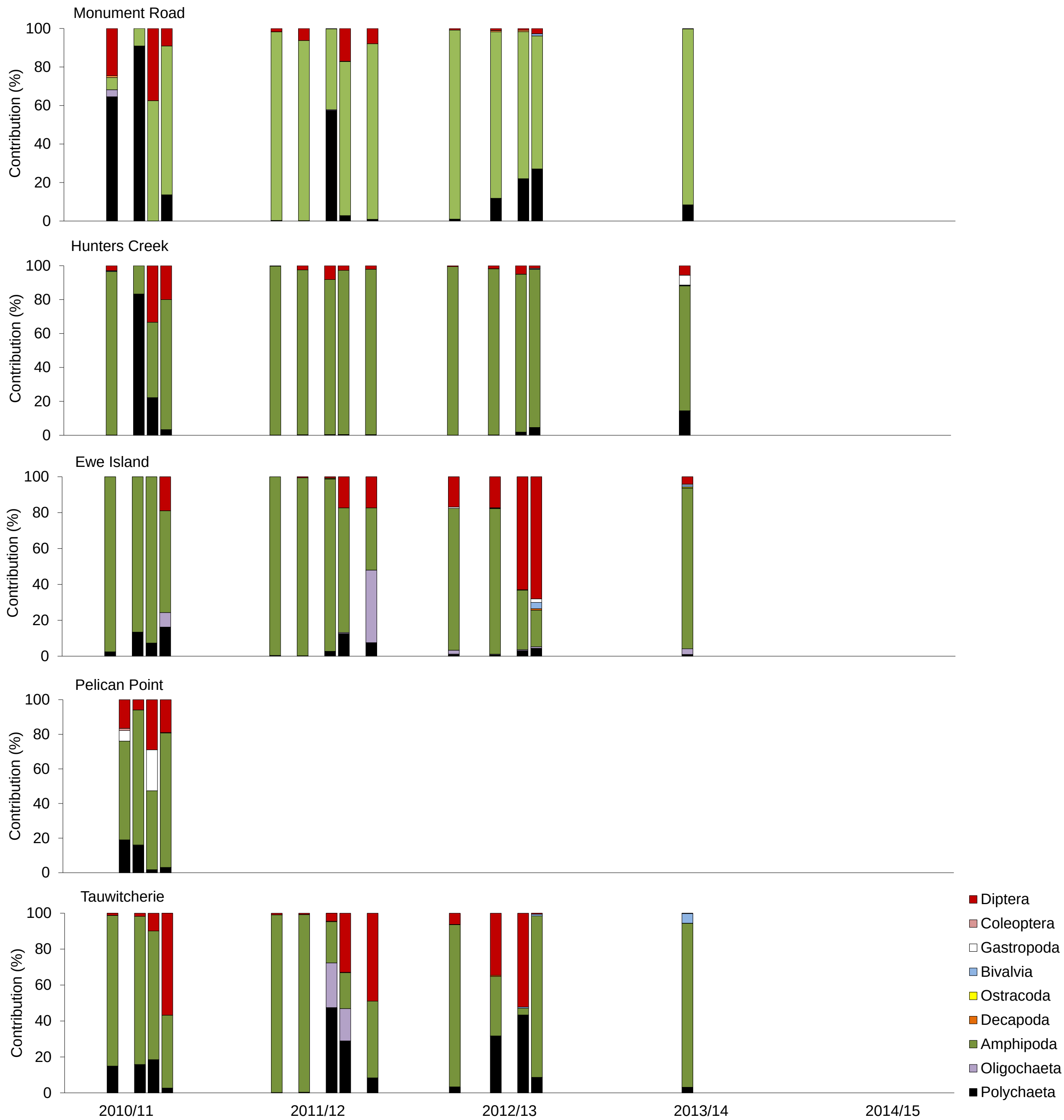


Figure A1.8: Percent contributions of benthic macroinvertebrates sampled at subtidal sites in the Murray Mouth during multiple seasons within years from 2010 to 2015.

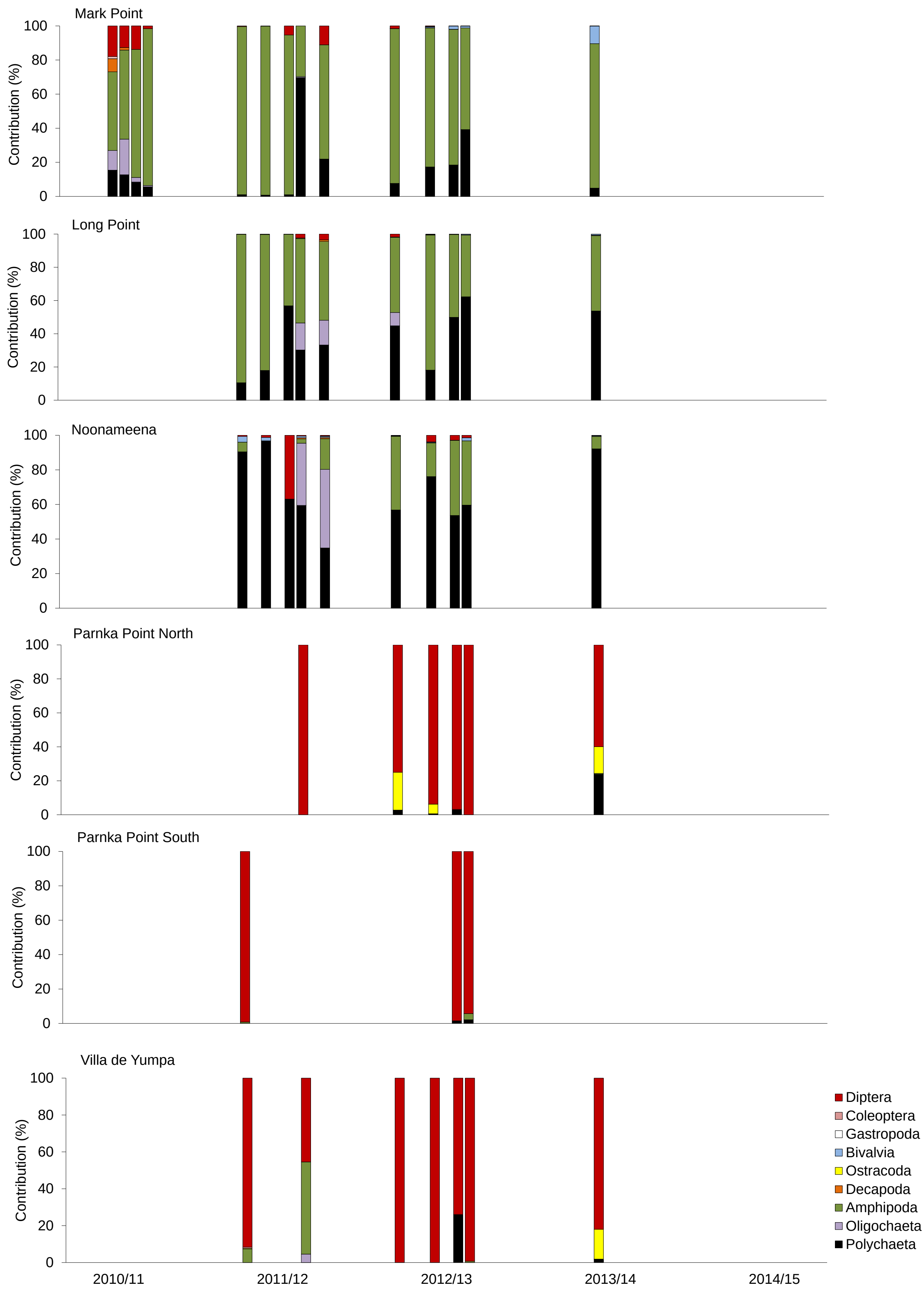


Figure A1.9: Percent contributions of benthic macroinvertebrates sampled at subtidal sites in the North and South Lagoon of the Coorong during multiple seasons within years from 2010 to 2015.

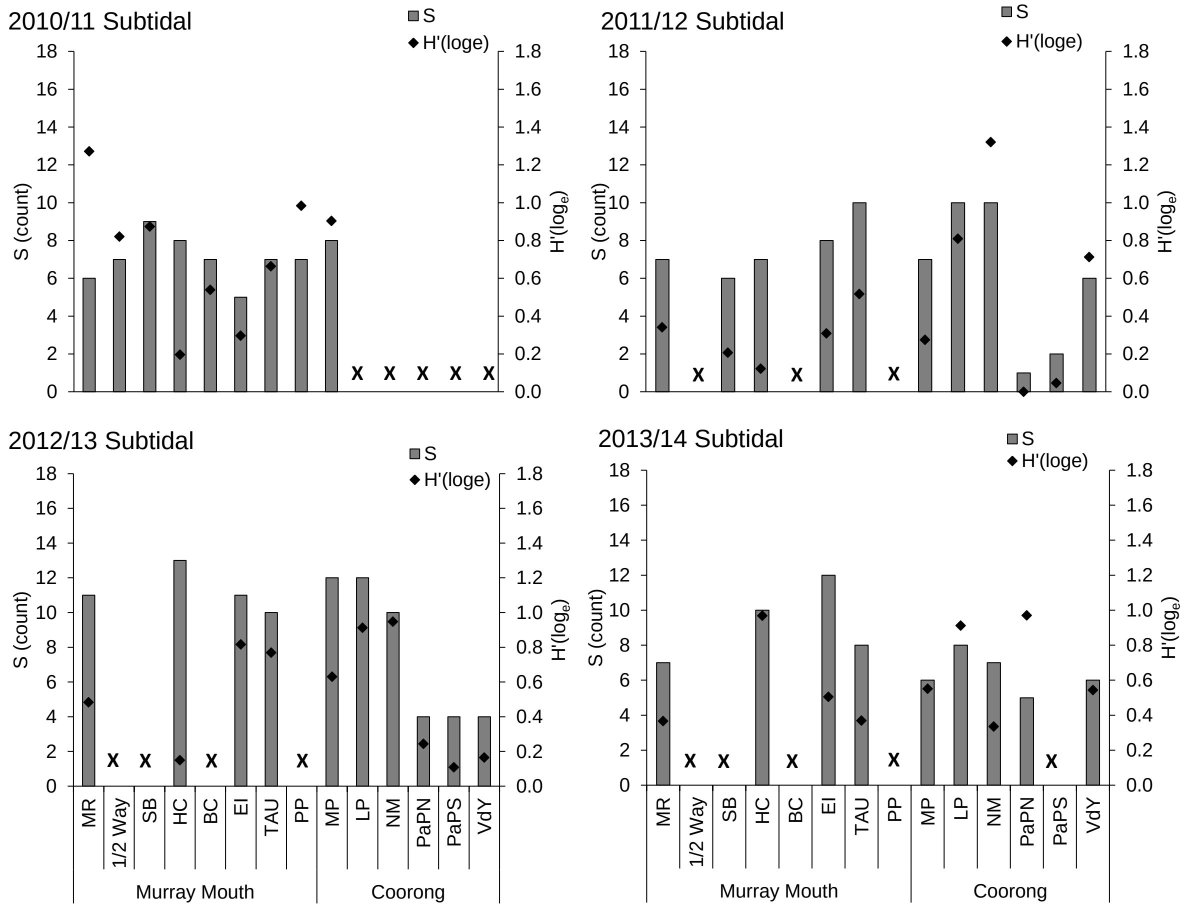


Figure A1.10: Species richness (S) and Shannon-Wiener diversity (H') of benthic macroinvertebrates sampled at subtidal sites in the Murray Mouth and Coorong across all years from 2010/11 to 2015.

Table A1.3: Summary results of PERMANOVA tests on intertidal macroinvertebrate data to determine if different levels of taxonomic resolution could identify change over time. Values are *P* (perm) for each test. Test results were either NS = no significant difference; SIG = significant difference, or no = no change in test results.

Source	All taxa/species	Class	Change?	Phyla/Subphyla	Change?
Year (Y)	0.0001	0.0089	Reduced strength	0.0480	Reduced strength
Region (R)	0.0006	0.0001	no	0.0001	no
Month(Year) (M(Y))	0.0001	0.0002	no	0.0001	no
Site(Region) (S(R))	0.0001	0.0001	no	0.0001	no
Y x R	0.0003	0.0002	no	0.0001	no
Y x S(R)*	0.0676	0.0002	NS to SIG	0.0003	NS to SIG
M(Y) x R*	0.0001	0.0843	SIG to NS	0.2154	SIG to NS
M(Y) x S(R)*	0.0001	0.0001	no	0.0001	no

* term has one or more empty cells (not all sites/regions sampled at that year/month)

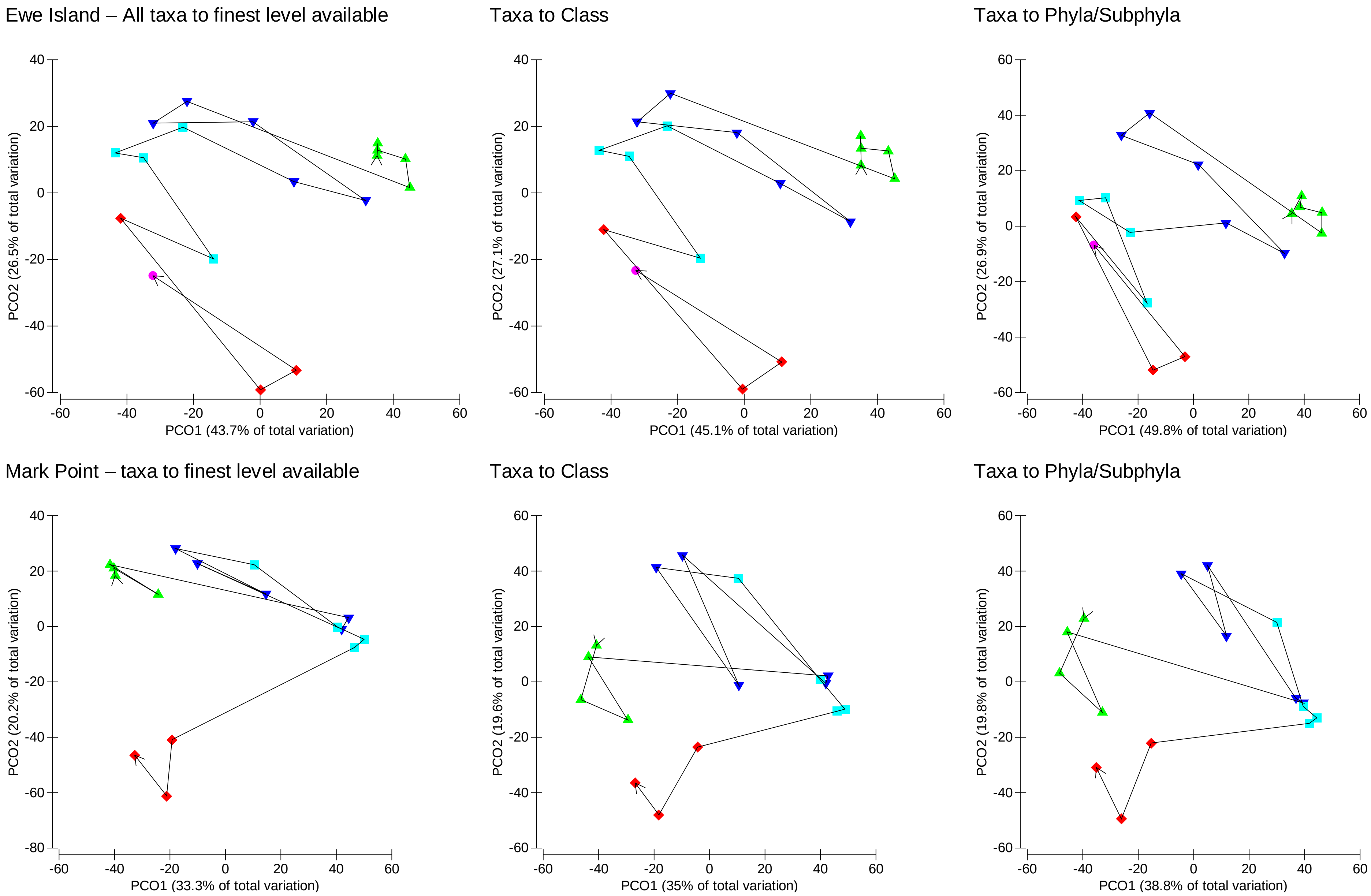


Figure A1.11: Reduced taxonomic distinction: effects on overall temporal trends observed at community level.

A2. Recovery

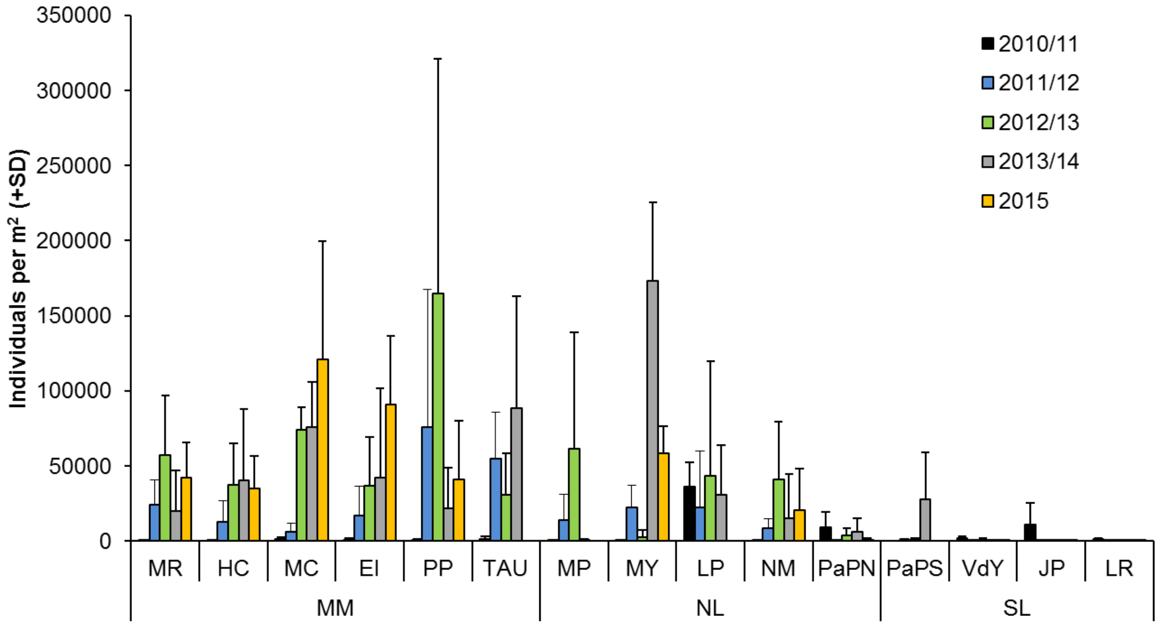


Figure A2.1. Total abundance (mean individuals per m^2 ± SD) of benthic macroinvertebrates at each sampling site in the Murray Mouth and Coorong Lagoons, since environmental flows recommenced in 2010/11 to the most recent sampling event (2015). Note that not all sites were sampled again in 2015.

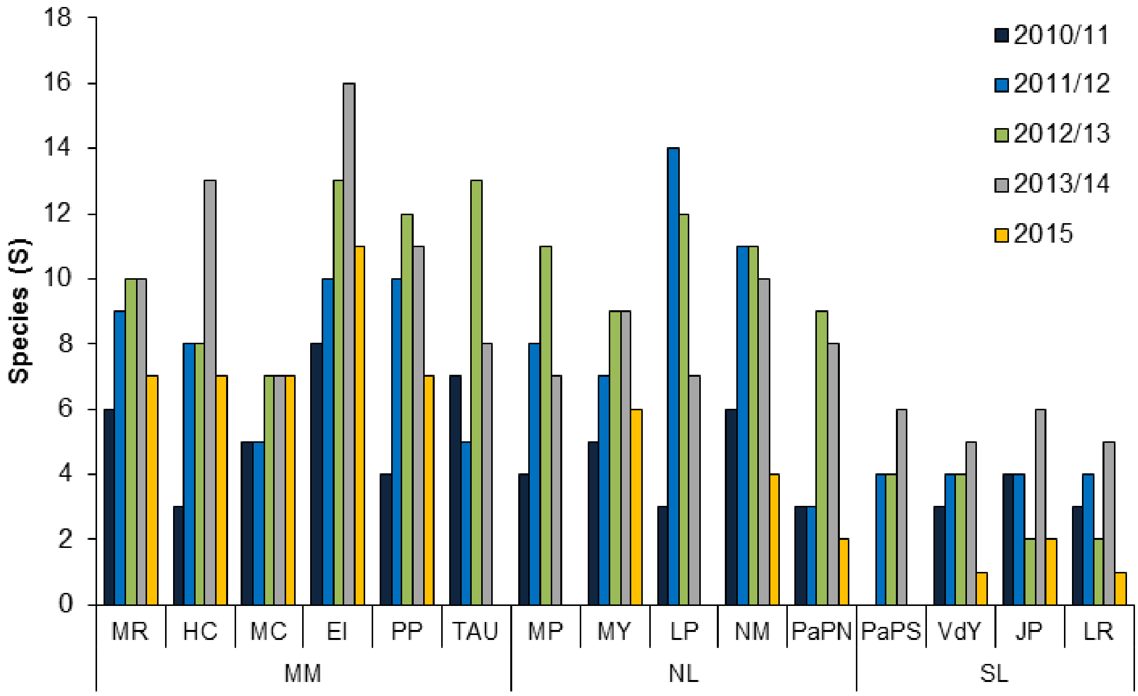


Figure A2.2. Total number of species (count per site) of benthic macroinvertebrates for each sampling site in the Murray Mouth and Coorong Lagoons, since environmental flows recommenced in 2010/11 to the most recent sampling event (2015). Note that not all sites were sampled again in 2015.

Table A2.1: Summary of PERMANOVA results for total abundance, species number and community structure. Numbers are *P* (permutation-based) values, with significant values highlighted in bold.

Source	Total Abundance		Species Number (S)		Community Structure	
	Intertidal	*Subtidal*	*Intertidal*	*Subtidal*	*Intertidal*	*Subtidal*
Region (R)	**0.0001**	**0.0125**	**0.0001**	**0.0089**	**0.0001**	**0.0009**
Year (Y)	0.4110	0.2214	0.0737	**0.0026**	**0.0006**	**0.0001**
Site (Region) (S(R))	**0.0031**	**0.0001**	**0.0030**	**0.0001**	**0.0001**	**0.0001**
Month (Year) (M(Y))	**0.0006**	0.8456	**0.0261**	**0.0003**	**0.0001**	**0.0001**
R x Y	**0.0037**	**0.0889**	**0.0001**	0.0509	**0.0003**	**0.0014**
R x M(Y)	0.7354	0.3116	0.3923	**0.0289**	0.0676	0.1224
Y x S(R)	**0.0387**	**0.0001**	0.0545	**0.0032**	**0.0001**	**0.0001**
S(R) x M(Y)	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**

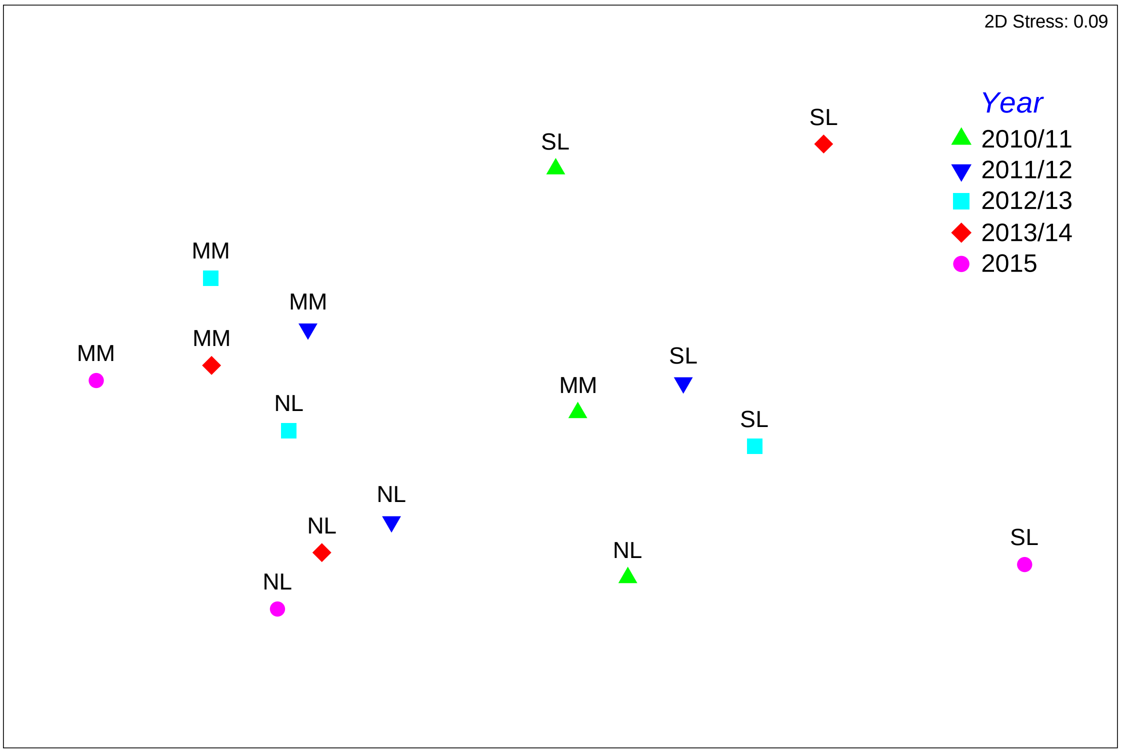


Figure A2.3. Multidimensional scaling plot (MDS) for benthic communities at intertidal sampling locations from 2010-2015. MM=sites in the Murray Mouth, NL= sites in the North Lagoon, SL= sites in the South Lagoon of the Coorong.

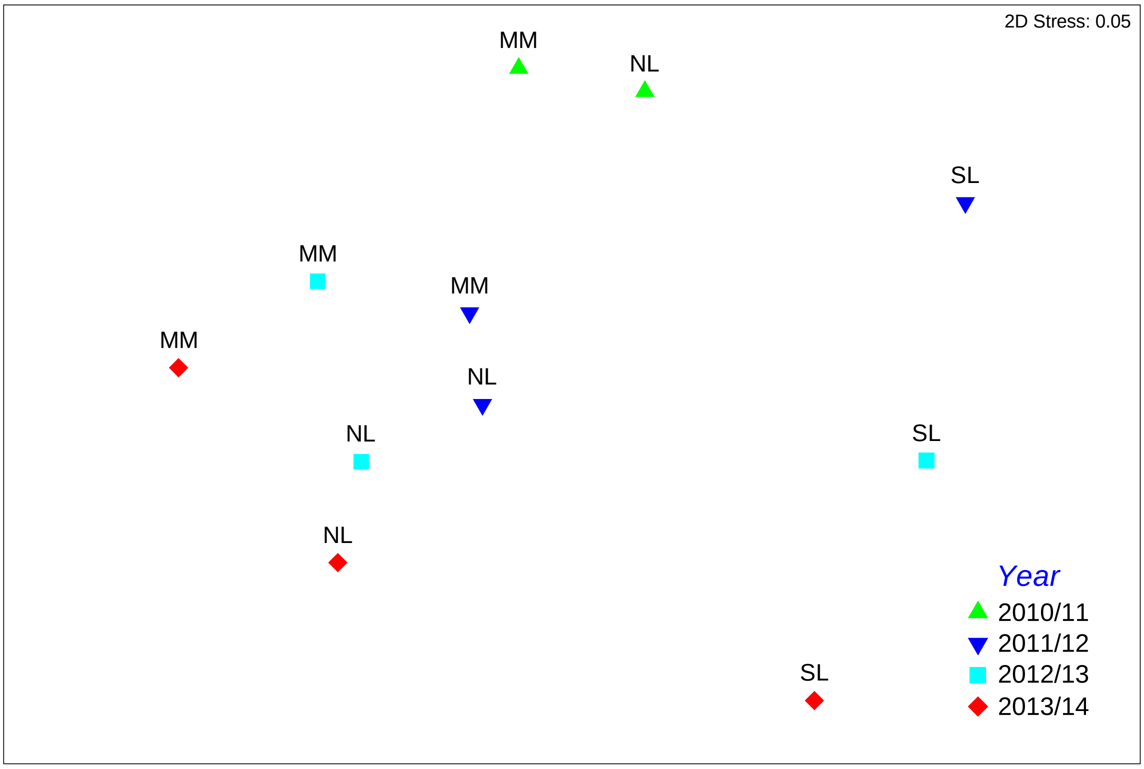


Figure A2.4. Multidimensional scaling plot (MDS) for benthic communities at subtidal sampling locations from 2010-2015. MM=sites in the Murray Mouth, NL= sites in the North Lagoon, SL= sites in the South Lagoon of the Coorong.

a) Intertidal

b) Subtidal

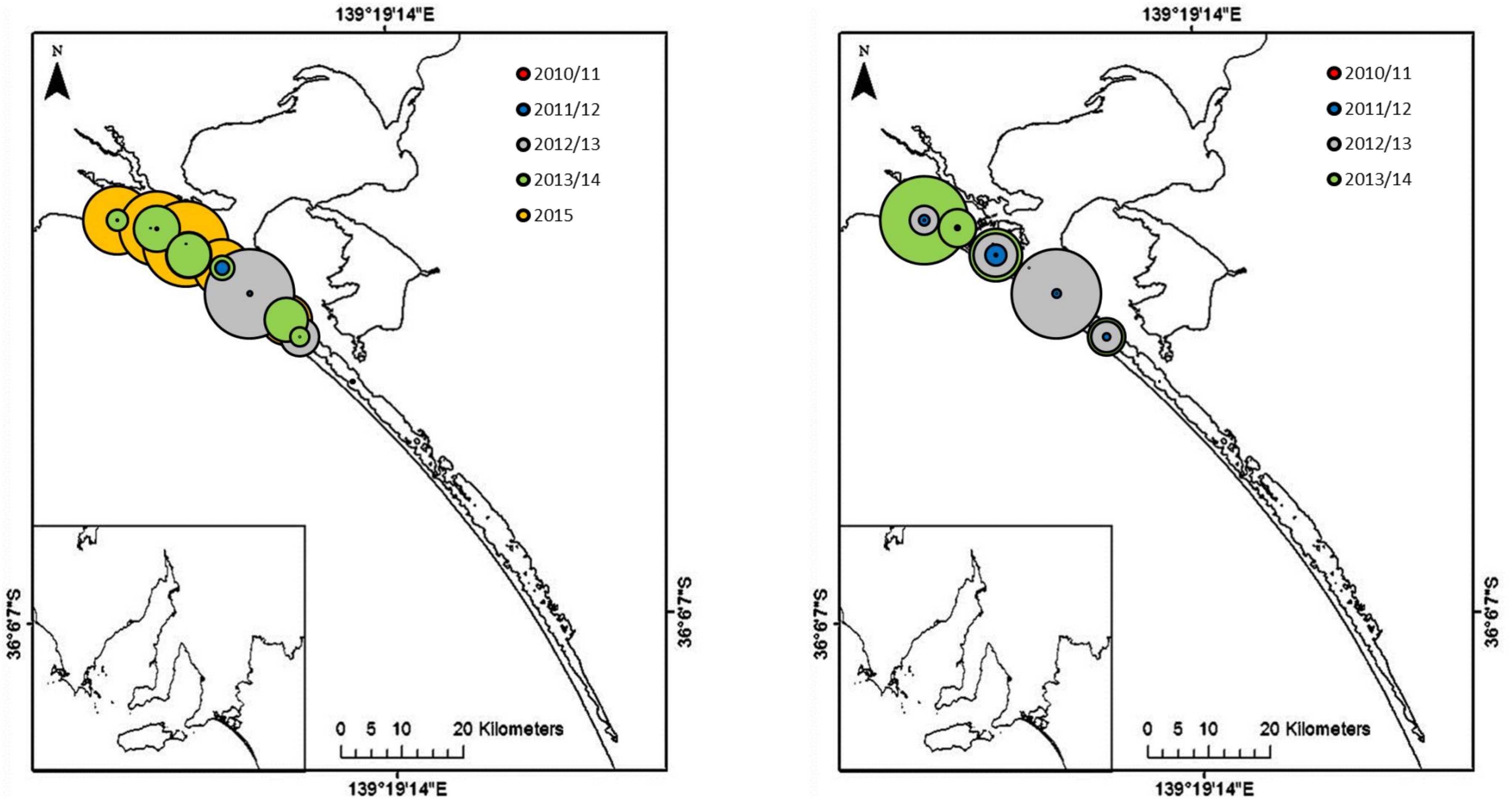


Figure A2.5. Distribution and relative abundance (averaged by year and site for each depth) of *Simplisetia aequisetis* in the a) intertidal, and b) subtidal sampling sites for each year since flows began in 2010. Bubbles are scaled to relative abundance (over the entire sampling period) and centred on each sampling site. Subtidal locations were not sampled in 2015.

a) Intertidal

b) Subtidal

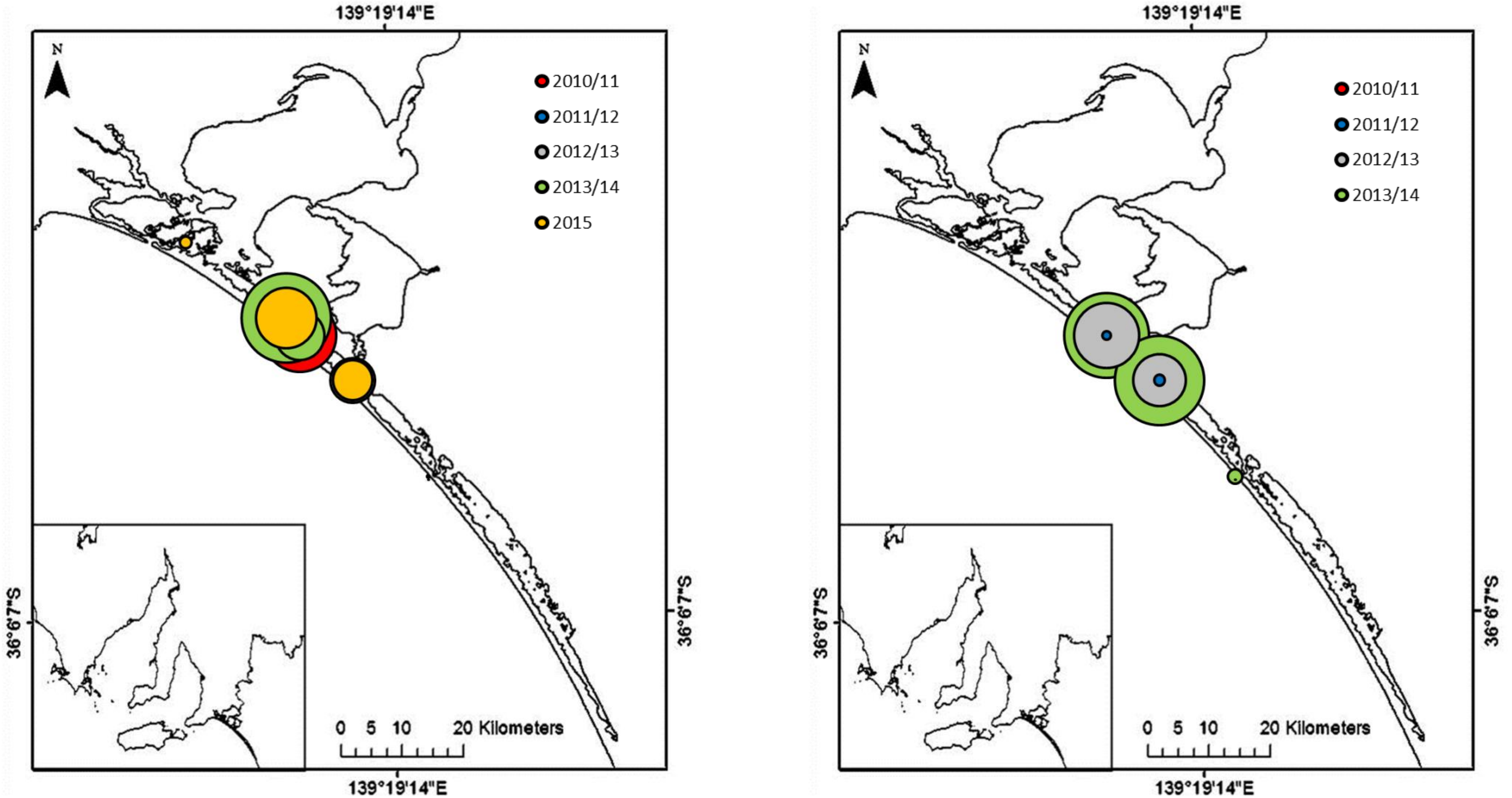


Figure A2.6. Distribution and relative abundance (averaged by year and site for each depth) of *Capitella sp.* in the a) intertidal, and b) subtidal sampling sites for each year since flows began in 2010. Bubbles are scaled to relative abundance (over the entire sampling period) and centred on each sampling site. Subtidal locations were not sampled in 2015.

a) Intertidal b) Subtidal

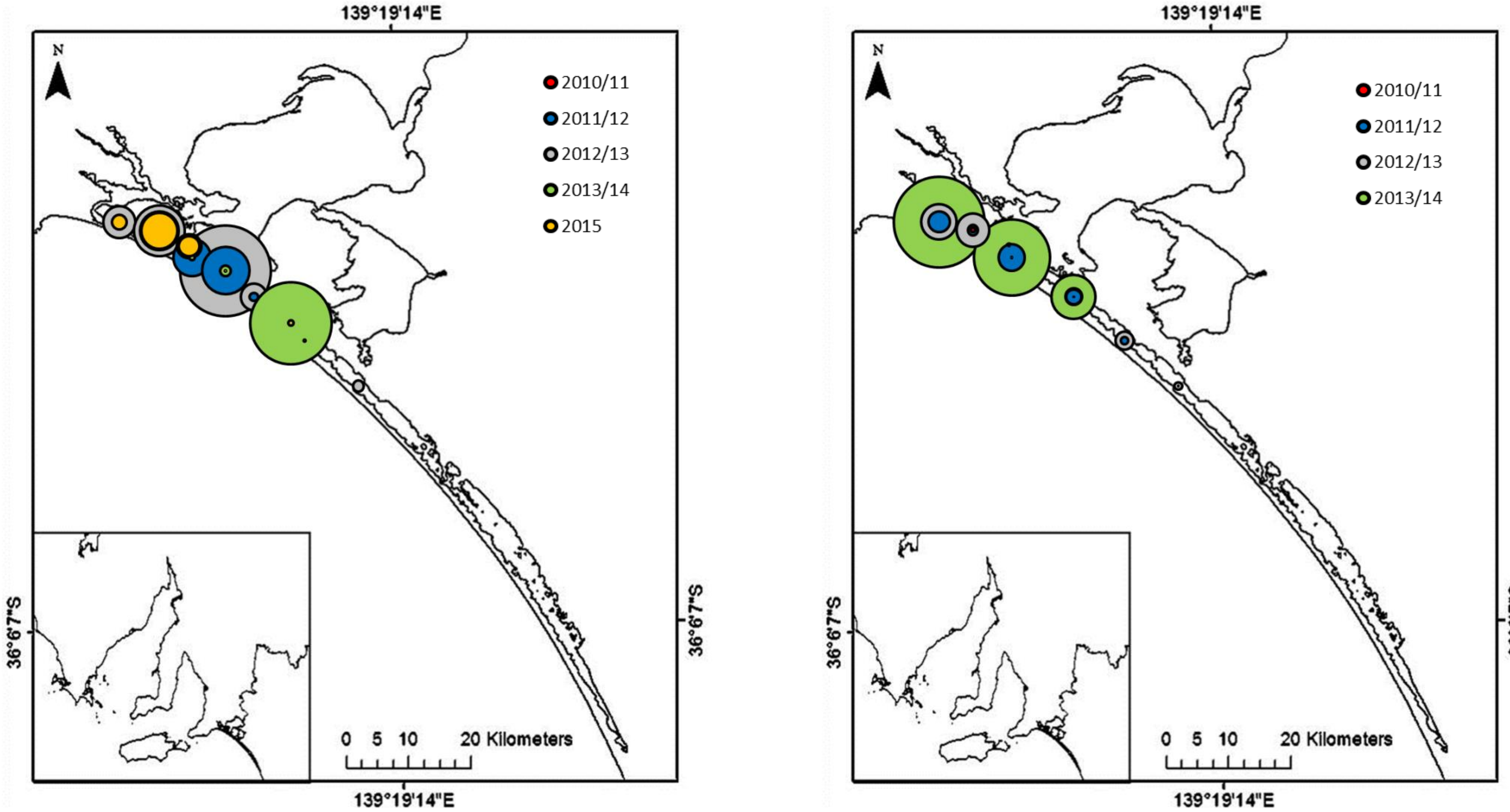


Figure A2.7. Distribution and relative abundance (averaged by year and site for each depth) of Amphipoda in the a) intertidal, and b) subtidal sampling sites for each year since flows began in 2010. Bubbles are scaled to relative abundance (over the entire sampling period) and centred on each sampling site. Subtidal locations were not sampled in 2015.

a) Intertidal

b) Subtidal

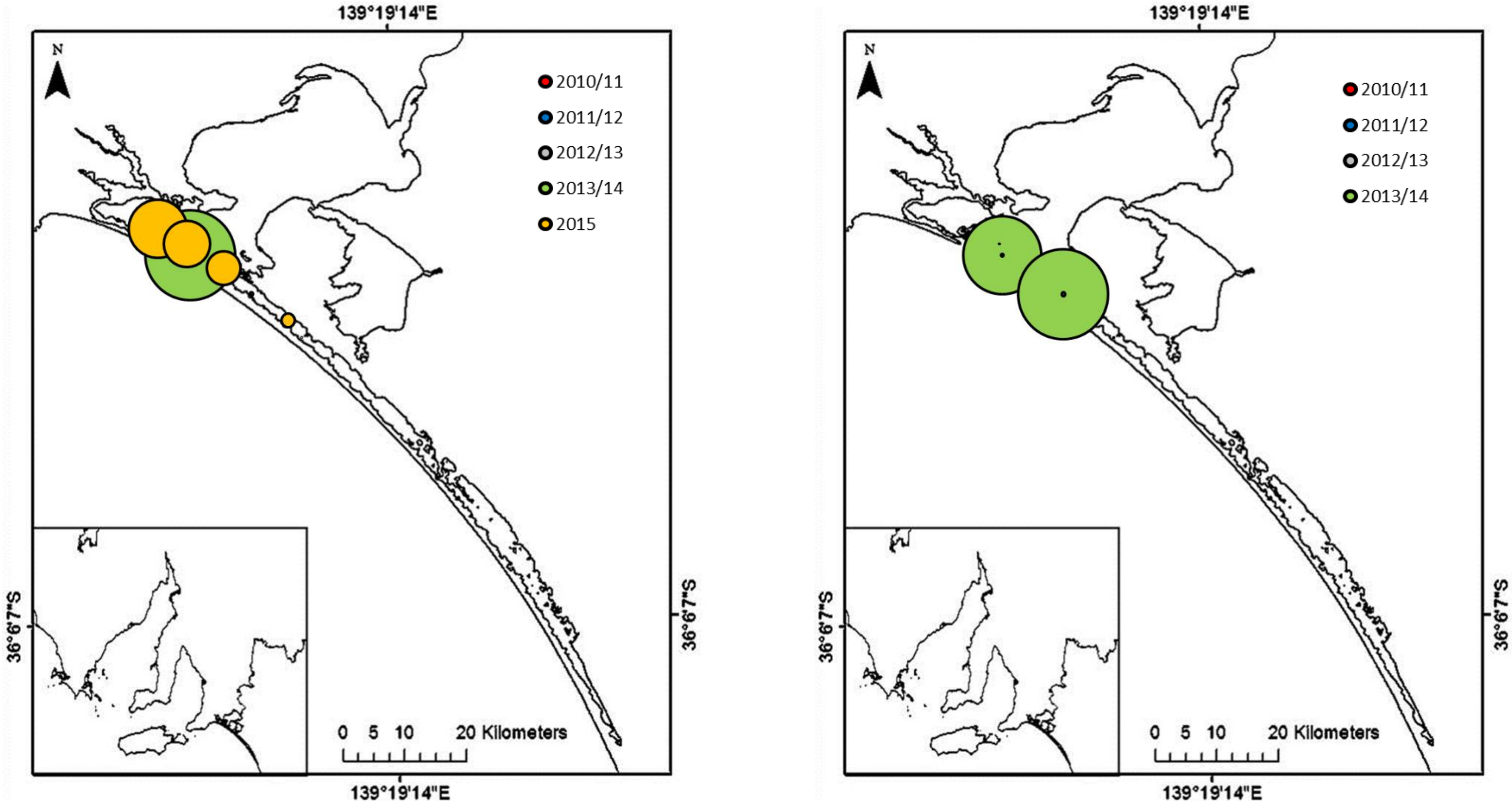
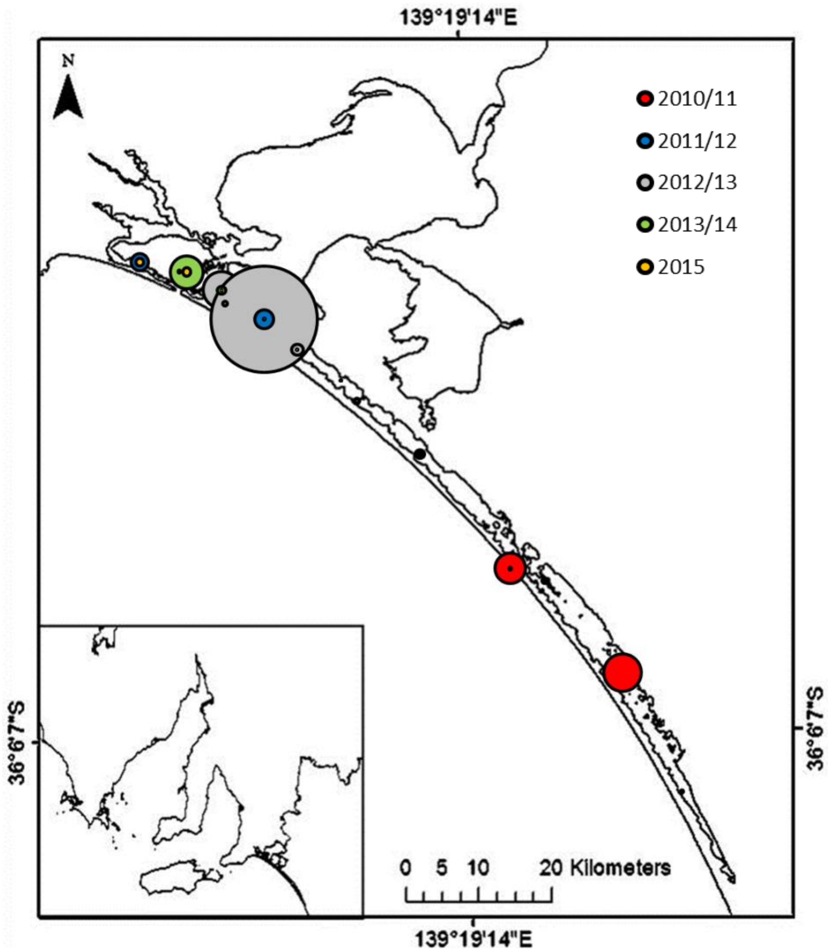


Figure A2.8. Distribution and relative abundance (averaged by year and site for each depth) of *Arthritica helmsi* in the a) intertidal, and b) subtidal sampling sites for each year since flows began in 2010. Bubbles are scaled to relative abundance (over the entire sampling period) and centred on each sampling site. Subtidal locations were not sampled in 2015.

a) Intertidal



b) Subtidal

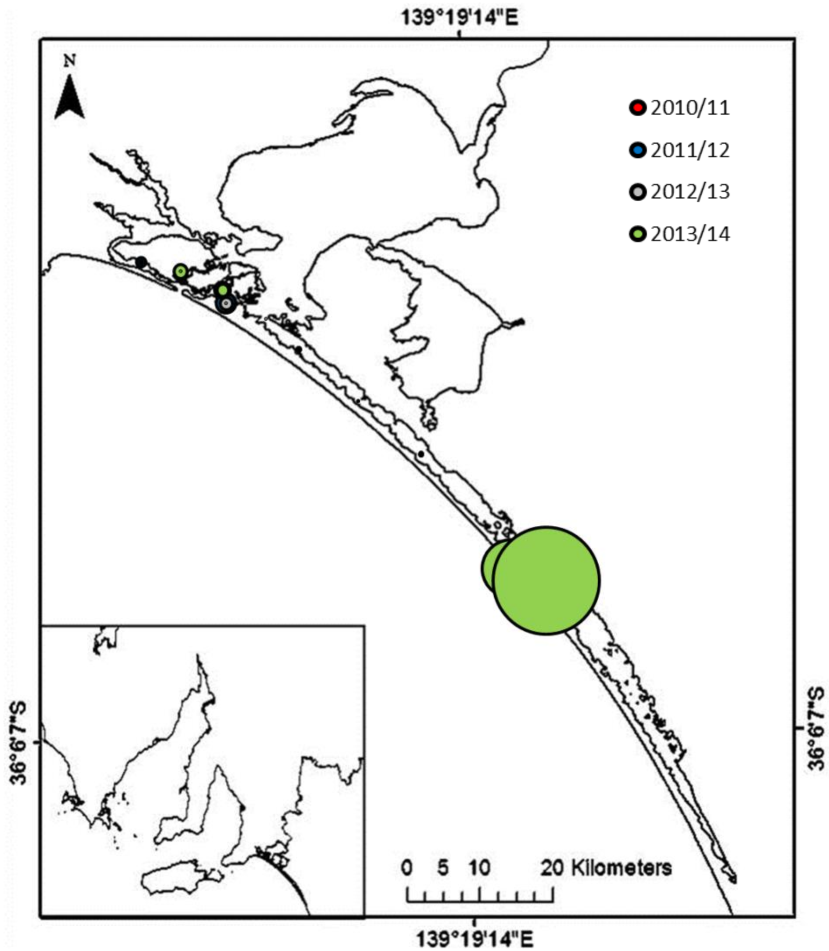
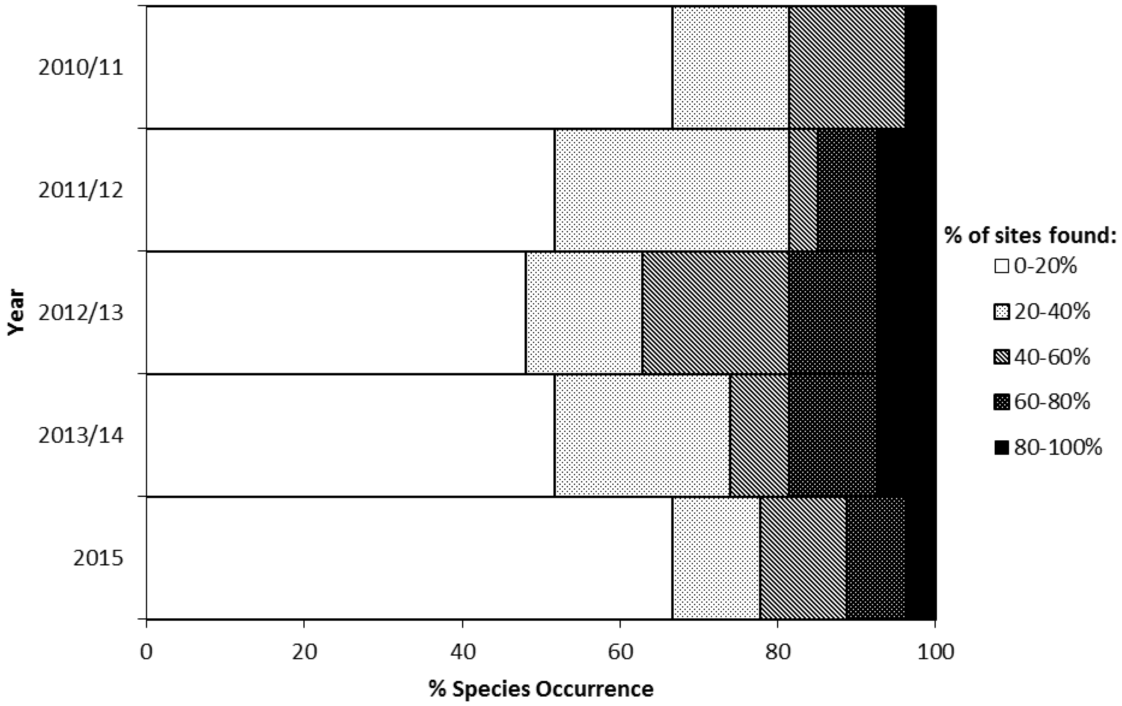


Figure A2.9. Distribution and relative abundance (averaged by year and site for each depth) of Diptera in the a) intertidal, and b) subtidal sampling sites for each year since flows began in 2010. Bubbles are scaled to relative abundance (over the entire sampling period) and centred on each sampling site. Subtidal locations were not sampled in 2015.

a) Intertidal



b) Subtidal

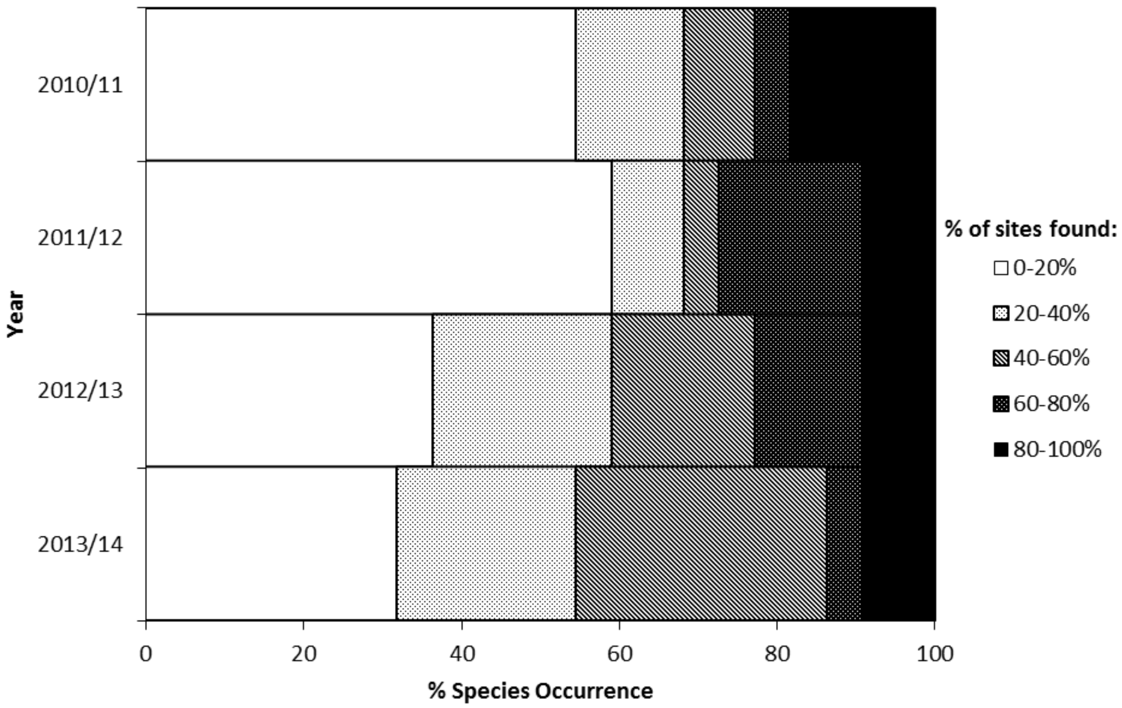


Figure A2.10. Index of species occurrence plots for a) intertidal and, b) subtidal sampling locations in the Murray Mouth and Coorong Lagoons for each monitoring year since 2010. Years are displayed on the y-axis (note that subtidal sampling was not undertaken in 2015). Shading indicates categorically the percentage of sites at which species were found (i.e. 0 – 20 % of sites [white shading] to 80 – 100 % of sites [black shading]; *i.e.* distribution category, with larger percentages indicating wider distribution ranges). The x-axis indicates the percentage of species (out of all species observed) that were found to occur in each distribution category, called per cent species occurrence.

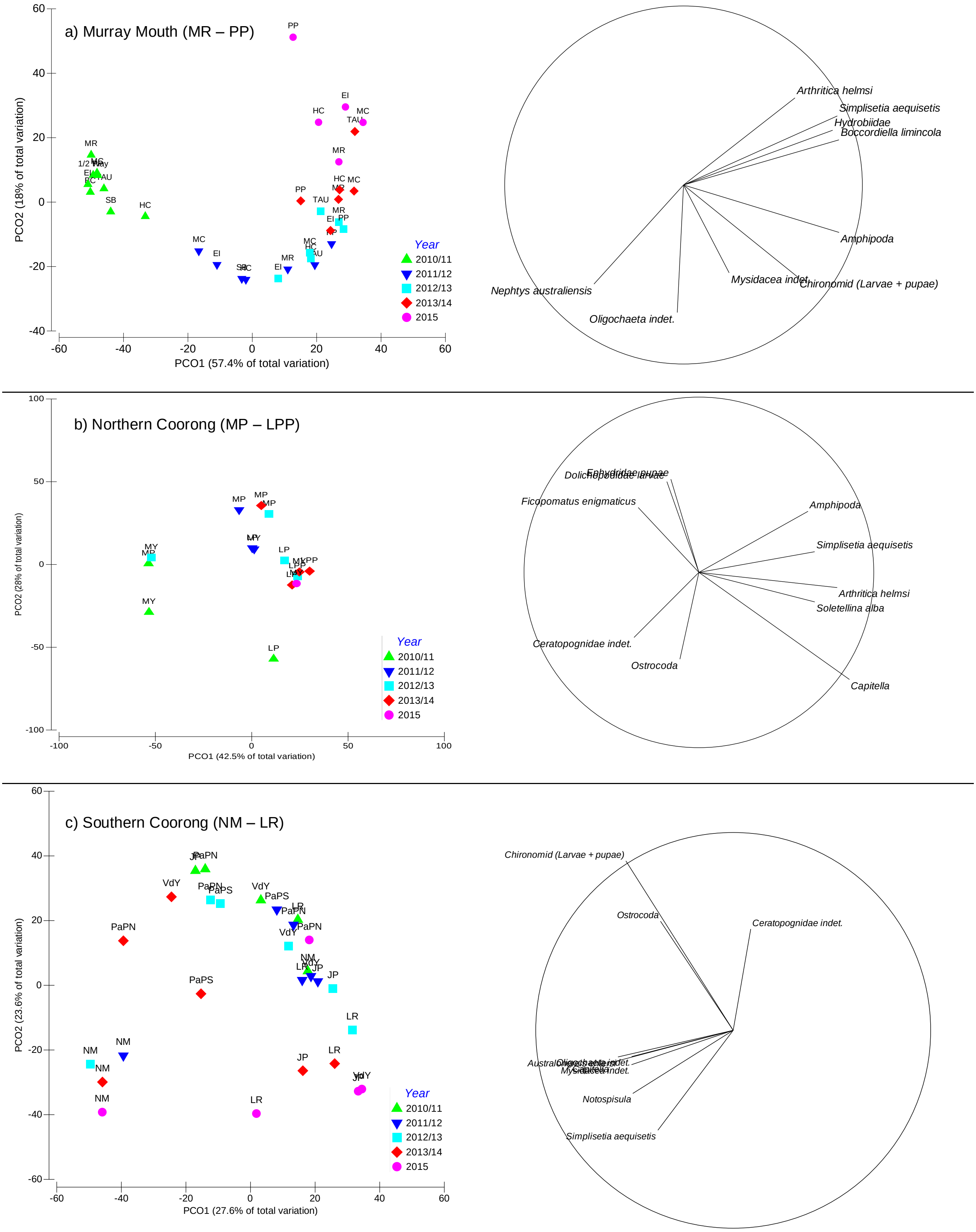


Figure A2.11. Principle-coordinates ordination (PCO) plots of benthic macroinvertebrate community structure for each site during each sampling year (data are averaged across all replicates collected at that site over all sampling events for that year). Each point represents the macroinvertebrate community (in terms of species composition and relative abundance) for a site. Vector overlays are Spearman correlation (> 0.5).

Table A2.2. Habitat requirements and important interactions for key benthic macroinvertebrate species, adapted from Tables 2 & 3 in Rolston *et al.* 2010 with additional information on life history strategies from Dorsey 1981; Glasby 1986, Beesley *et al.* 1998 (and references therein) and historical records for these species in the system (Geddes & Butler 1984; Geddes 1987).

Taxa	**Species**	**Habitat**			**Trophic Interactions**		**Other Interactions**	**Life History Strategies**		**Other**
		Substrate	**Salinity**	**Other**	**Feeding Mode**	**Predators**		larvae	Recruitment	
Annelida	*Ficopomatus enigmaticus*	Hard	35 – 65 ppt	Reef forming species	Filter Feeder	Fish	Ecosystem Engineer (tube reef builder)	Planktonic larvae	Summer, Spring tides	Possibly invasive
	Capitella sp.	Soft	5 – 80 ppt	Tolerant of poor environmental conditions	Deposit Feeder (non-selective)	Birds, Fish	Construct mucus-lined burrows	Multiple spawning events		Pollution indicator
	Nephtys australiensis	Soft	5 – 60 ppt		Predator	Birds, Fish	Burrow, not tube forming	Planktonic		
	Boccardiella limnicola	Soft	5 – 45 ppt	Tolerates freshwater habitats	Filter/Deposit Feeder	Birds, Fish	Sediment stabilisation			
	Australonereis ehlersi	Soft, fine sandy	5 – 45 ppt	Intolerant of low oxygen concentration, adverse environmental conditions	Omnivore, Deposit Feeder, possible suspension feeder	Birds, Fish	Bioturbation, Ecosystem Engineer (tube builder)	Planktonic larvae (unknown duration)	Spring	
	Simplisetia aequisetis	Soft	5 – 45 ppt Adults tolerate riverine conditions	Tolerates low oxygen concentrations, organically enriched sediments	Omnivore, Selective deposit feeder, possible predator of zooplankton	Birds, Fish	Bioturbation, Ecosystem Engineer (burrow builder)	Dioecious, direct developer (brooder)	Spring	
	Oligochaeta	Soft	Freshwater to marine		Deposit Feeder, detritovore	Birds, Fish				
Crustacea	Amphipoda (multiple species)	Both	1 – 62 ppt		Deposit Feeder, omnivore, predator	Birds, Fish	Sediment destabilisation	Brooders		
	Decapoda	Both	35 – 60 ppt		Predator	Birds, Fish	Ecosystem Engineer	Brooders		
Insecta	Insect Larvae	Soft	up to 74 ppt		Predator/Deposit Feeder	Birds, Fish	Burrowers - surface layers	n/a		
Mollusca	*Arthritica helmsi*	Soft	5 – 65 ppt		Filter Feeder	Birds, Fish				
	Spisula trigonella	Soft	5 – 65 ppt		Filter Feeder	Birds, Fish				
	Soletellina alba	Soft	Polyhaline (18-30 ppt)		Filter Feeder	Birds, Fish				

A.3 Annual Trends

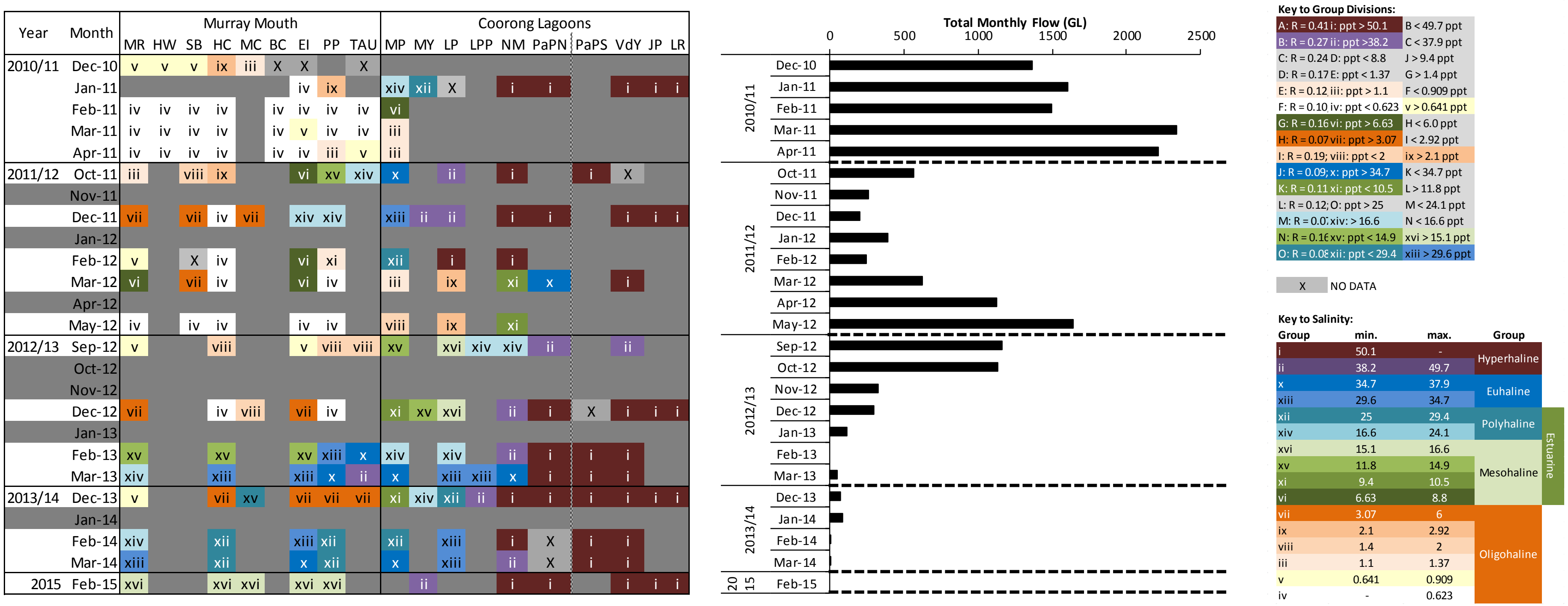


Figure A3.1: Macroinvertebrate community groupings based on salinity changes across the system for each sampling event from December 2010 to February 2015, plotted against total monthly flow into the system across the barrages. Roman numerals indicate group numbers. Keys to the salinity transition points and ranges for each macroinvertebrate community grouping are given in the keys below the plot, as well as keys to the colour scheme, which reflects salinity conditions defined for estuaries (see Whitfield *et al*. 2012).

Table A3.1: Summary of SIMPER results. Taxa contributing to 80 % similarity within groups are listed.

		Salinity Range (ppt)		Annelida					Mollusca		Crustacea		Insecta		
Salinity	Group	Min	Max	*Capitella*	*Simplisetia aequisetis*	*Nephtys australiensis*	*Boccardiella limnicola*	Oligochaeta	*Arthritica helmsi*	Hydrobiidae	Amphipoda	Mysidaceae	Chironomidae	Ephydridae	Dolichopodidae
Hyperhaline	1	50	-	6.8							10.4		70.4	4.1	
	2	38	50	35.5	3.2			7.3			27.5		18.7		
Euhaline	10	35	38	4.6	21.3				5.7		33.8		25.7		
	13	30	35	8.1	32.5				7.3		30.0		12.6		
Polyhaline	12	25	30	4.7	29.6		5.5	6.9	21.3		15.3		7.6		
	14	16	25		12.0			5.6			49.3		23.5		
Mesohaline	16	15	16.5		24.0		7.5		14.0	6.4	23.2		16.5		
	15	11.5	15		17.9			5.2			44.6		25.3		
	11	9.5	10.5	10.4	14.2			14.2			24.8	5.2	20.1		5.3
	6	6.5	9			7.6					60.0	10.2	19.5		
Oligohaline	7	3	6		10.6	2.4	3.7				49.3		26.1		
	9	2	3		12.1			16.8			27.9		41.2		
	8	1.5	2		13.8			6.6			52.4		20.8		
	3	1	1.4		40.4						28.2		26.5		
	5	0.6	1		8.75						49.9		36.3		
	4	-	0.6		7.25						45.5		42.8		

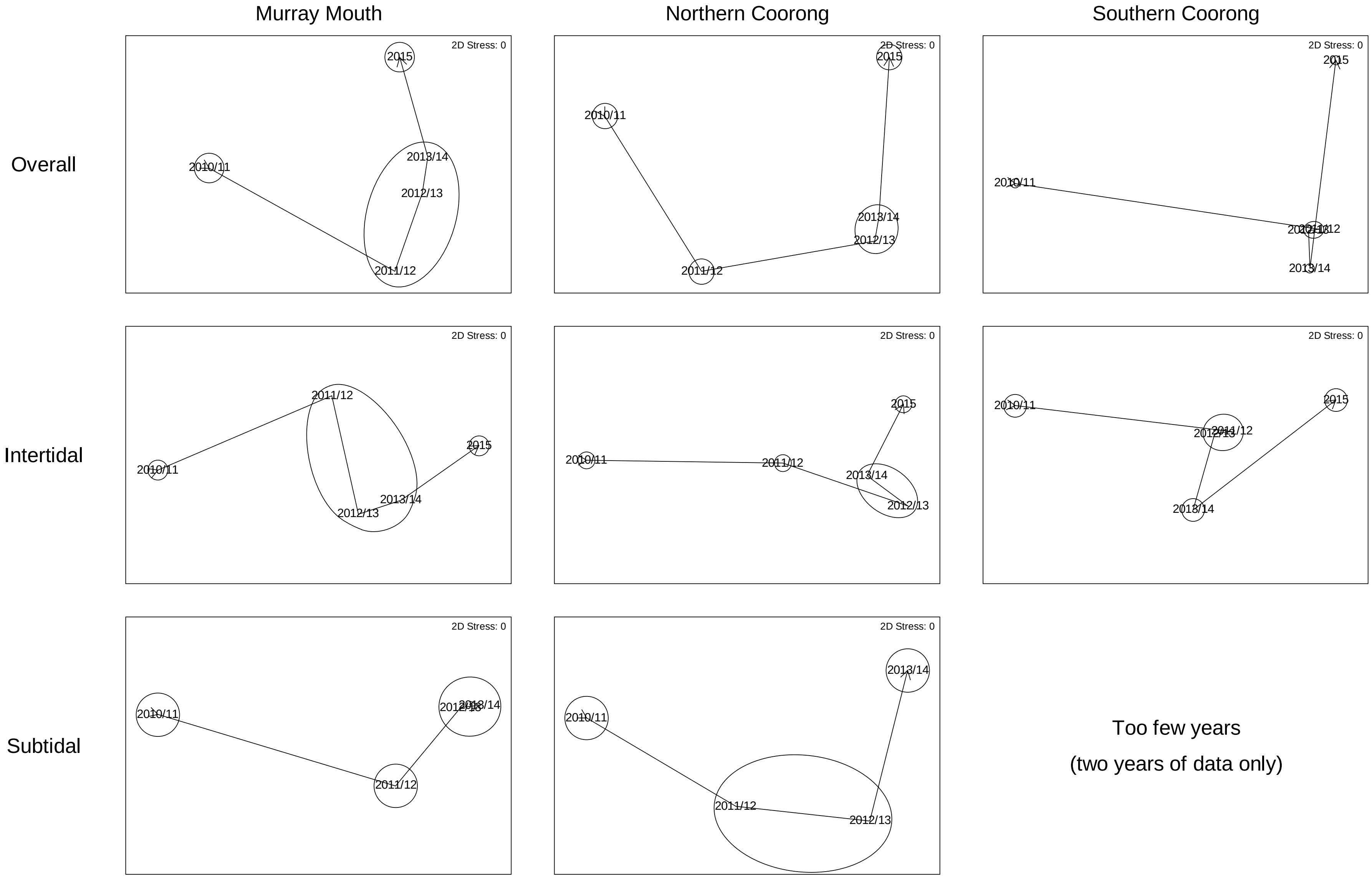


Figure A3.2: MDS trajectory plots for each region (top row), and each region by depth (intertidal = second row; subtidal = third row).

Table A3.2: Summary of SIMPER results for the Murray Mouth region. Average similarity (ave. sim.) is given for each group, and percent contribution (% Cont.) for each species.

	Year	2010/11			2011/12 2012/13 2013/14			2015		
Group		**Group 1 (ave. sim = 63.18 %)**			**Group 2 (ave. sim = 65.28 %)**			**Group 3 (ave. sim = 79.61 %)**		
Taxa		**Rank**	**Abundance**	**% Cont.**	**Rank**	**Abundance**	**% Cont.**	**Rank**	**Abundance**	**% Cont**
Annelida	*Simplisetia aequisetis*	3	6.28	15.42	3	15.8	15.31	1	18.68	22.49
	Boccardiella limnicola	-	-	-	5	7.97	4.77	4	10.9	11.85
	Nephtys australiensis	4	4.9	10.57	-	-	-	-	-	-
	Oligochaeta	5	3.06	6.31	4	8.23	6.75	-	-	-
Mollusca	Hydrobiidae	-	-	-	6	6.03	4.39	5	9.67	10.14
	Arthritica helmsi	-	-	-	-	-	-	2	21.01	22.16
Crustacea	Amphipoda	1	14.73	36.35	1	35.14	38.06	3	20.16	20.55
	Mysidacea	-	-	-	7	3.97	2.58	-	-	-
Insecta	Chironomidae	2	9.52	24.54	2	18.73	18.53	6	9.65	9.93

Table A3.3: Summary of SIMPER results for the Northern Coorong region.

	Year	2010/11			2011/12			2012/13 2013/14			2015
Group		**Group 1 (ave. sim = 25.91 %)**			**Group 2 (ave. sim = 64.46 %)**			**Group 3 (ave. sim. = 55.76 %)**			**Group 4 (MY only)**
Taxa		**Rank**	**Abundance**	**% Cont.**	**Rank**	**Abundance**	**% Cont.**	**Rank**	**Abundance**	**% Cont.**	**Abundance**
Annelida	*Capitella spp.*	2	10.12	27.95	3	15.07	13.41	2	20	18.17	27.11
	Simplisetia aequisetis	-	-	-	5	11.36	9.91	3	17.2	17.64	20.54
	Australonereis ehlersi	-	-	-	6	4.07	2.68	-	-	-	-
	Oligochaeta	1	5.14	44.70	2	11.91	15.05	6	7.49	5.70	7.55
Mollusca	*Arthritica helmsi*	-	-	-	-	-	-	4	10.27	9.34	20.99
Crustacea	Amphipoda	-	-	-	1	30.66	38.87	1	28.77	33.54	19.28
	Mysidacea	4	3.2	11.65	-	-	-	-	-	-	-
Insecta	Chironomidae	3	4.27	15.70	4	11.15	12.73	5	8.62	6.64	-

Table A3.4: Summary of SIMPER results for the Southern Coorong region.

Group	Year	2010/11 Group 1 (ave. sim = 53.86 %)			2011/12 | 2012/13 Group 2 (ave. sim = 42.29 %)			2013/14 Group 3 (ave. sim. = 38.67 %)			2015 Group 4 (ave. sim. = 23.31 %)		
Taxa		Rank	Abundance	% Cont.	Rank	Abundance	% Cont.	Rank	Abundance	% Cont.	Rank	Abundance	% Cont.
Annelida	Capitella	-	-	-	4	7.44	5.09	3	10.33	15.95	-	-	-
Crustacea	Amphipoda	-	-	-	2	7.51	18.23	2	6.04	20.61	-	-	-
	Ostracoda	-	-	-	-	-	-	5	10.03	11.63	-	-	-
Insecta	Chironomidae	1	12.73	69.67	1	13.40	60.77	1	12.09	31.50	1	4.68	93.31
	Ceratopogonidae	2	4.58	15.82	3	2.26	5.68	-	-	-	-	-	-
	Ephydridae	3	2.20	6.66	5	1.80	3.65	4	5.64	11.94	-	-	-

Table A3.5: Water quality conditions and taxonomic group responses to environmental freshwater flows with water release through the barrages into the Coorong from 2010 to 2015. The red text indicates that there was no improvement compared to the previous year on community structure or for specific indicator species. Blue text indicates that there was an increase in species diversity resulting in increased community complexity or increased abundances of indicator species compared to the previous year sampled. The results from the 2015 year obtained from within this report are only given for macroinvertebrate responses and is currently being prepared on all other taxonomic groups by other research providers.

	2010/11	2011/12	2012/13	2013/14	2015	Reference
<u>Water quality</u>	High freshwater flows. Salinity decreasing	Salinity decreasing.	Salinity decreasing.	Large decrease in freshwater flows. Salinity decreasing.	Low but consistent freshwater flows. Salinity decreasing.	Within this report, Oliver et al. 2014, Leterme et al. 2015
<u>Taxonomic group</u> Phytoplankton/ microalgae	Similar composition of phytoplankton across Coorong sites	MM - dominated by cyanobacteria. SL - dominated by chlorophytes.	Peak of chlorophytes northward along Coorong.	Complex mix of phytoplankton along length of Coorong. MM/NL – mostly chlorophytes. SL - diatoms important.		Oliver et al. 2014,Leterme et al. 2015
Zooplankton	MM/NL - *Stenosomella lacustris* important in northern Coorong.	MM/NL - Keratella tropica important	Calanoid nauplii along entire Coorong & MM/NL - tintinnids important, freshwater species.	MM/NL - similar to 2012/13.		Oliver et al. 2014
Macroinvertebrates	MM- amphipods, polychaetes, chironomids important NL- oligochaetes, capitellids, chironomids important SL- insect larvae important	MM – Gastropods arrive, increase in polychaete species NL- *Simplisetia aequisetis* increase abundances SL – amphipods increase abundances	MM – similar to 2011/12. NL – *Arthritica helmsi* increase abundances. SL – Similar to 2011/12.	MM - similar to 2011/12 & 2012/13. NL - Similar to 2012/13. SL - capitellids & ostracods increase abundances	MM – *A. helmsi* increase abundances, polychaetes increase abundances, gastropods increase abundances. NL – *S. aquesitis*, *A. helmsi* increase abundances. SL – Mainly insect larvae	Within this report
Fish	MM/NL -Dominated by freshwater fish species and some estuarine species.	Increase in estuarine/marine species MM -sandy sprat,	Increasing recruitment overall. Increase in recruitment of diadromous species.	MM/NL -Lower abundances of sandy sprat since 2011/12 (possibly		Bice and Zampatti 2014, Livore et al. 2013.

Fish (cont'd)	Low species diversity overall. SL – smallmouthed hardyhead important	small mouthed hardyhead, Tamar goby, bony herring important NL- sandy sprat, smallmouthed hardyhead, bony herring, yelloweye mullet, mulloway important SL – similar to 2010/11	Decrease in freshwater species dominance. Increase in large-bodied estuarine species. MM- sandy sprat, yelloweye mullet, bony herring important NL- smallmouth hardyhead, sandy sprat, congoli, yelloweye mullet, mulloway important SL- similar to 2011/12	due to decrease in freshwater flows). Increase in young of year catadromous congoli and common galaxias due to increased flows and connectivity. Higher species diversity overall		
Birds	Declining overall bird numbers since previous year. Increase in some species, particularly migratory shorebirds	Low bird numbers, particularly migratory shorebirds. Reduced foraging habitat in 2011 due to higher water levels with large flows	Migratory shorebird numbers increasing.	Increase in bird numbers overall in 2014 compared to 2013. Notably; grey teal, red-necked stint, sharp-tailed sandpiper		Dittmann et al. 2013, Paton and Bailey 2014

A4. Conceptual models

Table A4.1: Species list of all taxa collected in all macrobenthic samples (including intertidal and subtidal sites) during the entire monitoring period from 2010/11 to the most recent monitoring event in 2015. Ticks (✓) indicate that taxa was present in that region during that monitoring year, blank spaces indicate that taxa was not recorded. Presence/absence of taxa across years is indicated separately for each region. Summary counts of total number of taxa found in each region during each monitoring event, and total number of taxa found in each region overall are included at the bottom of the table (final two rows).

Taxa		**Murray Mouth**					**North Lagoon**					**South Lagoon**				
		2010/11	**2011/12**	**2012/13**	**2013/14**	**2015**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2015**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2015**
Annelida	Oligochaeta indet.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
	Capitella species complex (*C. capitata*)		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
	Phyllodoce novaehollandiae				✓	✓										
	Simplisetia aequisetis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
	Australonereis ehlersi	✓	✓	✓	✓	✓		✓	✓	✓						
	Nephtys australiensis	✓	✓	✓	✓		✓	✓	✓	✓						
	Boccordiella limincola	✓	✓	✓	✓	✓			✓							
	Ficopomatus enigmaticus	✓		✓	✓		✓	✓	✓							
	Euchone variabilis								✓							
Mollusca	*Arthritica helmsi*	✓	✓	✓	✓	✓			✓	✓	✓				✓	
	Spisula (Notospisula) trigonella		✓	✓	✓			✓	✓	✓						
	Soletellina alba		✓	✓	✓	✓		✓	✓	✓						
	Hydrobiidae (6 spp.)	✓	✓	✓	✓	✓			✓							
	Salinator fragilis	✓	✓	✓	✓	✓		✓	✓							
	Coxiella striata														✓	
Crustacea	Ostracoda	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓		✓	
	Isopoda									✓			✓			
	Amphipoda	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
	Mysidacea	✓	✓	✓	✓		✓	✓	✓	✓						
	Parartemia sp.											✓				
	Paragrapsus gaimardii	✓	✓	✓	✓			✓	✓		✓					
	Helograpsus haswellianus	✓														
	Amarinus laevis	✓		✓				✓								
Hexapoda	Chironomidae (larvae + pupae)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Ephydridae (pupae)	✓		✓	✓		✓		✓	✓		✓		✓	✓	
	Dolichopodidae larvae		✓	✓	✓			✓	✓	✓	✓		✓		✓	
	Muscidae (larvae)									✓						
	Ecnomidae (larvae)									✓					✓	
	Sciomyzidae (larvae + pupae)								✓							
	Tipulidae (larvae)	✓					✓									
	Ceratopognidae (larvae)	✓	✓	✓			✓		✓			✓	✓	✓	✓	
	Culicidae (larvae)	✓					✓	✓					✓			
	Corixidae (larvae)	✓														
	Hydrophilidae (larvae)								✓							
	Coleoptera indet. (larvae + pupae)									✓					✓	
Total # taxa by year and region		21	18	21	20	12	13	17	23	18	8	5	9	7	13	3
Total # taxa by region				26					30					16		

Table A4.2: Environmental tolerances (as descriptive statistics "Min., Max., Range, Average, Median and Mode") for nine key species as calculated from data collected in the Murray Mouth and Coorong Lagoons between 2010/11 and 2015. Also included are descriptive statistics for conditions when very low or very high abundances were observed, and for the full range of conditions observed in the system during macrobenthic monitoring.

a) Water Quality

Key Species			Salinity (ppt)						DO (%)					
Taxa		**Species**	**Min.**	**Max.**	**Range**	**Average**	**Median**	**Mode**	**Min.**	**Max.**	**Range**	**Average**	**Median**	**Mode**
Annelida	Oligochaeta	Oligochaeta indet.	0.17	52.40	52.23	14.76	9.93	0.30	63.67	171.70	108.03	107.30	101.00	
	Polychaeta	*Simplisetia aequisetis*	0.17	69.70	69.53	16.19	12.32	0.40	58.80	187.10	128.30	105.50	102.53	96.33
		Capitella spp.	0.23	188.30	188.07	39.81	37.53	49.73	61.83	226.10	164.27	110.10	103.90	
		Nephtys australiensis	0.23	35.37	35.13	7.57	4.30		64.00	171.70	107.70	96.86	90.48	88.63
		Boccordiella limincola	0.40	40.00	39.60	18.23	16.35	24.10	74.13	180.90	106.77	112.73	112.73	
Mollusca	Bivalvia	*Arthritica helmsi*	0.93	43.00	42.07	22.27	26.00	35.33	65.20	180.90	115.70	117.95	113.70	
	Gastropoda	Hydrobiidae	0.25	35.37	35.11	14.63	13.68	12.27	75.80	180.90	105.10	121.15	119.35	
Crustacea	Amphipoda	Amphipoda	0.11	80.13	80.03	15.09	7.17	0.30	58.80	187.10	128.30	101.13	96.93	96.57
Insecta	Diptera	Chironomid (Larvae + pupae)	0.11	109.33	109.23	24.42	12.37	0.30	56.23	236.53	180.30	103.37	98.33	96.33
		Very low abundances (< 1,000 ind.m^{-2})	0.19	104.33	104.14	28.27	1.20		49.80	132.80	83.00	93.01	93.73	100.73
		Very high abundances (> 1,000,000 ind.m^{-2})	0.50	35.93	35.43	13.17	5.83		73.77	173.93	100.17	105.85	103.10	
		Full Range of Conditions Experienced	0.11	188.30	188.19	23.87	10.23	0.30	49.80	236.53	186.73	101.61	97.33	107.33

b) Sediment Characteristics

Key Species			OM (%)						Median GS (µm)					
Taxa		**Species**	**Min.**	**Max.**	**Range**	**Average**	**Median**	**Mode**	**Min.**	**Max.**	**Range**	**Average**	**Median**	**Mode**
Annelida	Oligochaeta	Oligochaeta indet.	0.18	3.03	2.85	0.89	0.87	0.87	18.05	908.72	890.67	265.32	211.89	
	Polychaeta	*Simplisetia aequisetis*	0.18	6.52	6.34	1.26	1.11	1.10	16.59	718.18	701.59	189.25	168.16	
		Capitella spp.	0.37	3.80	3.43	1.22	0.89	0.62	34.00	579.42	545.42	199.50	194.90	
		Nephtys australiensis	0.34	1.37	1.04	0.85	0.96	0.99	130.90	220.20	89.31	179.13	180.22	
		Boccordiella limincola	0.62	6.52	5.90	1.54	1.28		16.59	339.46	322.87	128.86	142.59	
Mollusca	Bivalvia	*Arthritica helmsi*	0.62	6.52	5.90	1.62	1.36		16.59	718.18	701.59	167.33	144.08	
	Gastropoda	Hydrobiidae	0.62	6.52	5.90	1.63	1.19		75.48	339.46	263.98	162.83	147.39	
Crustacea	Amphipoda	Amphipoda	0.18	9.76	9.58	1.18	0.99	0.62	16.59	2549.79	2533.20	215.28	185.86	
Insecta	Diptera	Chironomid (Larvae + pupae)	0.09	18.29	18.19	1.66	1.14	0.62	16.59	1237.90	1221.31	207.59	185.17	
		Very low abundances (< 1,000 ind.m^{-2})	0.42	4.24	3.82	1.96	1.99		121.15	645.27	524.12	278.12	219.83	
		Very high abundances (> 1,000,000 ind.m^{-2})	0.88	2.35	1.47	1.38	1.20		29.60	305.19	275.60	152.78	141.37	
		Full Range of Conditions Experienced	0.09	18.29	18.19	1.58	1.09	0.62	16.59	2549.79	2533.20	229.75	192.02	

c) Chlorophyll-a Content

Key Species			Chl-a (mg.m^{-2})					
Taxa		**Species**	**Min.**	**Max.**	**Range**	**Average**	**Median**	**Mode**
Annelida	Oligochaeta	Oligochaeta indet.	0.00	6.15	6.15	2.24	1.89	
	Polychaeta	*Simplisetia aequisetis*	0.00	6.26	6.26	1.81	1.44	2.07
		Capitella spp.	0.00	4.92	4.92	1.41	0.98	
		Nephtys australiensis	0.11	7.01	6.90	2.20	1.44	
		Boccordiella limincola	0.00	4.68	4.68	1.62	1.44	1.60
Mollusca	Bivalvia	*Arthritica helmsi*	0.07	5.69	5.62	1.21	0.88	0.07
	Gastropoda	Hydrobiidae	0.10	9.43	9.33	2.10	1.31	
Crustacea	Amphipoda	Amphipoda	0.00	9.43	9.43	1.67	1.23	0.37
Insecta	Diptera	Chironomid (Larvae + pupae)	0.00	9.43	9.43	1.58	1.01	0.00
		Very low abundances (< 1,000 ind.m^{-2})	0.03	2.19	2.16	0.97	0.64	
		Very high abundances (> 1,000,000 ind.m^{-2})	0.10	2.07	1.97	0.84	0.68	
		Full Range of Conditions Experienced	0.00	9.43	9.43	1.42	0.93	0.00

Table A4.3: Taxa traits and preferences as defined from the data for the Murray Mouth and Coorong Lagoons.

a) Taxa size, longevity and life history traits

Taxa		Size & Longevity		Reproduction/Life History			
		Individual Size	Life span	Method	Rearing method	Deposition	Larval Type
Annelida	Oligochaeta indet.	Large (> 20 mm)	Medium (1 - 3 years)	Sexual	shed eggs	benthic	Benthic
	Capitella species complex (*C. capitata*)	Large (> 20 mm)	Short (< 1 year)	Sexual	brood eggs	carried	Pelagic-planktonic/Pelagic lecithotrophic
	Phyllodoce novaehollandiae	Large (> 20 mm)	Medium (1 - 3 years)	Encapsulation	gelatinous mass	benthic	Pelagic-planktonic
	Simplisetia aequisetis	Large (> 20 mm)	Medium (1 - 3 years)	Sexual	brood eggs	carried	Brooder
	Australonereis ehlersi	Large (> 20 mm)	Medium (1 - 3 years)	Sexual	brood eggs	carried	Pelagic-planktonic/Benthic
	Nephtys australiensis	Large (> 20 mm)	Long (3 - 10 years)	Sexual	shed eggs	pelagic	Pelagic-planktonic
	Boccordiella limincola	Large (> 20 mm)	Medium (1 - 3 years)	Sexual	brood eggs	carried	Pelagic-planktonic/Pelagic lecithotrophic
	Ficopomatus enigmaticus	Large (> 20 mm)	Long (3 - 10 years)	Sexual	shed eggs	pelagic	Pelagic-planktonic
Mollusca	*Arthritica helmsi*	Small (0.5 - 5 mm)	Medium (1 - 3 years)	Sexual	brood eggs	carried	Benthic/Brooder
	Spisula (Notospisula) trigonella	Large (> 20 mm)	Long (3 - 10 years)	Sexual	shed eggs	pelagic	Pelagic-planktonic
	Soletellina alba	Large (> 20 mm)	Medium to Long	Sexual	shed eggs	pelagic	Pelagic-planktonic
	Hydrobiidae (6 spp.)	Small (0.5 - 5 mm)	Medium (1 - 3 years)	Sexual	shed eggs	benthic	Pelagic-planktonic/Benthic
	Salinator fragilis	Medium (5 - 20 mm)	Short to Long	Encapsulation	gelatinous mass	benthic	Pelagic-planktonic
Crustacea	Ostracoda	Small (0.5 - 5 mm)	Short (< 1 year)	Sexual	brood eggs	carried	Pelagic-planktonic/Benthic
	Amphipoda	Small (0.5 - 5 mm)	Short to Medium	Sexual	brood eggs	carried	Brooder
	Paragrapsus gaimardii	Medium (5 - 20 mm)	Medium to Long	Sexual	brood eggs	carried	Pelagic-planktonic
Hexapoda	Chironomidae (larvae + pupae)	Small (0.5 - 5 mm)	Short (< 1 year)	Encapsulation	gelatinous mass	benthic	Pelagic-planktonic/Benthic

b) Taxa roles and environmental preferences

Taxa		Role in the environment				Environmental tolerances	
		Feeding Habit	Living Habit	Environmental position	Sediment Movement	Salinity	Sediment Grain Size
Annelida	Oligochaeta indet.	Grazer/Surface deposition	Burrow/Free-living	Shallow/Deep	Surficial modifier	Oligohaline	Fine sand (125 - 250 µm)
	Capitella species complex (*C. capitata*)	Surface/Sub-surface deposition/Predator	Burrow-dwelling	Shallow (< 3 cm)/Bentho-pelagic	Surficial modifier	Polyhaline - Hyperhaline	Fine sand (125 - 250 µm)
	Phyllodoce novaehollandiae	Scavenger/Predator	Free-living	Shallow (< 3 cm)	Surficial modifier	Polyhaline - Euhaline	Fine to Medium sand (125 - 500 µm)
	Simplisetia aequisetis	Surface deposition/Predator	Burrow-dwelling	Deep (> 3 cm)	Bio-irragator (deep mixing)	Oligohaline	Fine sand (125 - 250 µm)
	Australonereis ehlersi	Sub-surface deposition/Predator	Burrow-dwelling	Deep (> 3 cm)	Bio-irragator (deep mixing)	Oligohaline - Mesohaline, Euhaline	Fine sand (125 - 250 µm)
	Nephtys australiensis	Sub-surface deposition/Predator	Burrow-dwelling	Deep (> 3 cm)	Bio-irragator (deep mixing)	Oligohaline	Fine sand (125 - 250 µm)
	Boccordiella limincola	Filter/Suspension/ Surface deposition	Free-living	Shallow (< 3 cm)	Surficial modifier	Oligohaline, Euhaline	Very fine - Fine sand (63 - 250 µm)
	Ficopomatus enigmaticus	Filter/Suspension	Tube dwelling	Shallow (< 3 cm)	No bio-turbation	Oligohaline - Mesohaline	Fine to Medium sand (125 - 500 µm)
Mollusca	*Arthritica helmsi*	Filter/Suspension	Burrow-dwelling	Deep (> 3 cm)	Surficial modifier/Bio-irrigator	Polyhaline - Euhaline	Very fine - Fine sand (63 - 250 µm)
	Spisula (Notospisula) trigonella	Filter/Suspension	Burrow-dwelling	Deep (> 3 cm)	Surficial modifier/Bio-irrigator	Polyhaline - Hyperhaline	Fine to Medium sand (125 - 500 µm)
	Soletellina alba	Filter/Suspension/ Surface deposition	Burrow-dwelling	Deep (> 3 cm)	Surficial modifier/Bio-irrigator	Polyhaline - Hyperhaline	Very fine - Fine sand (63 - 250 µm)
	Hydrobiidae (6 spp.)	Surface/Sub-surface deposition	Free-living	Shallow (< 3 cm)	Surficial modifier	Oligohaline - Polyhaline	Very fine - Fine sand (63 - 250 µm)
	Salinator fragilis	Surface deposition	Free-living	Shallow (< 3 cm)	Surficial modifier	Oligohaline, Polyhaline - Euhaline	Fine sand (125 - 250 µm)
Crustacea	Ostracoda	Grazer	Free-living	Bentho-pelagic	No bio-turbation	Oligohaline, Hyperhaline	Very fine - Medium (63 - 500 µm)
	Amphipoda	Filter/Suspension/ Surface deposition	Burrow/Free-living	Shallow (< 3 cm)/Bentho-pelagic	Surficial modifier	Oligohaline	Fine to Medium sand (125 - 500 µm)
	Paragrapsus gaimardii	Scavenger/Opportunist	Burrow/Free-living	Shallow/Deep	Surficial modifier/Bio-irrigator	Oligohaline - Mesohaline, Euhaline	Very fine - Fine sand (63 - 250 µm)
Hexapoda	Chironomidae (larvae + pupae)	Opportunist/Predator	Burrow/Free-living	Shallow (< 3 cm)/Bentho-pelagic	Surficial modifier	Oligohaline - Mesohaline	Fine to Medium sand (125 - 500 µm)

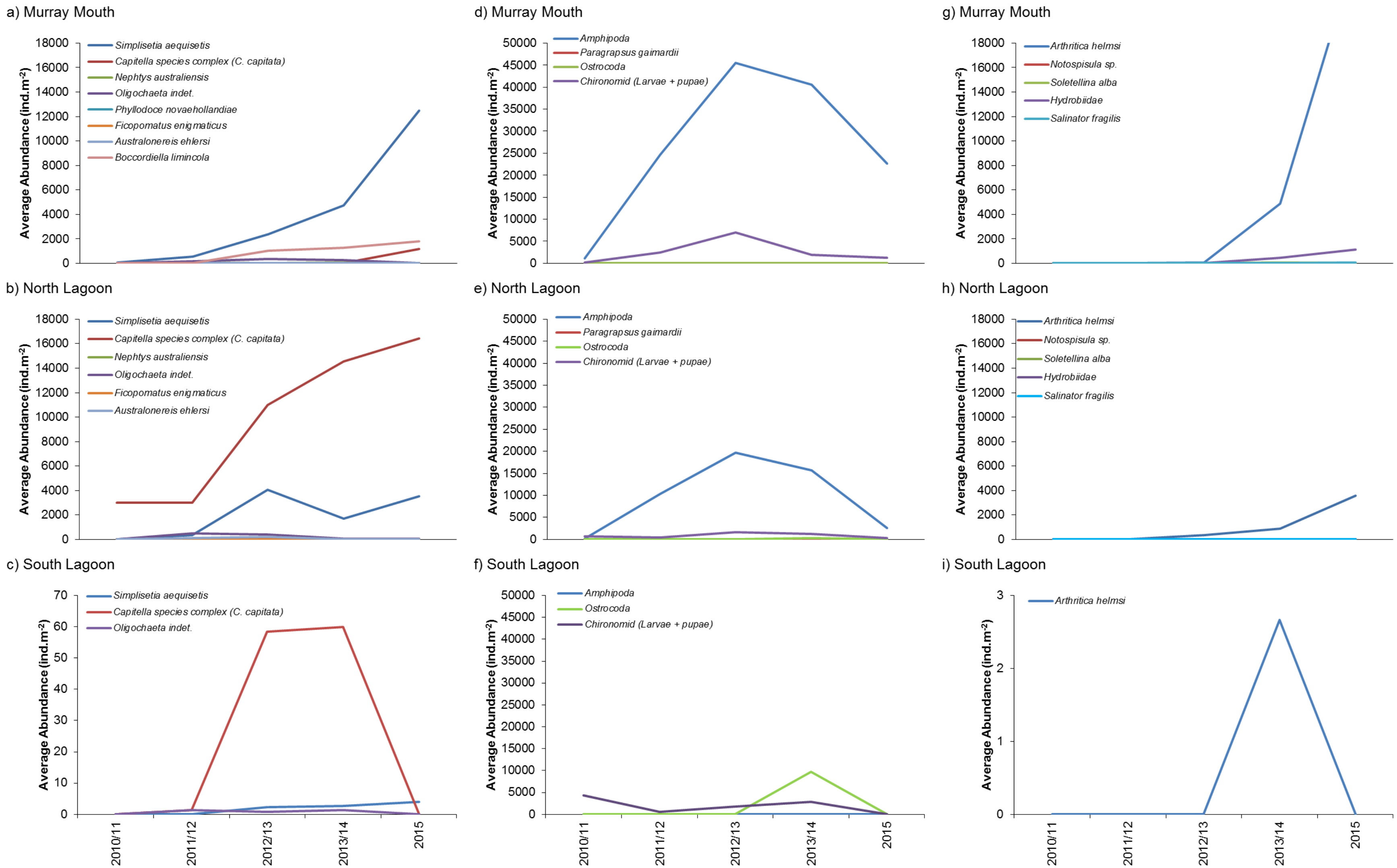


Figure A4.1: Taxa abundance over time for each region. The plots are arranged for Annelids (left hand column, plots a-c); Arthropods (middle column, plots d-f); and Molluscs (right-hand column, plots g-i). Note the difference in scale of the y-axes for plots in the South Lagoon

Table A4.4A: Historical communities for the Coorong from 1981 – 1985. Colour codes are used for ease of comparison to how these salinity ranges correspond to those observed for different community types during 2010 – 2015 monitoring (Part B).

	Historical communities (Geddes and Butler 1984; Geddes 1987)			
Taxa	Freshwater (0 - 2 ppt)	Estuarine (5 - 30 ppt)	Hypermarine (35 - 50 ppt)	Hypersaline (50+ ppt)
Simplisetia aequisetis	absent	abundant		
Australonereis ehlersi	rare	present		
Nephtys australiensis	absent	present		
Ficopomatus enigmaticus		abundant		
Capitella species complex (*C. capitata*)	absent		present	
Arthritica helmsi		present		
Spisula (Notospisula) trigonella	rare	present		
Hydrobiidae (6 species)		abundant	present	
Salinator fragilis	rare		present	
Ostracoda				present
Isopoda				present
Amphipoda		abundant	abundant	
Chironomidae (larvae + pupae)			present	present
Ephydridae (pupae)			present	present

Table A4.4B: Current communities defined for the Murray Mouth and Coorong from 2010 – 2015. Community types are approximately divided into Oligohaline (0.5 – 5 ppt), Mesohaline (5 – 18 ppt), Polyhaline (18 – 30 ppt), Euhaline (30 – 40 ppt) and Hyperhaline (> 40 ppt) salinity ranges as defined for estuaries by Whitefield *et al.* (2012). Colour coding represents how these community types correspond to historical communities observed in the Coorong Lagoons during the 1980s (Part A) and the new community type not previously observed termed Marine (salinity 30 – 35 ppt).

	Communities identified during LinkTREE and SIMPER analysis during 2010-2015 (see Table A3; Appendix 4.3: this report)															
	Oligohaline						Mesohaline				Polyhaline		Euhaline		Hyperhaline	
	Freshwater					Estuarine							Marine	Hypermarine		Hypersaline
Taxa	4	5	3	8	9	7	6	11	15	16	14	12	13	10	2	1
Simplisetia aequisetis	very rare	very rare	present	present	very rare	present		rare	present	abundant	rare	present	abundant	rare	very rare	
Australonereis ehlersi																
Nephtys australiensis						very rare	very rare									
Ficopomatus enigmaticus																
Capitella species complex (*C. capitata*)								rare				very rare	very rare	very rare	present	rare
Arthritica helmsi										abundant		very rare	present	very rare		
Spisula (Notospisula) trigonella																
Hydrobiidae (6 species)										very rare						
Salinator fragilis																
Ostracoda																
Isopoda																
Amphipoda	present	present	present	abundant	present	abundant	present	present	abundant	present	abundant	rare	present	present	rare	very rare
Chironomidae (larvae + pupae)	present	present	present	abundant	present	abundant	present	present	abundant	present	present	present	present	present	present	present
Ephydridae (pupae)																very rare

Table A4.5: Biological traits present in each region across the years from 2010 to 2015. Lighter shade colours indicate the first occurrence of particular traits. The following traits were not observed in macroinvertebrates and were removed from the table: medium size (5-20 mm); benthic and pelagic shed eggs; grazing, filter/suspension, scavenging and sub-surface deposition feeding habits; tube-dwelling living habits; pelagic (lecithotrophic) larval type; no bioturbation; mesohaline (5-18), polyhaline (18-30) and hyperhaline (>40) salinity preferences; and very fine sand (63-125) sediment affinity.

		2010/11			2011/12			2012/13			2013/14			2015		
Categories	**Traits**	**MM**	**NL**	**SL**	**MM**	**NL**	**SL**	**MM**	**NL**	**SL**	**MM**	**NL**	**SL**	**MM**	**NL**	**SL**
Size	Small (0.5-5 mm)															
	Large (>20 mm)															
Life span	<1 year															
	1-3 years															
Reproductive method (Sexual)	Encapsulation															
	Brood eggs															
Feeding habit	Surface deposition															
	Opportunist															
	Predator															
Living habit	Burrow dweller															
	Free living															
Larval type	Pelagic (planktonic)															
	Benthic															
	Brood															
Environmental position	Surface shallow (<3 cm)															
	Deep sediment (>3 cm)															
	Bentho-pelagic															
Sediment movement	Surficial modifier															
	Bio-irrigator (deep mix)															
Salinity preferred	Oligohaline (0-5)															
	Euhaline (30-40)															
Sediment affinity	Fine sand (125-250)															
	Medium sand (250-500)															
Similarity within region (%)		47	17	67	72	46	49	74	56	26	67	27	25	82	45	6

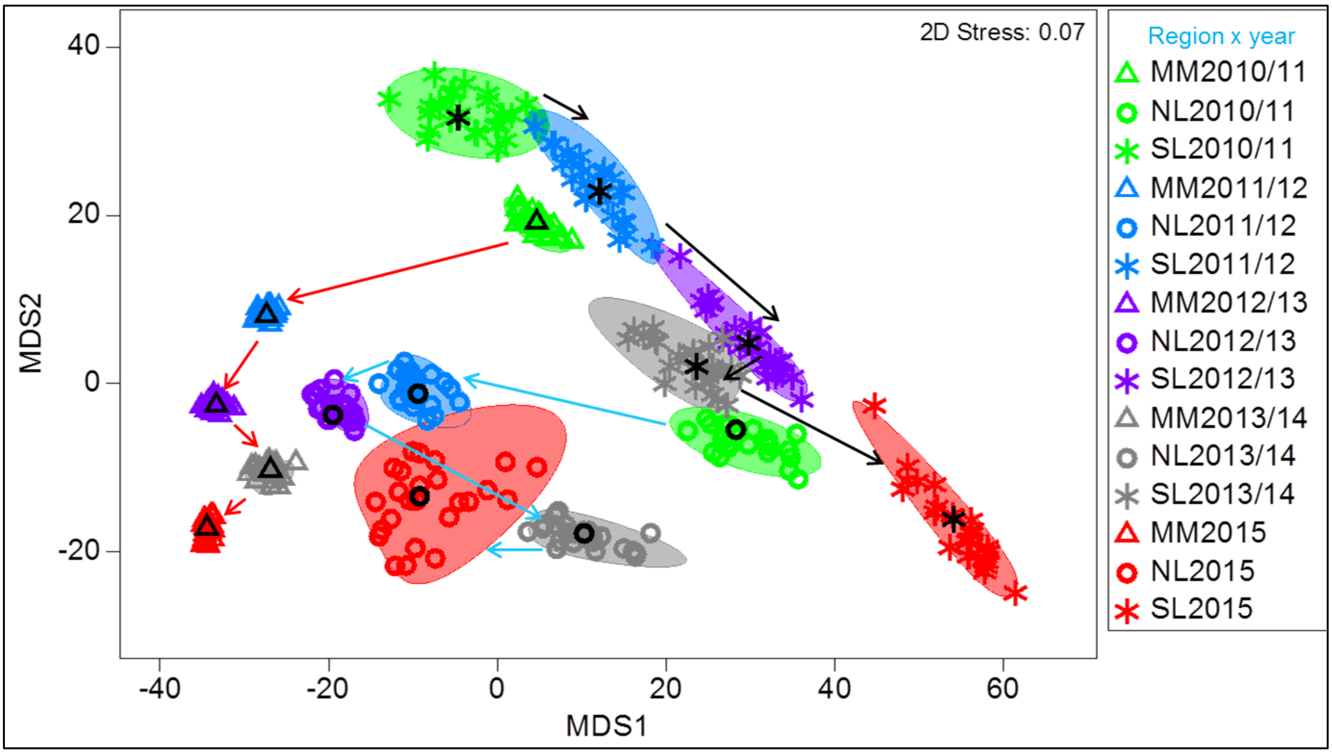


Figure A4.2: Bootstrap MDS of intertidal macrobenthic biological traits for the Murray Mouth (MM), North Lagoon (NL) and South Lagoon (SL) regions for the 2010-2015 sampling years.

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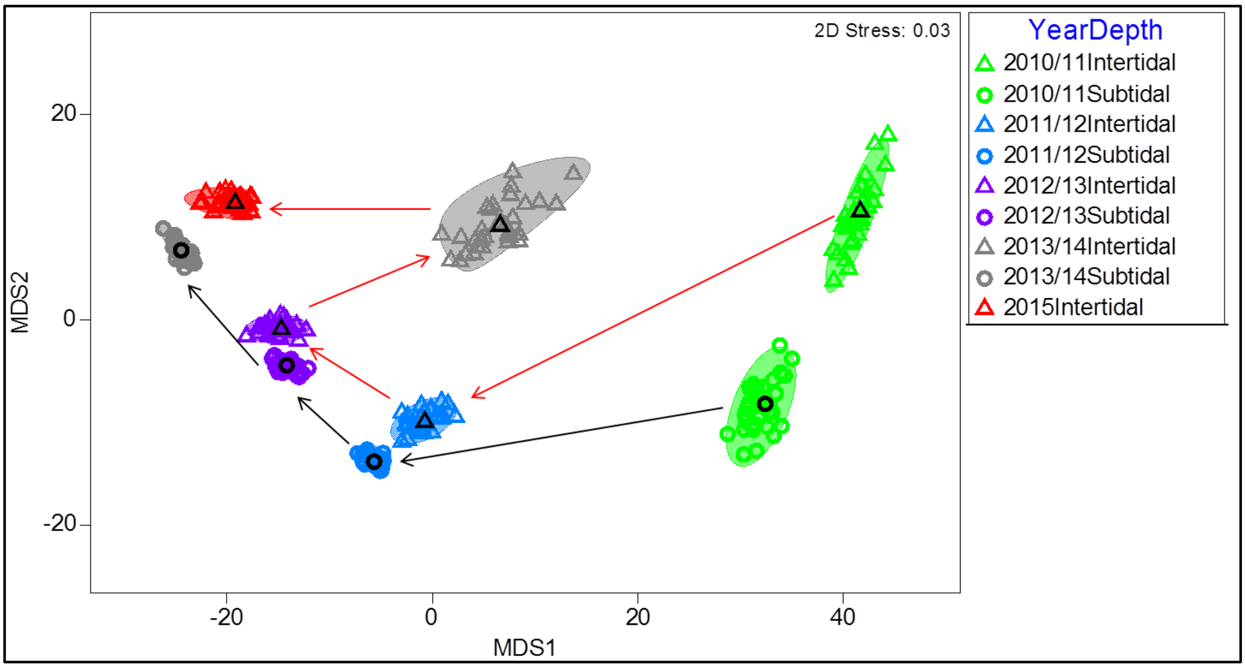
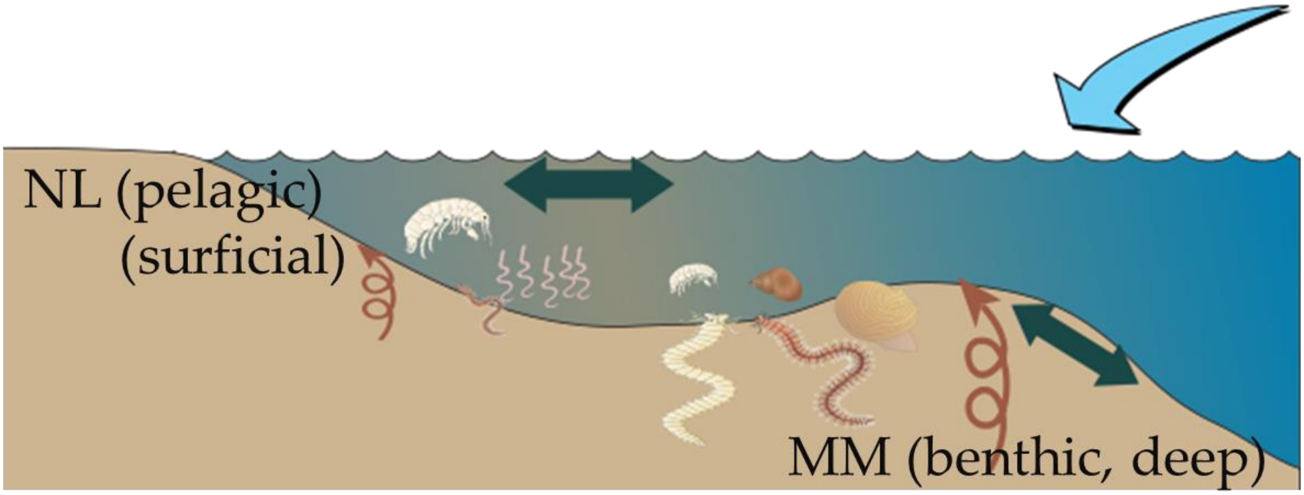


Figure A4.3: Bootstrap MDS of macrobenthic biological traits for the four sites that were sampled for intertidal and subtidal macrobenthos in the Murray Mouth and North Lagoon regions during the 2010-2015 sampling years.



NL		MM
shallow	**bioturbation**	deep
commencing	**Benthic-pelagic coupling**	increasing
simple	**Food web**	diversifying

Figure A4.4: Conceptual model of biological functioning determined from biological traits analysis of the macrobenthos in the Murray Mouth (MM) and North Lagoon (NL) during 2015. The ecological functions that are currently operating (2015) at the macrobenthic level for each region are displayed.

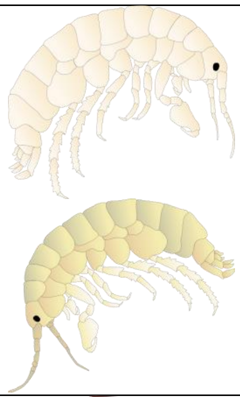
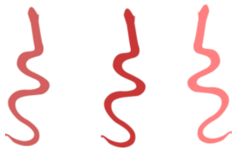
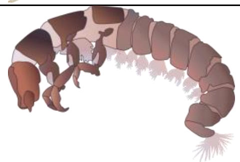
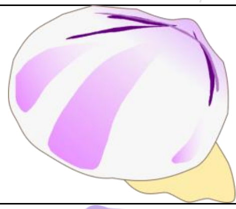
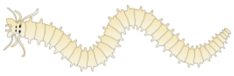
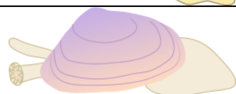
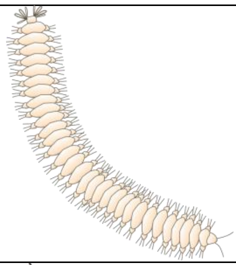
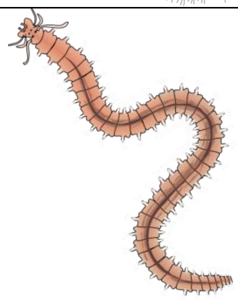
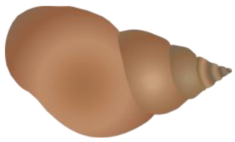
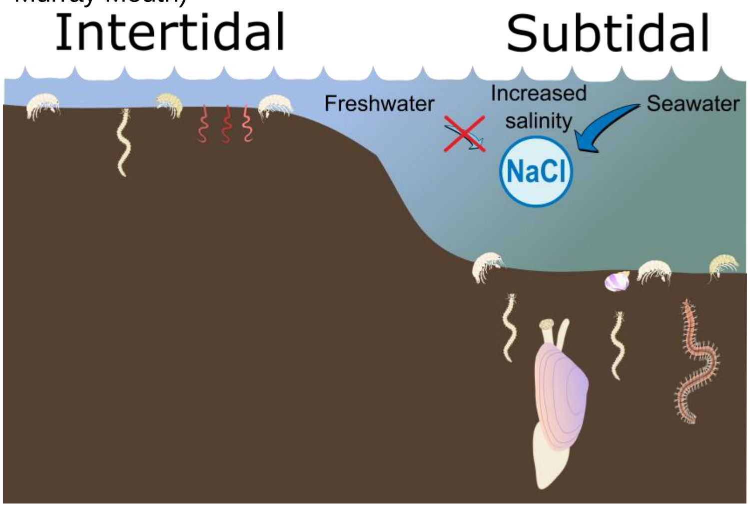
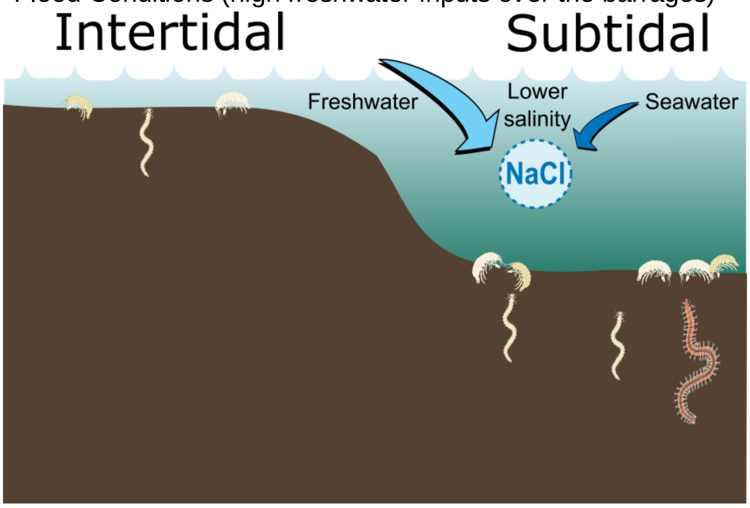
Oligochaeta		Amphipoda	
Capitella species complex		Insect larvae	
Boccardiella limnicola		*Arthritica helmsi*	
Simplisetia aequisetis		*Soletellina alba*	
Australonereis ehlersi		*Spisula trigonella*	
Nephtys australiensis		Hydrobiidae	

Figure A4.5: Key to species depicted in conceptual models for different scenarios of water release based on sampling of benthic macroinvertebrates from 2010 to 2015.

a) Drought Conditions (no freshwater input and limited exchange with ocean via Murray Mouth)



b) Flood Conditions (high freshwater inputs over the barrages)



c) Estuarine Conditions (continued freshwater inputs over the barrages and oceanic exchange via Murray Mouth)

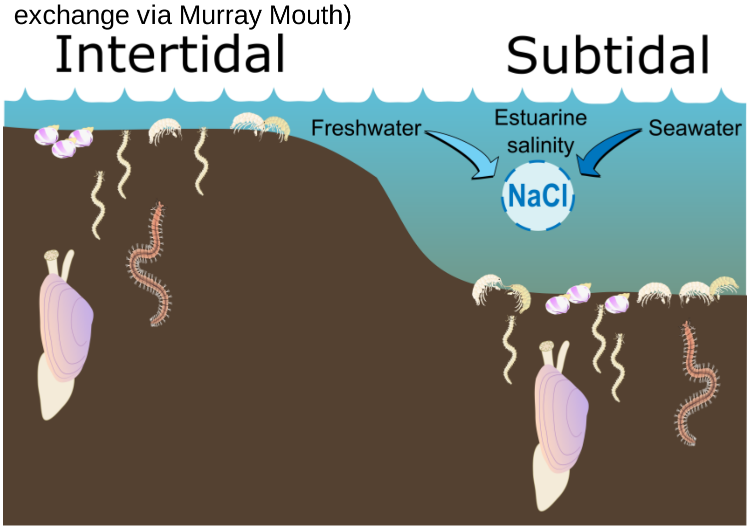


Figure A4.6:. Subtidal habitats as benign refugia for benthic macroinvertebrates during a) Drought; b) Flood; and c) Estuarine (hypothetical ideal) conditions.

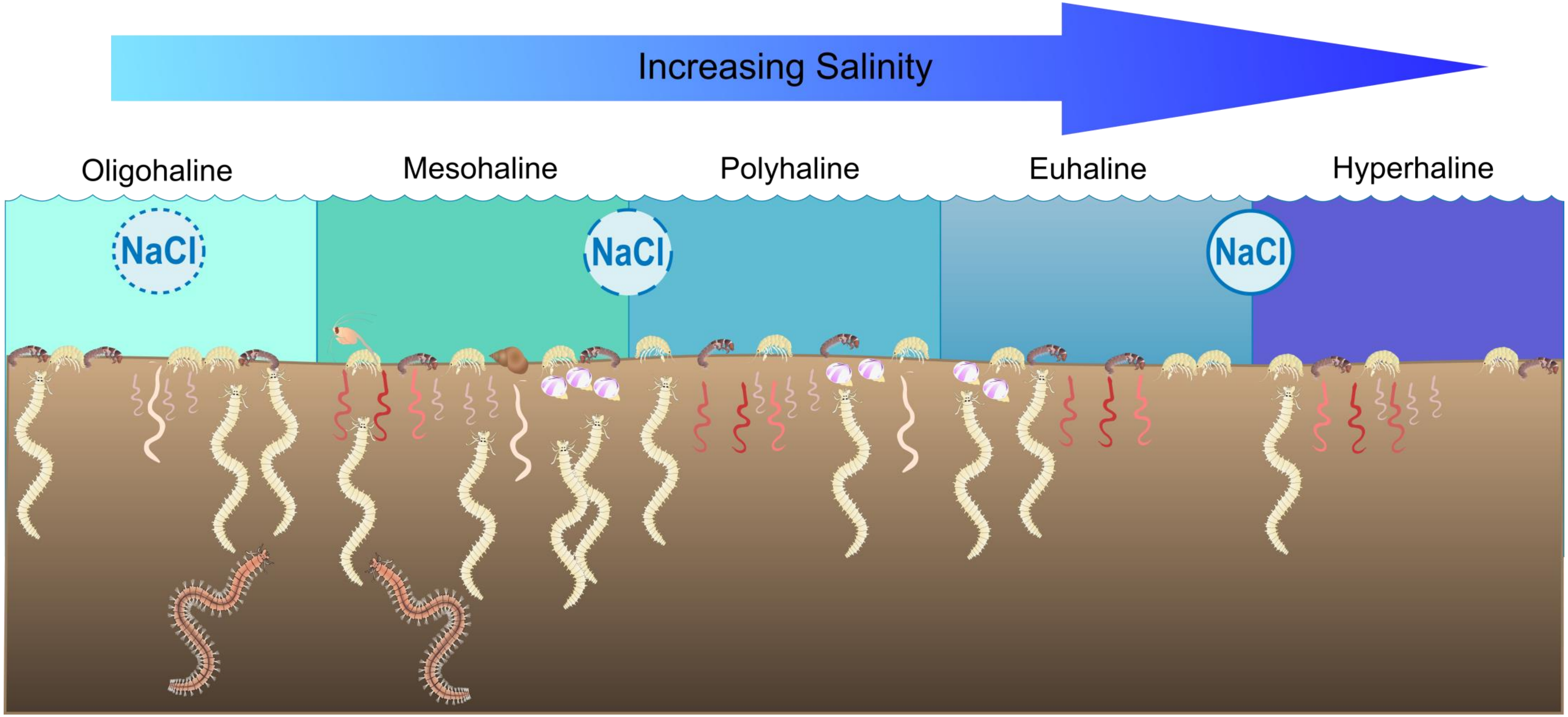


Figure A4.7: Conceptualisation of macroinvertebrate communities observed in the Murray Mouth and Coorong Lagoons under a range of salinity states observed in the system based on benthic monitoring from 2004 to 2015: Oligohaline (freshwater/low salinity; 0 – 6 ppt); Mesohaline (low salinity/estuarine; 6 – 16 ppt); Polyhaline (estuarine; 16 – 30 ppt); Euhaline (marine; 30 – 40 ppt); and Hyperhaline (high salinity; > 40 ppt). Based on data presented in Table 3.1, Annual Trends, this report. For a key to species see Appendix.

Capitella spp.

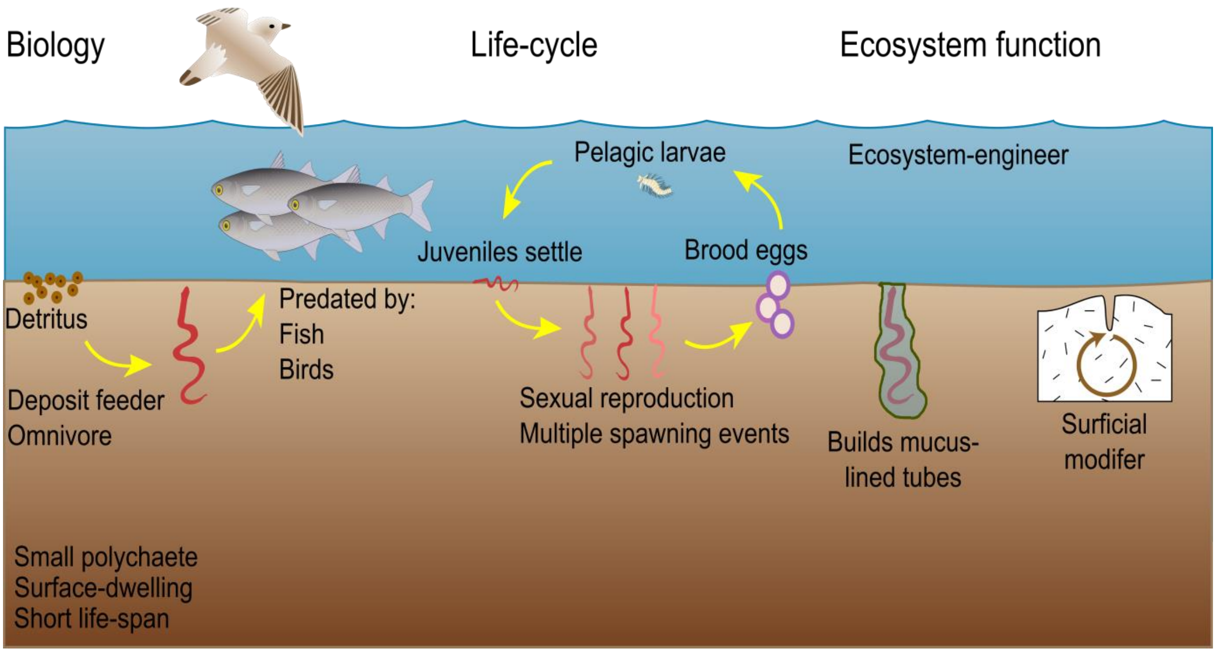


Figure A4.8: Biology, life-cycle and ecosystem function of the *Capitella* species complex

Simplisetia aequisetis

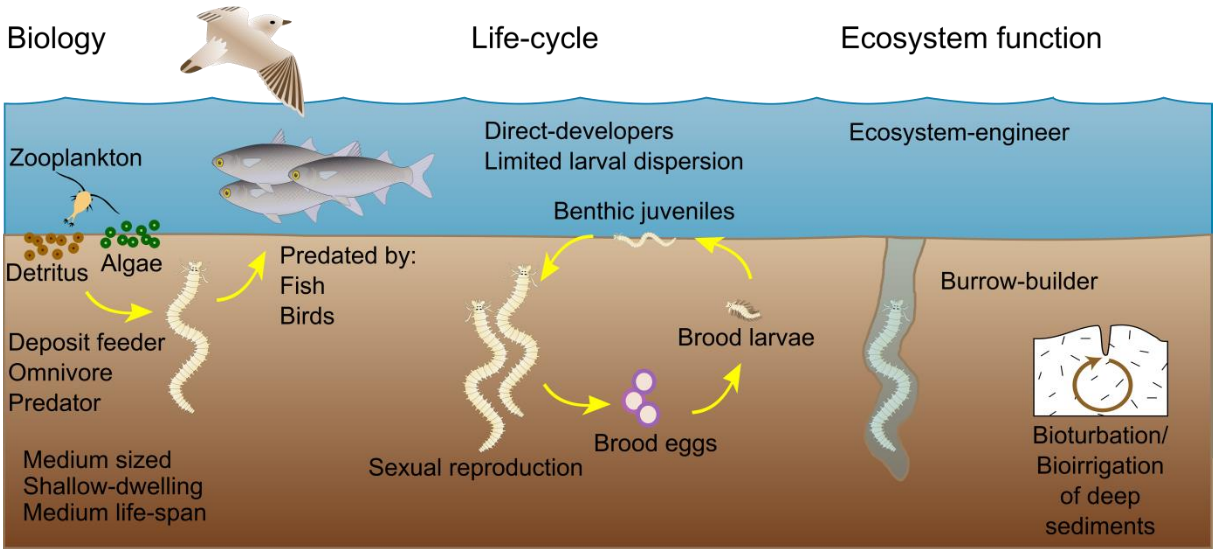


Figure A4.9: Biology, life-cycle and ecosystem function of *Simplisetia aequisetis*

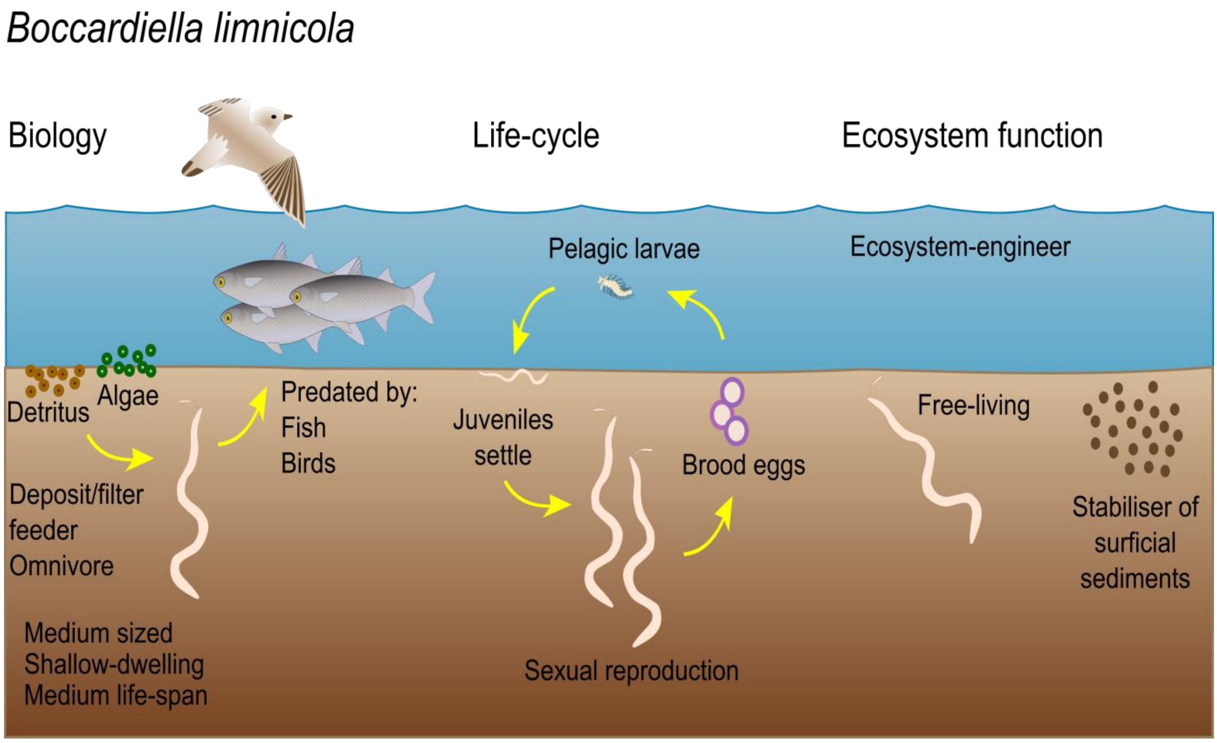


Figure A4.10:Biology, life-cycle and ecosystem function of *Boccardiella limnicola*

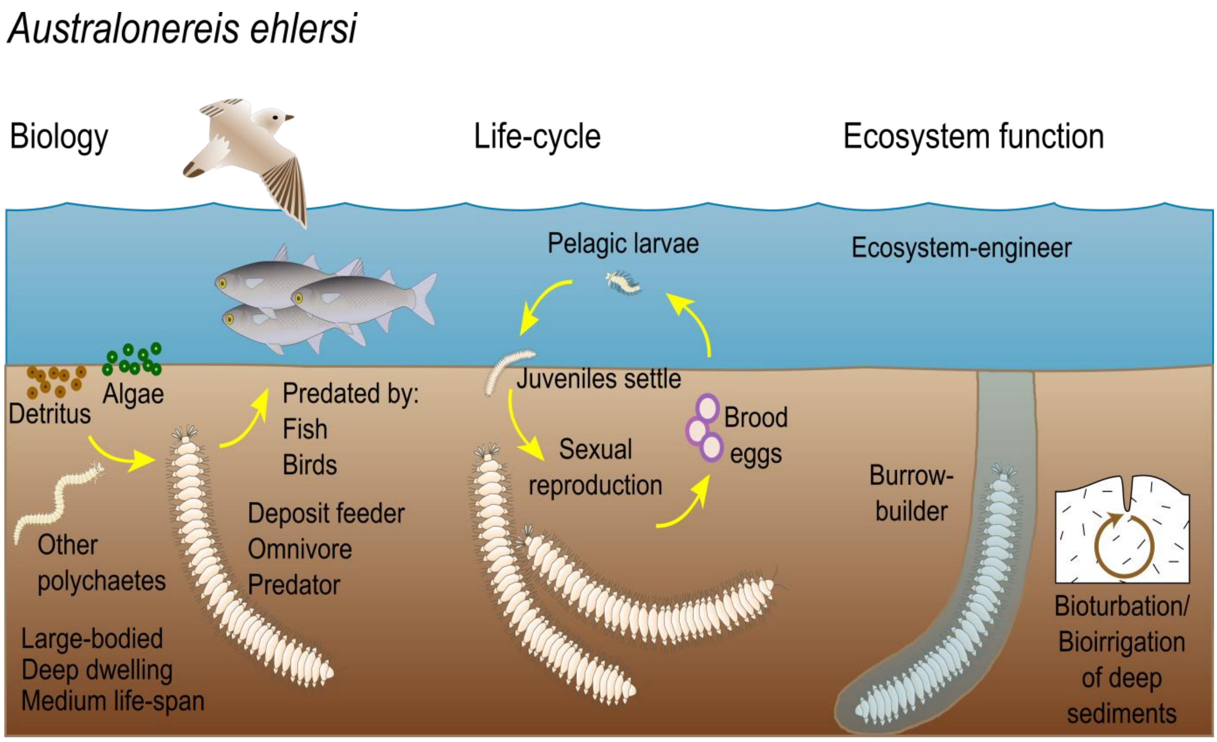


Figure A4.11: Biology, life-cycle and ecosystem function of *Australonereis ehlersi*

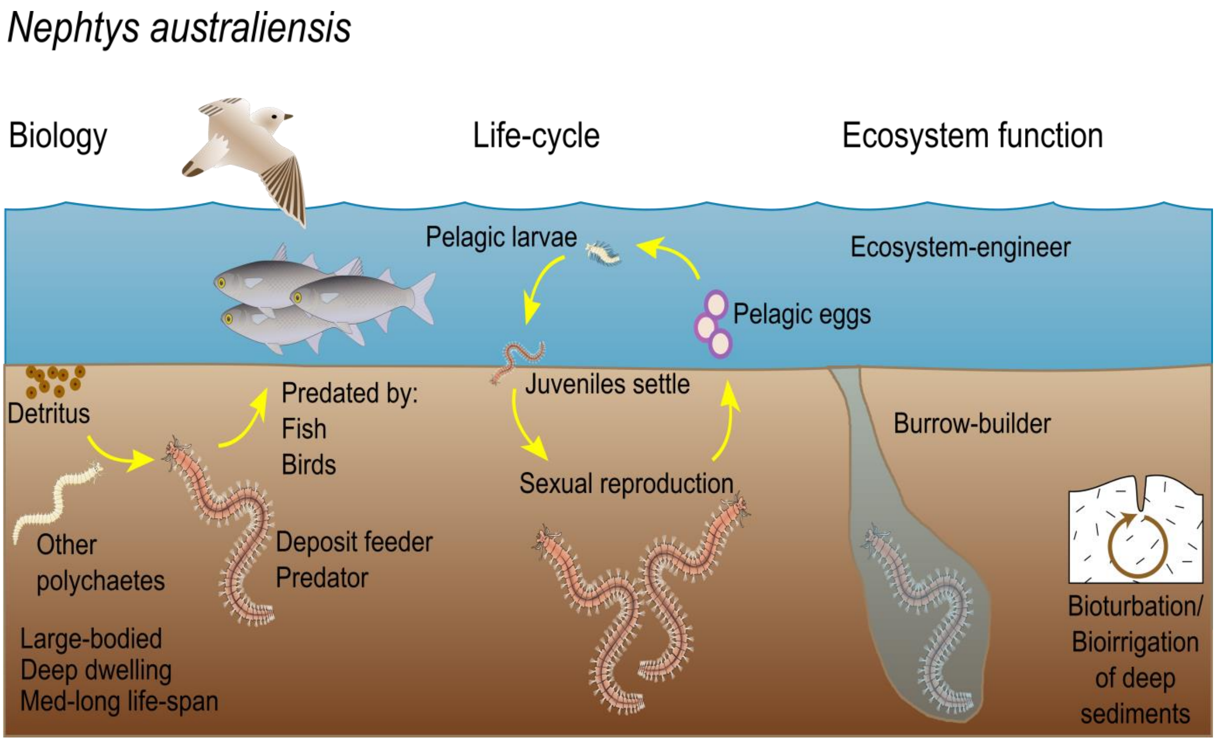


Figure A4.12: Biology, life-cycle and ecosystem function of *Nephtys australiensis*

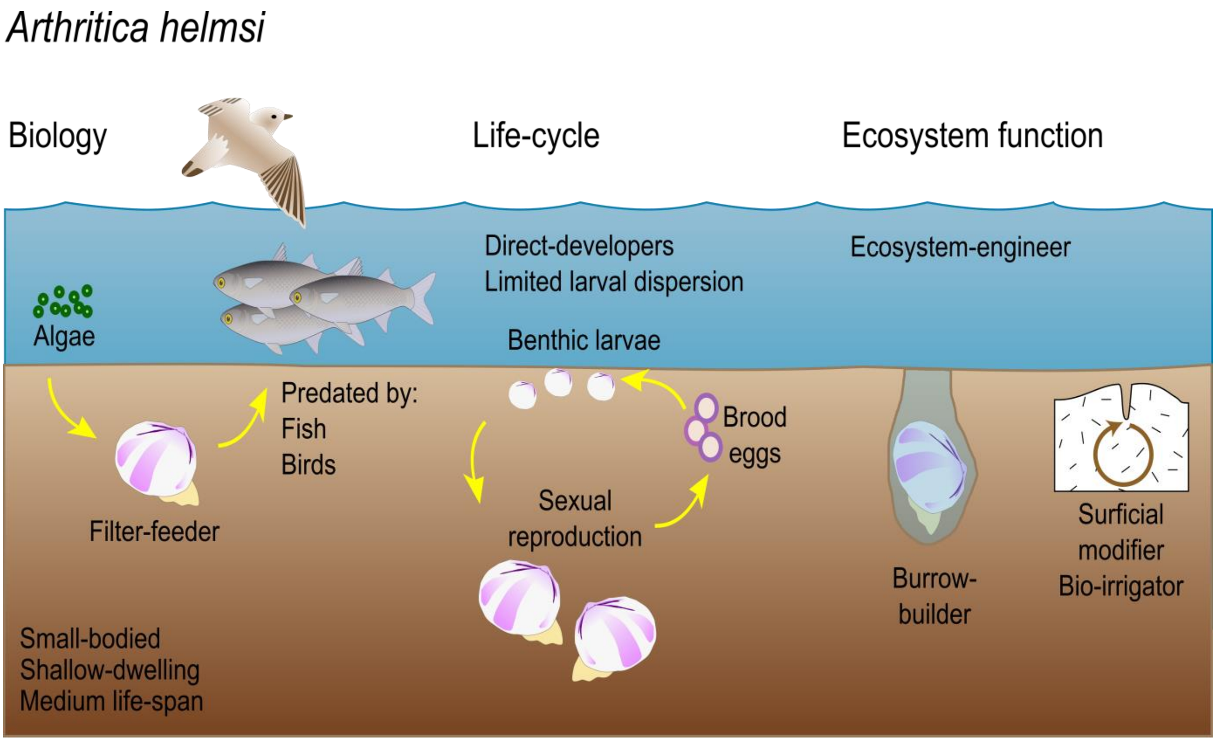


Figure A4.13: Biology, life-cycle and ecosystem function of *Arthritica helmsi*

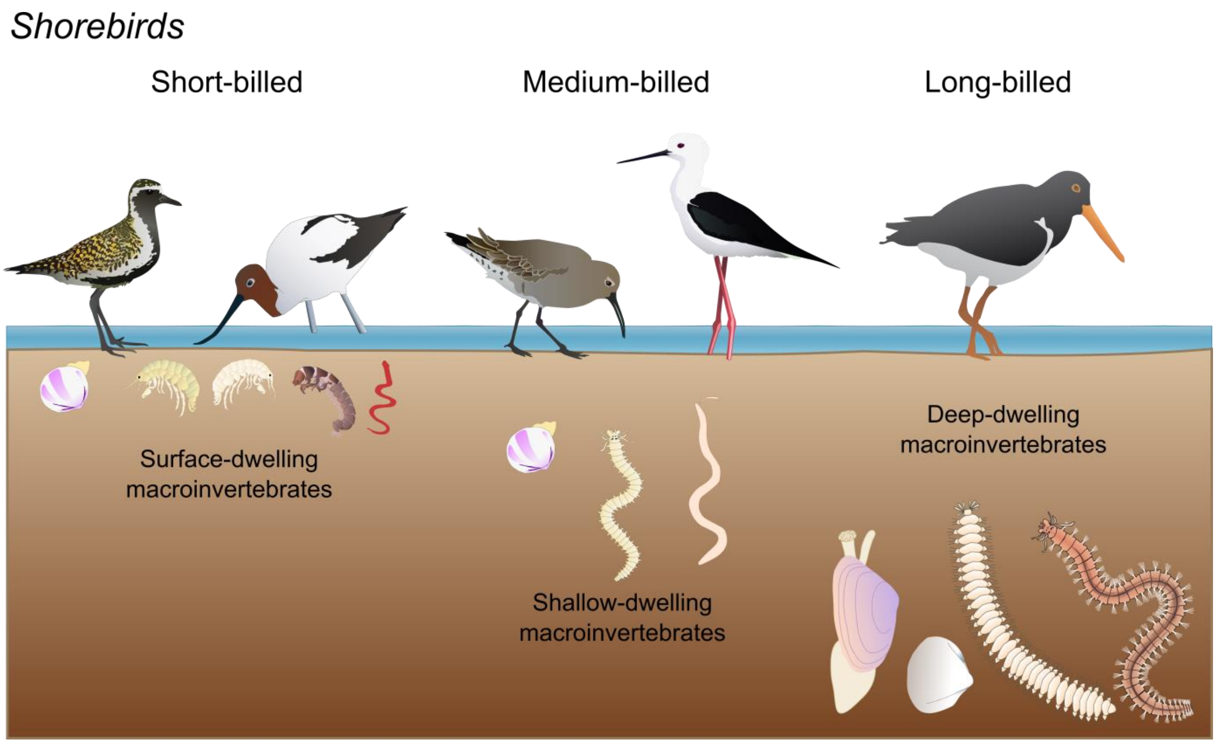


Figure A4.14: Macroinvertebrate prey typically foraged by different types of shorebirds based on shorebird bill length, which determines foraging depth in the sediment, and location of macroinvertebrate species within the substrate as typically surface, shallow (0-5 cm depth) and deep-dwelling (greater than 5 cm depth) species

A5: Change in Ecological Character

Table A5.1: Macroinvertebrate communities at sites throughout the Murray Mouth and Coorong at the time of Ramsar listing 1985 (Geddes 1987) and currently (2013/14 – 2015 monitoring events). Colours indicate approximate salinity conditions at the site (green: estuarine; blue: estuarine – marine; orange: marine to hyperhaline; and red: hyperhaline to extreme hyperhaline) based on Whitefield *et al.* (2012). Dashed lines are for sites that were not sampled for a particular survey. Salinity ranges for 1984-85 from Figure 1 in Geddes (1987). Salinity ranges for current conditions from LinkTREE analysis (see Figure A22; Appendix A.3; this report).

Time of Listing (1984 - 1985)		Polychaeta						Arthropoda					Mollusca				
Sites	Salinity Range (ppt)	*Ficopomatus enigmaticus*	*Capitella capitata*	*Nephtys australiensis*	*Boccardiella limnicola*	*Australonereis ehlersi*	*Simplisetia aequisetis*	Ampihpoda	Isopod	Ostracod	Decapoda	Insect Larvae (Diptera/Chironomidae)	*Arthritica helmsi*	*Spisula trigonella*	*Soletellina alba*	Hydrobiidae	*Salinator fragilis*
Monument Road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hunters Creek	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mundoo Channel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ewe Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pelican Point	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pelican Point Gate	10 - 30	**P**	**P***	**P***	P	P	**P***	**P**	X	X	P	P	**P**	**P**	P	**P**	P
Mark Point	10 - 30	**P**	**P**	**P**	P	P	**P**	**P**	X	X	P	P	**P**	**P**	P	**P**	P
Mulbin-Yerrok	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Long Point	10 - 30	**P**	**P**	**P**	P	P	**P***	**P**	X	X	P	P	**P**	**P**	P	**P**	P
Dodd Point	10 - 30	**P**	**P**	**P**	P	P	**P**	**P**	X	X	P	P	**P**	**P**	P	**P**	P
Noonameena	20 - 40																
Robs Point	30 - 50	P	P**	X	X	X	P	P	X	X	P	P**	P	P	X	P**	P**
The Needles	30 - 50	P	P**	X	X	X	P	P	X	X	X	P**	P	P	X	P	P
Parnka Point (NL)	50+	X	X	X	X	X	X	X	P	P	X	P	X	X	X	X	X
Parnka Point (SL)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Villa dei Yumpa	50+	X	X	X	X	X	X	X	P	P	X	P	X	X	X	X	X
Stony Well Island	50+	X	X	X	X	X	X	X	P	P	X	P	X	X	X	X	X
Woods Well	50+	X	X	X	X	X	X	X	P	P	X	P	X	X	X	X	X
Jacks Point	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Policeman Point	50+	X	X	X	X	X	X	X	P	P	X	P	X	X	X	X	X
Loop Road	50+	X	X	X	X	X	X	X	P	P	X	P	X	X	X	X	X
Bul Bul Basin	50+	X	X	X	X	X	X	X	P	P	X	P	X	X	X	X	X

Current (2013/14 - 15)		Polychaeta						Arthropoda					Mollusca				
Sites	Salinity Range (ppt)	*Ficopomatus enigmaticus*	*Capitella capitata*	*Nephtys australiensis*	*Boccardiella limnicola*	*Australonereis ehlersi*	*Simplisetia aequisetis*	Ampihpoda	Isopod	Ostracod	Decapoda	Insect Larvae (Diptera/Chironomidae)	*Arthritica helmsi*	*Spisula trigonella*	*Soletellina alba*	Hydrobiidae	*Salinator fragilis*
Monument Road	0.6 - 35	R	X	X	**P**	X	**P**	**P**	X	X	X	**P**	P	X	X	**P**	P
Hunters Creek	3 - 30	X	R	R	**P**	X	**P**	**P**	X	X	X	**P**	**P**	R	X	P	P
Mundoo Channel	12 - 16.5	X	X	X	**P**	X	**P**	**P**	X	X	X	**P**	**P**	X	X	**P**	R
Ewe Island	3 - 40	X	P	P	P	R	**P**	**P**	X	X	X	**P**	**P**	R	P	P	R
Pelican Point	3 - 30	X	R	X	P	X	**P**	**P**	X	X	X	P	**P**	X	X	P	R
Pelican Point Gate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mark Point	9.5 - 40	X	R	X	X	X	R	P	X	X	X	P	P	X	P	X	X
Mulbin-Yerrok	16 - 50	X	**P**	X	X	X	**P**	**P**	X	X	X	P	**P**	X	X	X	X
Long Point	25 - 35	X	**P**	X	X	X	**P**	P	X	X	X	R	P	X	X	X	X
Dodd Point	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Noonameena	40 - 50+	X	**P**	X	X	R	R	P	X	X	X	P	X	X	X	X	X
Robs Point	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
The Needles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parnka Point (NL)	50+	X	P	X	X	X	X	X	R	P	X	**P**	X	X	X	X	X
Parnka Point (SL)	50+	X	X	X	X	X	X	R	X	P	X	P	X	X	X	X	X
Villa dei Yumpa	50+	X	X	X	X	X	X	R	X	R	X	P	R	X	X	X	X
Stony Well Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Woods Well	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jacks Point	50+	X	R	X	X	X	R	R	X	X	X	P	X	X	X	X	X
Policeman Point	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Loop Road	50+	X	R	X	X	X	R	R	X	X	X	R	X	X	X	X	X
Bul Bul Basin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Key:

X	Absent	**P**	Abundant
R	Rare	**P***	Abundant when estuarine but absent when fresh
P	Present	P**	Present when salinity higher (> 50 ppt)

Table A5.2: Detailed macroinvertebrate species abundances (numbers are average individuals/m^2 for each site/sampling occasion) at each site sampled and each sampling occasion for the monitoring period 2013/14 – 2015. Zero abundances are highlighted by dark hatching. Groups identify community types from the LinkTREE(+SIMPER) analysis (see Annual Trends; this report) with their associated salinity ranges also listed (Salinity (ppt)). Colours have been used to highlight the different groups and correspond to those used in Figure A3.1.

Ave. Macroinvertebrate abundance (ind/m2)						Polychaeta							Arthropoda						Mollusca				
Region	Site	Year	Month	Group	Salinity (ppt)	*Ficopomatus enigmaticus*	*Capitella capitata*	*Nephtys australiensis*	*Boccordiella limincola*	*Australonereis ehlersi*	*Simplisetia aequisetis*	*Phylodoce novaehollandia*	Amphipoda	Isopoda	Ostrocoda	Decapoda	Chironomid (Larvae + pupae)	Ephydridae pupae	*Arthritica helmsi*	*Spisula trigonella*	*Soletellina alba*	Hydrobiidae	*Salinator fragilis*
MM	MR	2013/14	Dec	5	0.6 - 1				2172		7753		38286				2268					72	49
		2013/14	Feb	14	16 - 24				672		234		276				1224					1272	72
		2013/14	Mar	13	30 - 35	12			156		288		3				144					168	7
		2015	Feb	16	15 - 16.5				2964		13226		2763				2364		198			1128	24
	HC	2013/14	Dec	7	3 - 6				1584		5317		8897				3865		397			37	12
		2013/14	Feb	12	25 - 30			12	1464		4213		325				192		66	96		12	24
		2013/14	Mar	12	25 - 30		12		132		4369		379				55		4333			288	49
		2015	Feb	16	15 - 16.5				1284		7369		9974				852		15242			168	24
	MC	2013/14	Dec	15	12 - 15				138		8953		54825				9650		252			553	
		2015	Feb	16	15 - 16.5				3589		14354		51764				2424		46135			234	12
	EI	2013/14	Dec	7	3 - 6			18	7	37	1956		1337				6937		216		96	192	
		2013/14	Feb	13	30 - 35		37	49	18	12	5533		18				156		1224		7	12	24
		2013/14	Mar	10	35 - 40		156		12		475		264				49	24	445	12		24	
		2015	Feb	16	15 - 16.5		5893		276	37	1653		299				37		36690		7	1668	37
	PP	2013/14	Dec	7	3 - 6				876		9962		44575				493	12	589			168	
		2013/14	Feb	12	25 - 30		12		49		1668		24				24	12	84			12	12
		2013/14	Mar	12	25 - 30				49		2352		168				96		168			7	24
		2015	Feb	16	15 - 16.5				888		1166		1824				132		26752			397	
NL	MP	2013/14	Dec	11	9.5 - 10.5		12				49		96					996	144				
		2013/14	Feb	12	25 - 30													12	144				
		2013/14	Mar	10	35 - 40								24					168					
	MY	2013/14	Dec	14	16 - 24		4411				8413		115999				397		3325		7		
		2015	Feb	2	40 - 50		29777				9866		769						176				
	LP	2013/14	Dec	12	25 - 30		29849				5365		6529				12		397				
		2013/14	Feb	13	30 - 35		35454				3949		12						565				
		2013/14	Mar	13	30 - 35		7777				216		216						49				
	NM	2013/14	Dec	1	> 50		38634			156			228				1548	1236					
		2013/14	Feb	1	> 50		132											385					
		2013/14	Mar	2	40 - 50		198										12	984					
		2015	Feb	1	> 50		19575				672						18						
	PaPN	2013/14	Dec	1	> 50		4153							12	1524		6842						
		2015	Feb	1	> 50												78						
SL	PaPS	2013/14	Dec	1	> 50										52484		433	12					
		2013/14	Feb	1	> 50										16983		49						
		2013/14	Mar	1	> 50								12		12338		72	49					
	VdY	2013/14	Dec	1	> 50								24		192		24	3	24				
		2013/14	Feb	1	> 50												72						
		2013/14	Mar	1	> 50												12						
		2015	Feb	1	> 50												37						
	JP	2013/14	Dec	1	> 50		12				24		7				7	12					
		2015	Feb	1	> 50								12				24						
	LR	2013/14	Dec	1	> 50		12						24				24						
		2015	Feb	1	> 50						12												