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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

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July 2014

Report prepared for the Department of Environment, Water and Natural Resources, the Government of South Australia

THE UNIVERSITY of ADELAIDE

The Murray-Darling Freshwater Research Centre

Water for a Healthy Country Flagship Report series ISSN: 1835-095X

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Citation

Oliver, RL, Lorenz, Z, Nielsen, DL, and Shiel, RJ (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.

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Acknowledgments

This was a joint project between CSIRO Land and Water Flagship, the University of Adelaide and the Murray Darling Freshwater Research Centre. The support of DEWNR is gratefully acknowledged and especially the assistance from Ann Marie Jolley, Dr Liz Barnett and Paul McEvoy. Thanks also to Dr Luke Mosley and staff at the SA Environmental Protection Authority for providing the data from the monitoring programs.

This work was funded by the Department of Environment, Water and Natural Resources as part of the Coorong, Lower Lakes and Murray Mouth Program. Lower Lakes and Coorong Recovery is part of the South Australian Government's $610 million *Murray Futures* program funded by the Australian Government's $12.9 billion *Water for the Future* program.

Executive summary

The purpose of this study was to analyse the water quality, microalgae and zooplankton monitoring data collected from the Coorong, Lower Lakes and Murray Mouth region (CLLMM) in order to describe changes in environmental conditions across the system. A particular focus was on examining changes resulting from the Millennium Drought (2000 to 2010) as the monitoring data provided opportunities to compare pre-drought, drought and post-drought conditions. This enabled an assessment of the extent of the post-drought recovery.

The CLLMM region has undergone significant reductions in flow due to upstream reallocations of water with a detrimental impact on its ecology. This is a common problem for estuaries around the world and international efforts have been made to try and halt or reverse this decline through improved estuarine management. A key issue is the identification of appropriate environmental targets that could be used to formulate management strategies, assess the outcomes of management actions, and measure their benefits. Environmental sustainability is a broad goal commonly set for natural resource management but is poorly defined for most ecological systems. To set sustainability as a management target requires information on ecological responses to changing environmental conditions and identification of a persistent or frequently occurring core of community composition types that can be considered an appropriate state for the system. Monitoring programs are a critical source of information to identify these requirements.

Monitoring in the CLLMM has included water quality from the 1970's, microalgae from the 1980's and more recently zooplankton from 2010. Although some of these programs cover significant periods of time the monitoring has not always been carried out consistently or continuously. For example, there have been changes in sampling stations, measured parameters, analytical methods, cell enumeration techniques and taxonomic resolution. These problems fragement and undermine the value of data sets and require significant effort to address.

A preliminary requirement of the project was to collate the data sets for water quality, microalgae and zooplankton and standardise or rationalise nomenclature, locations, times and measurements. Coincident sets of water quality, microalgae and zooplankton were extracted from these data sets to enable statistical comparisons over space and time. Statistical analyses were undertaken using non-parametric, multivariate statistical techniques provided in the Primer 6 and PERMANOVA+ software packages (Anderson, Gorley & Clarke 2008).

The water quality parameters extracted from the monitoring data were Conductivity; oxides of Nitrogen (NOx as N); Total Kjeldahl Nitrogen (TKN as N); Total Nitrogen (TN as N); pH; Total Phosphorus (TP as P) and Turbidity. This standard set represents a balance between including a suite of relevant water quality parameters and maximising the length of periods available for analyses. In general the inclusion of more water quality parameters reduces the period of coincident data. If different time periods were chosen then the availability of parameters could increase or decrease. In fact there are many data combinations possible depending on the specific questions being addressed, but most were not explored.

Flow data utilised in the analyses were the Lock 1 daily discharge (Disch) and average five day Lock 1 discharge (Disch5) of the River Murray, and the daily flow (Barrage) and average five day flow (Barrage5) over the barrages between Lake Alexandrina and the Coorong.

The microalgae data was collated to genus while the zooplankton data was used as provided and had a mix of species and genus level classifications. Statistical analyses were carried out on the abundance data using all of the identified organisms.

The analyses for Lake Alexandrina demonstrated that water quality altered significantly between 2006/07 and 2009/10 during the drought, but returned to pre-drought conditions once flows re-established in 2010/11. Changes were associated with reductions in flow and increases in conductivity. Changes in TP, TN and turbidity also influenced water quality, but these effects were largely within the various drought periods. In contrast the microalgae communities shifted significantly during the drought but following the return of flows remained more similar to the drought communities and significantly different from the pre-drought communities. The zooplankton assemblages were dominated by freshwater River Murray taxa but monitoring of the zooplankton only occurred post-drought following the return of flows to the system.

The water quality in Lakes Alexandrina and Albert remained similar up until 2005/06 but then diverged and remained significantly different after that. Water quality in Lake Albert has not returned to pre-drought conditions. The differences in water quality were due to reduced flows and higher conductivities and TP and TN concentrations in Lake Albert. Microalgae in Lakes Alexandrina and Albert were similar up to 2007/08 but then diverged and remain significantly different. In Lake Albert the microalgae communities remain drought like and significantly different to pre-drought communities. Halotolerant zooplankton predominated in Lake Albert reflecting the increased salinity.

In the Goolwa Channel water quality changed significantly during the drought due to increases in conductivity, but post-drought it has returned to 2005/06 conditions and is similar to Lake Alexandrina. Although acidification occurred in parts of the Currency Creek and Finniss River sections of the Goolwa Channel due to the exposure of acid sulfate soils as water levels declined, no major influence of pH was observed in the broad analyses. Site specific analyses might provide further insights to these interactions. The microalgae community in the Goolwa channel differed significantly from that in Lake Alexandrina during the drought, but post-drought the two became similar, although neither has returned to pre-drought conditions. Zooplankton communities were highly diverse in the Goolwa Channel due to the influx of littoral and epiphytic microfauna from Currency Creek and the Finniss River.

Water quality in the Coorong changed significantly between years during the drought. It remains significantly different to the pre-drought conditions but appears to be moving back in that direction with the 2013/14 water quality conditions similar to those of 2005/06. Water quality changed significantly along the length of the Coorong with persistent differences between South Coorong, North Coorong and Murray Mouth locations. Longitudinal water quality differences were associated mainly with discharge and conductivity. Microalgae communities also showed persistent longitudinal differences between the South, North and Murray Mouth locations with a major shift in community composition south of Mark Point where a green alga dominated the highly saline environment. Zooplankton communities also showed persistent longitudinal differences between the South, North and Murray Mouth locations with obligate halophiles in the south grading to halotolerant species in the north. Some freshwater species also occurred in the north carried in by barrage flows.

Based on the microalgae data and some of the water quality data the system has not returned to conditions that prevailed prior to the Millenium Drought. It is recommended that monitoring be continued to ensure data is logged for future assessments of environmental condition. The analyses showed that flow had a major influence on water quality and biota and a more complete analysis of flow characteristics for statistical assessment is warranted. The statistical analyses have identified major periods of interaction and change that could be used to select suitably constrained data sets for applying modelling and statistical techniques to address specific questions. The statistical analyses could be extended to include other organisms if appropriate census data existed (eg. macroinvertebrates, fish) and inform on foodweb changes resulting from the environmental perturbations. Major shifts in microbiota, as observed following the onset of the drought, are expected to have major effects on the trophic connections of foodwebs and the capacity of the system to sustain higher trophic levels.

These analyses have demonstrated that despite the intermittent and inconsistent nature of the monitoring programs they provide valuable information that describes the changing characteristics of the CLLMM system, providing a basis that enables assessment of their status for management purposes. Further efforts to analyse the monitoring data are warranted as, compared with the data collection costs, the added return on improved system understanding makes the data analyses highly cost-effective.

1 Introduction

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region at the end of the Murray River in South Australia has significant economic, environmental and cultural values and these are recognized regionally, nationally and internationally. The environmental value of the area has been long established and it is designated as a Living Murray Icon site by the Murray Darling Basin Authority. Its international significance was confirmed in 1985 when the region was listed as a Ramsar *Wetland of International Importance*. The listing includes the Murray River inflow, Lake Alexandrina, Lake Albert, The Goolwa Channel and its associated creeks, the Murray Mouth, and the Coorong (Figure 1). The site supports a number of threatened species that are uniquely Australian including the Southern Bell Frog, Murray Cod, and Mount Lofty Ranges Southern Emu-wren, but perhaps most recognized is its importance as an area for waterbirds. At least 85 bird species have been recorded from the Ramsar site, 25 of which are listed under international migratory conservation agreements.

The geomorphology and hydrology of the region is complex and as a result a wide range of aquatic habitats are supported. The Murray River flows into the eastern side of Lake Alexandrina and out to the ocean through the Murray Mouth Estuary (Figure 1). Lake Albert is a terminal lake connected to Lake Alexandrina, its primary source of water, by a narrow channel. The Coorong is a long, shallow, brackish to hypersaline lagoon more than 100 km in length that is connected to the southern end of the Murray Mouth Estuary and separated from the Southern Ocean by a narrow sand dune peninsula. The Coorong and Murray Mouth Estuary were disconnected from the Lakes and the Murray River by a series of barrages built in the 1930's to stop the movement of saline water upstream. The hydrological conditions of the Lower Lakes are substantially managed through the regulation of inflows from the river and outflows through the barrages. Conditions within the Coorong are influenced by the relative volumes of freshwater flows through the barrages from the lakes and oceanic exchanges through the Murray Mouth. Under conditions of low barrage releases the southern end of the Coorong can become hypersaline through evapoconcentration of the seawater source. High flows through the barrages result in the slow transport of freshwater down through the Coorong reducing the salinity gradient.

The aquatic ecosystems within the region are dependent on the Murray River which is the major source of water supply. Flows in the Murray River are highly regulated with water delivery tightly controlled in all cases except for major floods. Over the last few decades there have been substantial increases in upstream allocations of water for consumptive uses and as a result the supply of water to the CLLMM has decreased. Not only has the total volume of water declined but also the characteristic flow patterns that influence the water quality and biota of the interconnected lake and estuary system have been altered. This situation was exacerbated by the Millennium Drought that impacted the southern parts of Australia between 2000 and 2010. This long and severe drought caused significant reductions in stored water resources and allocations were significantly reduced to all water users, including for consumptive and environmental needs. Environments and industries throughout the Murray-Darling Basin were severely impacted by the reduced water availability, but for the CLLMM region at the end of the river system the impact was extreme, with inflows reduced to minimal levels from 2002 and barrage outflows stopped for long periods (Figure 2). As a result of the reduced inflows and high evaporation rates, water levels in the lakes fell to record lows, resulting in increased conductivity due to concentration of salts, and acidification in exposed wetlands as water levels receded. Large areas of the lake floor were exposed. Due to the lack of flows over the barrages an intense salinity gradient was formed in the Coorong with salt concentrations in the Southern Coorong six times that of seawater (Brookes *et al.* 2009).

Estuaries worldwide suffer from engineered droughts as a result of river regulation and environmentally unsustainable water allocations, and from increased loads of materials including nutrients, sediments and pollutants from catchment disturbance and agricultural and urban intensification (Montagna et al 2002; Duarte et al 2013). Widespread deterioration of estuaries and coastal ecosystems has led to international efforts for their recovery and restoration. In many cases the difficulty is to specify recovery targets, to

Figure 1 Major locations within the Coorong, Lower Lakes and Murray Mouth region.

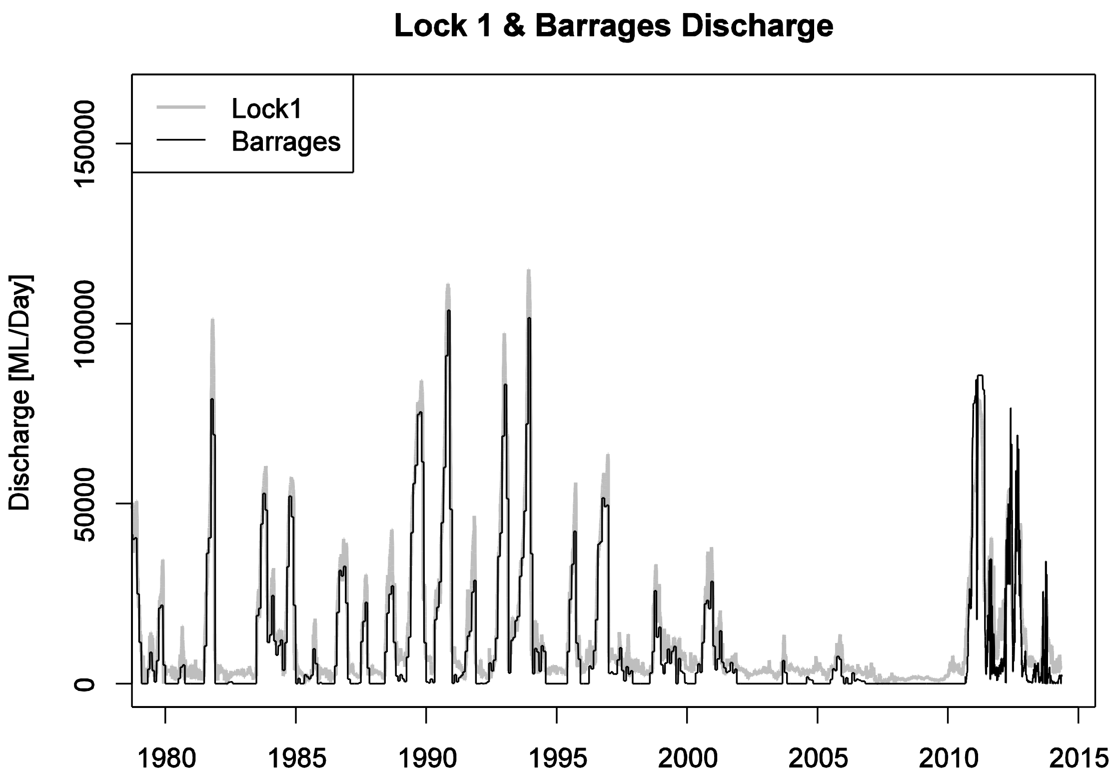


Figure 2 Discharge at Lock 1 (data SA Water) and flow over the barrages in Lake Alexandrina (data DEWNR).

define metrics for assessing recovery, and to develop management strategies that will achieve the targeted outcomes (Montagna et al 2002; Duarte et al 2013).

Previous studies that have described the responses of microalgae to changing flows within Lake Alexandrina have been based on limited sets of data. Based on this data the general patterns of occurrence of microalgae were reviewed by Aldridge et al. (2010). Although mixed communities of microalgae occur in the Lakes, particular groups are more likely to be dominant under certain conditions. In Lake Alexandrina from 1975 to 1978 a filamentous green alga (*Planctonema lauterbornii*) accounted for more than 95% of microalgal cells (Geddes 1988, Baker 2000) and was associated with high flows. In contrast, blooms of cyanobacteria (*Nodularia spumigena*, *Anabaena* spp. and *Aphanizomenon* spp.) occurred regularly in Lake Alexandrina and Lake Albert between 1990 and 1995 and were associated with extended periods of low flow (Aldridge et al 2010). Towards the end of the Millennium Drought in 2008/09, when river inflows were minimal and lake depths had fallen to unprecedented levels, both Lakes Alexandrina and Albert regularly experienced blooms of picocyanobacteria, notably *Aphanocapsa* spp, *Planktolyngbya* spp., *Aphanizomenon* spp. and *Pseudanabaena* spp. (Aldridge et al 2010). It was also during the extended drought period that the first recorded bloom of the cyanobacterium *Cylindrospermopsis raciborskii* occurred in the Lower Lakes in 2006 (Cook *et al*. 2008). Although the data available for each of these analyses was limited, it clearly demonstrates a strong influence of river flows on the types of microalgae that predominate within the Lower Lakes.

The importance of River Murray inflows to the microalgae community of the Coorong is largely due to barrage outflows and their impacts on hydrodynamic conditions and salinity levels, but there is also direct transport of freshwater microalgae species from the Lower Lakes. During periods of low or no flow over the barrages, often associated with reduced river inflows to the lakes, the microalgae of the Coorong are dominated by estuarine and marine species of diatoms and flagellates (Geddes and Butler 1984; Geddes 1987). During a period of prolonged barrage closure in 2004-2005, when the Coorong was operating as a marine coastal lagoon, two marine diatoms (*Chaetoceros* and *Asterionella),* made up 90% of the total cell number (Geddes and Francis 2008) and no freshwater species were observed (Geddes and Tanner 2007). Under these conditions a significant salinity gradient developed along the lagoon and salt tolerant halophytic species appeared, often dominated by high concentrations of green algae of the genus *Nannochloris,* particularly in the southern sites where cell numbers were in excess of 1million cells mL^{-1} (Geddes and Tanner 2007). During a period of high flow from the River Murray (1983-1984) the dominant microalgae at sites closest to the barrages were freshwater varities, presumably transported in the water from Lake Alexandrina, but as flows slowed, marine diatoms and flagellates became dominant again (Geddes 1987; 2005).

The zooplankton communities within the CLLMM region have been far less studied than the microalgae and there are currently few overviews of their community types, distributions or dynamics. Reports by Geddes (eg. 1984; 2005) and Shiel (eg. 2010) provide the current knowledge.

In order to manage these ecosystems it is necessary to distinguish patterns of responses to environmental changes that can provide a basis for the setting of management targets. The connections driving these patterns then provide the means by which these targets can be achieved. In this project a statistical approach was used to identify patterns of responses in nutrients, microalgae and zooplankton to flow and other environmental conditions that could underpin the future development of management targets and strategies (Table 1).

Table 1 Monitoring objectives and the hypotheses and key questions for consideration in the analyses of the Coorong and Lower Lakes water quality, microalgae and zooplankton monitoring data.

Monitoring Objective	Key Questions	Hypotheses
To assess the response of microalgae, nutrients and zooplankton to: The increased water flows following the recent drought. Different flow scenarios were possible (Low, med and high) • Pre-drought < 2007 years • Drought 2007 to late 2010 years • Post Drought - late 2010 onwards	1. How do nutrients and other materials respond to the different flow conditions including non-flow periods? - Concentrations and distributions 2. How do microalgal communities (analysis abundance) respond to different flow conditions including non-flow periods? - Cell concentrations and distributions - Shifts in community composition 3. How do zooplankton communities (analysis abundance) respond to different flow conditions? - Shifts/similarities in community composition - How do the 2013/14 zooplankton communities compare to previous monitoring - Is monthly monitoring frequent enough to determine changes in zooplankton communities related to environmental conditions (i.e. changes in flow) 4. Following on from the 2012-13 analyses do the water quality data demonstrate: - there is increased similarity in water quality to conditions that were present prior to the drought? - interactions between components e.g. salinity and turbidity, turbidity and nutrients, etc? 5. Are there interactions between flow, water quality, microalgae, nutrients and zooplankton that are described by the data? 6. Are the interactions between water quality, microalgae, nutrients and zooplankton expected to influence other trophic levels? 7. What drives the lag in trophic level recovery (water quality > microalgae > zooplankton)? 8. What are the range of conditions that are sufficiently similar, or occur sufficiently often, to create an environment that sustains the characteristics of the ecosystem?	It is hypothesised that: 1. In the Lower Lakes, in response to changing flow conditions (river inflow and barrage releases) 2. In the Lower Lakes in response to changing water levels. 3. In the Coorong In response to changing flow conditions (barrage releases and ocean exchange) there will be consistent seasonal, annual or long term patterns (all monitoring sites) in: • the concentrations and distributions of water quality attributes • the concentrations and community composition micro-algae • the concentrations and community composition of zooplankton. 4. A lag will continue to be seen in trophic level recovery (water quality > microalgae > zooplankton).

2 Methods

2.1 Data sets

2.1.1 GENERAL DESCRIPTION

Since the late 1970's there has been a number of sequential monitoring programs operating across the Lakes and Coorong measuring water quality parameters and microalgae. These programs have often used different sampling sites, measured different water quality and biotic parameters, and taken measurements at different times of the year and at different frequencies. Consequently the large and valuable data set recording the water quality history of the region is fragmented, making statistical analyses difficult and reducing its usefulness for assessing changes through time. More recently zooplankton sampling has been undertaken to complement the monitoring program, this commenced in late 2010 but did not always align with other monitoring programs until late 2012. Examples of the different patterns of sampling are given in Appendix A.

In a previous report the need for substantial checking and correcting of inconsistencies in the monitoring data was described (Oliver et al 2013). Problems of inconsistencies often arise in large natural resource databases that contain a wide range of data types collected over extensive spatial areas for prolonged periods of time. Invariably there are changes in names and acronyms for measured parameters, in the identification of organisms and in their taxonomy, as well as changes in sampling sites and locations. Substantial time was required to prepare and collate the data into a consistent and reliable form suitable for statistical analyses.

The analyses in this report differ from those in the Oliver et al (2013) report in a number of ways. One major difference is that the analyses of the biotic components are based on abundances rather than presence/absence data as in the first report. Also the analyses in this report are based on financial years that properly encompass a spring-summer-autumn growing season, unlike in the previous report where calendar years were used that combined the end of one growing season with the start of the next. This is important where preceding conditions may influence the biotic outcomes, for example, microalgae community responses in spring may influence the communities that follow in autumn. These changes are expected to improve the assessment of interactions between biotic and environmental attributes. In addition this report includes the Goolwa Channel, a location that was not previously considered, undertakes more detailed analyses of the zooplankton, and extends the analyses to include the recent 2013/14 monitoring season.

2.1.2 STATISTICAL ANALYSES

All analyses were undertaken using the methods within the statistical program Primer 6 and PERMANOVA+ (Anderson, Gorley & Clarke 2008). Patterns in microalgae and zooplankton community composition were displayed using non-metric multi-dimensional scaling (nMDS) and unless otherwise stated these were derived from a Bray-Curtis similarity matrix based on abundance data that was square root transformed in the case of microalgae, or fourth root transformed in the case of zooplankton.

Environmental and water quality parameters were treated in an analogous way to the microalgae and zooplankton except that the measurements were transformed using log(1+x) where necessary, then normalised and Euclidean distance used as the resemblance measure with patterns in water quality displayed using Principal Components Analysis (PCA).

PERMANOVA (a multivariate equivalent of ANOVA) was used to test if there were significant differences between data sets that were selected *a priori* (e.g. years). To gain the appropriate amount of replication for the analyses, samples collected within a given season were considered replicates, both within years and across years. In recognition that microalgae and zooplankton change in response to seasonal changes in the environment, data was averaged by season within financial year.

These types of non-parametric statistical analyses explore the similarity of community composition or sets of water quality parameters across locations and time. Plots of the nMDS and PCA results are in general easily interpreted in that points that are closer together are more similar to each other while points increasingly further apart are more dissimilar. The caveat to this is that multivariate data is being displayed on a two dimensional plot and at times this is not easily achieved, so the plots do not always clearly indicate the significance of differences between points. This is determined directly from the data using a PERMANOVA test. Throughout the text PERMANOVA results are reported as significant or not, but for simplicity the tables and significance values have not been included, rather the standard has been adopted that results reported as significant are so at least at the 5% significance level.

2.1.3 STANDARDISING SAMPLING SITES AND MICROALGAE

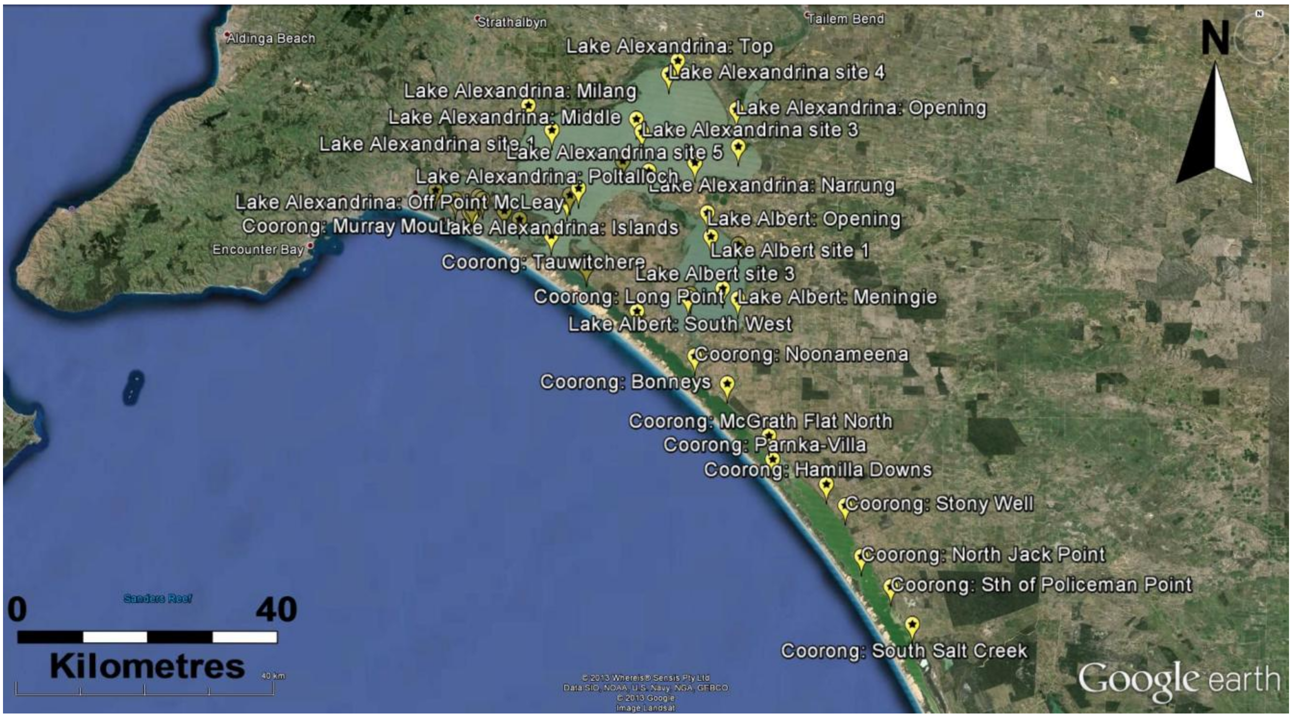
Standardising and collating sampling sites

Building on the procedures developed in the previous report (Oliver et al 2013), several consolidation exercises were undertaken in order to increase the data suitable for analyses. To maximise the periods of data available for the sampling sites, the original sampling names in the database were standardised to remove synonyms. Where it was appropriate, data collected at closely neighbouring sites were consolidated into one of the standardised sites based on visual interpretation of sampling positions on Google Earth. This was done across all of the major Locations considered in this report; Lake Alexandrina, Lake Albert, Goolwa Channel, Murray Mouth, Coorong North and Coorong South (Figure 1). The list of consolidated names for the sites used in this report and the original site names provided from the database are shown in Appendix B while the locations of these sites are shown in Figures 3 a-d.

Water quality and microalgae were generally collected at the same time although on some occasions they were collected separately but during the same week. When these data sets were collated measurements made at a site in the same week were nominally set to the start of the week so they could be combined for analyses. Managing the zooplankton data was more problematic as in the earlier monitoring periods from 2010-2012 the program was operated separately from the water quality and microalgae monitoring program and sampling times and sampling locations did not correspond. In these cases if water quality and microalgae samples were not collected within the same week as the zooplankton, but were collected during the working week before or after, then these were collated with the zooplankton data from the same site and set to the start of the week when the zooplankton were sampled. Although this significantly increased the matching data sets that included zooplankton, the validity of this approach has not been extensively tested and further analysis is warranted.

Microalgae and zooplankton data quality and nomenclature

A large number of microalgae and zooplankton taxa have been identified and enumerated at sampling sites in the CLLMM region during the series of monitoring projects. Unlike chemical analyses where standards of known concentration are included to ensure the reliability of the measurements, the identification and enumeration of microalgae and zooplankton is dependent on the taxonomy and microscopy skills of the analyst, with fewer opportunities for independent verification of the data. Skill levels are likely to vary between analysts, and to alter over longer periods of data collection due to staff changes. Adding to this inconsistency, different methods of enumeration may be used in different monitoring projects depending on their objectives. These sources of variability all add to the uncertainty of characterising and comparing the organisms across the sites. Due to these concerns the statistical analyses in the previous report were largely based on presence/absence data as this does not rely on consistent cell enumerations over time, but does still rely on consistent identifications. To mitigate problems associated with misidentifications microalgae were standardised to genera, as cell characteristics at this taxonomic level are often more reliably recognized than for species. The microalgae groups identified in the database and their affiliation a


Strathalbyn
Tailem Bend
Aldinga Beach
Lake Alexandrina: Top
Lake Alexandrina site 4
Lake Alexandrina: Milang
Lake Alexandrina: Opening
Lake Alexandrina: Middle
Lake Alexandrina site 3
Lake Alexandrina site 5
Lake Alexandrina: Poltalloch
Lake Alexandrina: Narrung
Lake Alexandrina: Off Point McLeay
Lake Albert: Opening
Lake Alexandrina: Islands
Encounter Bay
Lake Albert site 1
Coorong: Tauwitchere
Lake Albert site 3
Coorong: Long Point
Lake Albert: Meningie
Lake Albert: South West
Coorong: Noonameena
Coorong: Bonneys
Coorong: McGrath Flat North
Coorong: Parnka-Villa
Coorong: Hamilla Downs
Coorong: Stony Well
Coorong: North Jack Point
Coorong: Sth of Policeman Point
Coorong: South Salt Creek
N
0
40
Kilometres
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b


Langhorne Creek
Lake Alexandrina: Top
0
10
Kilometres
N
Wellington
Lake Alexandrina: Top
Lake Alexandrina: Toldero!
Lake Alexandrina site 4
Lake Alexandrina: Opening
Milang
Lake Alexandrina: Milang
Lake Alexandrina: Opening
Lake Alexandrina: Middle
Lake Alexandrina: Middle
Lake Alexandrina: Eckerts R
Lake Alexandrina site 1
Lake Alexandrina
Lake Alexandrina site 3
Lake Alexandrina site 5
Lake Alexandrina: Beacon 90=97
Lake Alexandrina: Narrung
Lake Alexandrina: Off Point McLeay
Lake Alexandrina: Narrung
Narrung
Lake Alexandrina: Off Point McLeay
Lake Alexandrina: Islands
Lake Albert: Opening
Google earth

c

d

Figure 3 CLLMM sampling sites (a) Overview of major sampling sites (b) sites in Lake Alexandrina (c) sites in Lake Albert, Murray Mouth and Southern Coorong (d) sites in Goolwa Channel and Northern Coorong. Red markers are zooplankton sampling sites, yellow markers are water quality and microalgae sampling sites.

with genera and with higher taxonomic grouping of taxonomic Classes (-phyceae) and Divisions (-phyta) is given in Appendix C. Note that for the purposes of this report the Cyanobacteria are included within the microalgae. The zooplankton identifications were considered more reliable and analyses were undertaken using the original taxonomic nomenclature. The identified zooplankton and their affiliations with higher taxonomic groupings are given in Appendix D.

Although reducing abundance data to presence/absence removes the reliance on reliable cell enumeration, it also decreases the sensitivity of the statistical analyses.Microalgae and zooplankton fluctuate rapidly over large cell concentration ranges in response to environmental conditions but this information is lost when data is converted to presence/absence. A further benefit of using abundances is that rare or uncommon species that might have little influence in the system, or are due to misidentification during enumeration, have a small effect on the analyses, unlike in presence/absence analyses where their influence is equivalent to that of the other species. However, a major concern with using abundance data is that the enumeration of species is not consistent through time. To assess this for the microalgae monitoring, abundance data and associated presence/absence data for the genera from all locations was displayed using nMDS (Figure 4). The similarity of these patterns suggests that the abundance data is well constrained and sufficiently reliable at the taxonomic level of genera for application in these analyses.

Zooplankton data were also previously analysed as presence/absence data, but as sample collection only commenced in 2010, and all identifications and enumerations were carried out by the same expert taxonomist, sufficient confidence was instilled to utilise the abundance data.

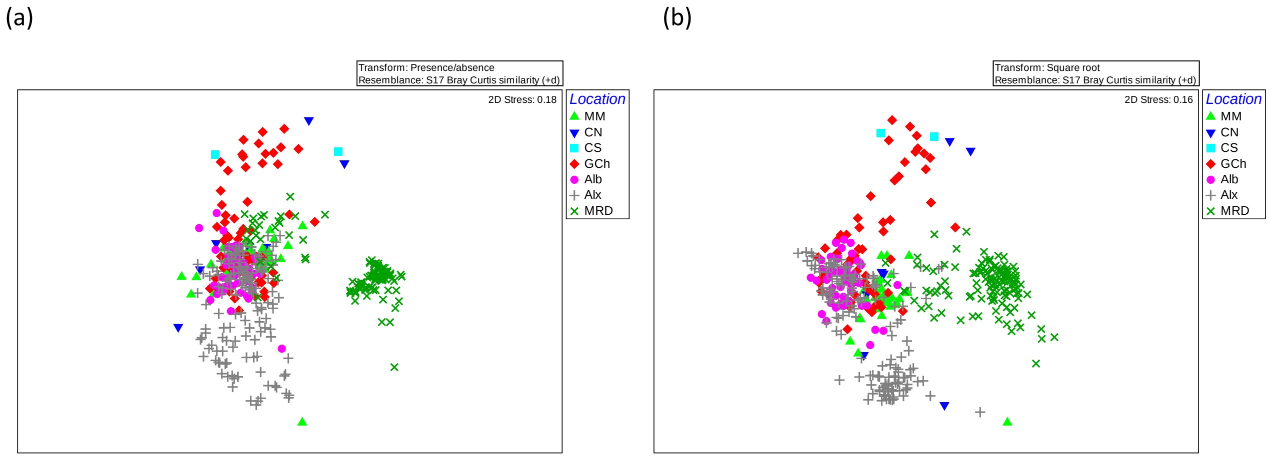


Figure 4 Comparison of microalgae community composition across all sites in each locations using nMDS based on Genera with data as either (a) Presence/absence or (b) Abundance. The figures depict the Locations: Murray Mouth (MM), Coorong North (CN), Coorong South (CS), Goolwa Channel (GCh), Lake Albert (Alb), Lake Alexandrina (Alx) and Murray River (MRD)

2.1.4 SAMPLING DATES AND CRITICAL DATES FOR ANALYSES

The CLLMM region has not had a consistent monitoring program making it difficult to construct collated data sets that describe the matching changes in water quality, microalgae communities and zooplankton communities over space and time, but this is required for comparative statistical analyses. Similarly, the lack of continuous, regular monitoring makes it difficult to assess changes over time as sampling dates are often infrequent and in many cases sampling ceased for extended periods of time, as shown in the examples in Appendix A. The difficulties caused by the irregular monitoring program are highlighted when selecting sites and dates for inclusion in the statistical analyses (Oliver et al 2013). Many different combinations of data are possible, and different selections will be more suited to some questions than others. An analysis of the changes in microalgae across the different sites would be most informed by using a sample set that contained all of the microalgae abundance data. Similarly an analysis of changes in zooplankton community composition would be most informed by using a sample set that contained all of the zooplankton abundance data. However, it would not be possible to directly compare these results and link changes in the microalgae and zooplankton communities, as not all microalgae and zooplankton sampling times coincided. To achieve this outcome a data set of coincident measurements needs to be extracted.

A fully inclusive analysis of the water quality data is not possible because many of the parameters were measured intermittently depending on issues of concern at the time (Appendix A Figure 2). However a number of core parameters were more frequently measured including conductivity, total phosphorus and nitrogen. Selecting these data to align with the microalgae and zooplankton data yielded the largest set of corresponding measurements. Such a selection would not inform on the effects of heavy metals for example, but specific questions could be addressed with differently targeted data selection. It was not possible in the time available to investigate the many data combinations, instead a single, optimised, data set was selected that incorporated key water quality parameters suitable for analyses across all sites and times and that maximised the combined data for microalgae and zooplankton analyses. The water quality parameters chosen were: the daily discharge (Disch) and average five day discharge (Disch5) of the River Murray; the daily flow (Barrage) and average five day flow (Barrage5) over the barrages; Conductivity; oxides of Nitrogen (NOx as N); Total Kjeldahl Nitrogen (TKN as N); Total Nitrogen (TN as N); pH; Total Phosphorus (TP as P) and Turbidity. Most of the analyses were based on this standard data set, although on occasions different data sets were used when it was considered necessary to examine a wider set of samples and these are indicated in the text.

In the analyses the period of the drought was considered to be from January 2001 to November 2010 inclusive. Management responses to the drought included the construction of temporaty regulators or bunds across sections of the system in order to isolate problem areas or to enable ponding so that water levels could be maintained. As these temporary regulators or bunds separated parts of the normally connected system they were considered in the analyses for their potential impact on water quality and biotic communities.

The Goolwa Channel is a narrow arm of Lake Alexandrina that is separated from the Murray Mouth estuary by the Goolwa Barrage (Figure 3d). In addition to flows from Lake Alexandrina it also receives inflows of water from the Southern Mt Lofty Ranges through Currency Creek and the Finniss River. During the drought when lake levels fell, sediments in the creeks and shallow regions of the Goolwa Channel were exposed to air and in some areas re-oxidation of acid sulfate sediments resulted in acidification. Concern about the spread of acidified water through the system in conjunction with a desire to reduce the impact by maintaining water levels in the Channel to cover the sediments, led to the construction of the Currency Creek Regulator in June 2009 and the Goolwa Channel Regulator in August 2009 (Figure 1 and 3d). The Goolwa Channel Regulator was removed in September 2010, and the Currency Creek Regulator in September 2013.

As water levels fell during the drought the connection between Lakes Albert and Alexandrina reduced and the water quality in Lake Albert declined. The Narrung Bund was built in March 2008 that disconnected Lake Albert and Lake Alexandrina and water was pumped from Lake Alexandrina into Lake Albert to maintain its water levels. The bund was removed in September 2010 after the return of substantive flows down the Murray River.

3 Results

3.1 Water Quality Patterns

3.1.1 REGIONAL WATER QUALITY PATTERNS

As described in the methods, a set of parameters was selected that provided a reasonable overview of water quality conditions while ensuring a representative selection of sampling sites and a suitable length of record that could be matched with microalgae abundance data for comparison. The selected parameters were conductivity, three forms of nitrogen (NO_X, TKN and TN), Total phosphorus, pH and turbidity. The analyses included two options for measures of discharge, the flow on the day of sampling or the integral flow over the previous 5 days, for both the Murray River (Disch or Disch5), and the barrages (Barrage or Barrage5). Comparison plots of the parameters indicated significant correlations between Disch, Disch5, Barrage and Barrage5 ($r>0.870$ for all combinations). Consequently for all analyses the parameter Disch5 was used as a surrogate of flow. TN and TKN were also highly correlated ($r = 0.995$) and TKN was removed from the analyses.

The water quality parameters for all locations including the Murray River were compared using PCA and show periods of overlap between sites, which suggests similar water quality conditions, and periods widely separated suggesting distinctly different conditions (Figure 5a). A PERMANOVA comparing locations using all data for each location indicated that they were on average significantly different from each other. To indicate the influence of the drought period on water quality within the Lakes and Coorong region, the data (excluding that for the Murray River) were re-coded to show their time of collection (pre-drought, drought or post-drought) on a PCA (Figure 5b). The Murray River data is not included in further analyses as the focus of this report is on the Lakes and Coorong regions. Only the historical Milang site on Lake Alexandrina had pre-drought information to provide a reference for comparison with drought and post-drought conditions (Figure 5c). The Lake Alexandrina drought sites had water quality quite different from the pre-drought period but appeared to move back to a similar water quality post-drought. During the drought the Lake Albert water quality was different from all other sites but post-drought it appeared to be moving closer to the pre-drought conditions observed in Lake Alexandrina. Similarly with the Goolwa Channel where water quality appeared to be different from other lake sites during the drought but more closely aligned with Lake Alexandrina following the drought. With the selected data set Coorong North was only sampled once during the drought and Coorong South not at all. Further analyses of the Coorong locations are warranted using different water quality data sets. A PERMANOVA comparing data from drought and post-drought periods individually for each of the sites where data was available indicated that there were significant differences in water quality in all cases.

Vectors of the contribution of each water quality parameter to the multivariate patterns across sites are shown on a PCA of locations (Figure 5d). This suggests that major changes in the water quality of Lake Albert and Lake Alexandrina were associated with increased TN concentrations during the drought and that this persisted in Lake Albert post-drought. Conductivity and average river discharge over five days formed a major set of opposing axes differentiating between drought and non-drought phases.

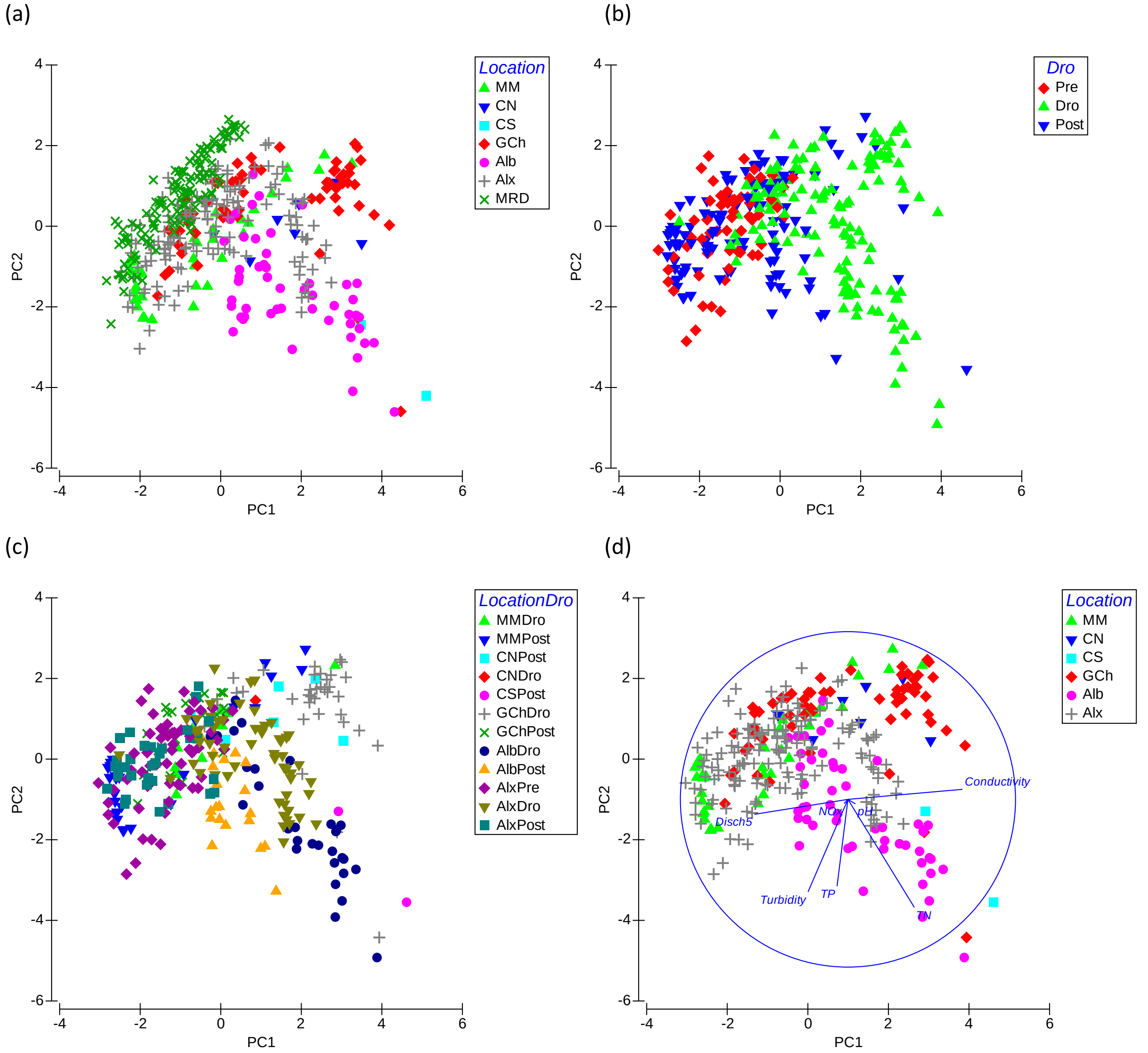


Figure 5 Water quality characteristics of sampling sites from the CLLMM region compared through PCA showing (a) sample locations (b) pre-, post- and drought periods (c) combined location and drought stage (d) location with an overlay of the influence of the selected water quality parameters (see text for definition).

3.1.2 INDIVIDUAL LOCATIONS AND COMPARISONS

Lakes Alexandrina and Albert

Data for Lake Alexandrina described through PCA indicated a major shift in water quality away from the pre-drought conditions during the drought and then a return in water quality following the drought (Figure 6a). All sampling sites with data collected during and after the drought showed a similar shift indicating a ubiquitous alteration in lake water quality (Figure 6b). Overlays of the influence of the individual water quality parameters indicated a major role of river discharge and conductivity in the shift between drought and non-drought conditions. Reduced flows are expected to lead to increased conductivity due to evapoconcentation and these appeared as major opposing water quality shifts. Turbidity and TP appeared to be important in influencing changing water quality conditions within the different phases, aligning with the data sets within the pre-drought, drought, and post-drought phases. In general, TN appeared higher in the drought period.

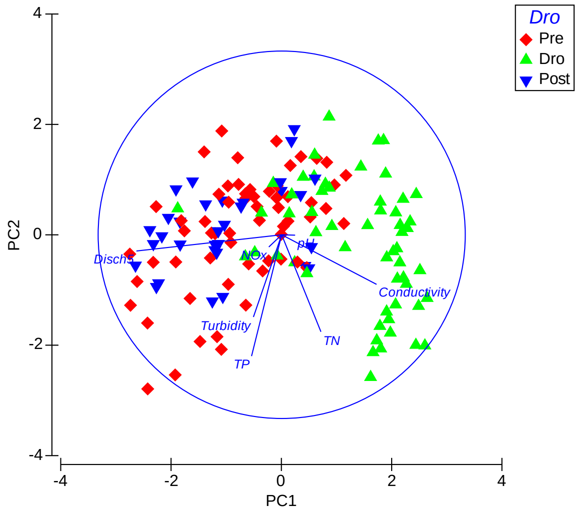
To visualise the sequential shifts in water quality in Lake Alexandrina the centroids for the seasonal data of each financial year were plotted with a line connecting the sequence of years (Figure 7). Periods that were not significantly different as determined by PERMANOVA are enclosed in ellipses such that by following the sequential line an ellipse crossed prior to reaching a data point encloses periods that were not significantly different (Figure 7). The analysis of the chosen parameters indicated that water quality within Lake Alexandrina changed significantly during the drought, but then returned to pre-drought conditions.

There were no pre-drought samples for Lake Albert in the chosen data set so it was not determined directly whether the apparent water quality shift from the drought to the post-drought period represented a return of water quality to previous conditions (Figure 8a). The PCA of data collected during the drought suggested that water quality conditions were different across the sampling sites in Lake Albert, while the post-drought data from different sampling sites appeared to be similar (Figure 8b). This presumably reflects a reduction in connectivity between the sites during the drought. The overlay of water quality parameters indicated that reductions in discharge were a major driver of the altered water quality conditions between the drought and post-drought phases. The differences between sites during the drought were associated with changes in TN concentrations, which were almost completely due to shifts in the total organic nitrogen concentration at this time (Oliver et al 2013). More detailed analyses are required to tease apart these interactions.

To provide a broader context for assessing the changes in Lake Albert water quality, and to assess whether it was returning to pre-drought conditions, measurements were analysed in combination with Lake Alexandrina and the data displayed using PCA (Figure 9). Prior to the drought the water quality in Lakes Alexandrina and Albert were similar (Oliver et al 2013). The PCA results suggested that water quality of the drought samples collected from Lake Albert and Lake Alexandrina were different from each other and that following the drought, when flows had returned to the system, Lake Albert water quality still did not match that of Lake Alexandrina. The overlay of water quality parameters showed again the importance of flow and conductivity in discriminating between the non-drought and drought periods. The difference between Lake Albert and Lake Alexandrina during both drought and post-drought periods appeared to be due to increased conductivity and TN and TP concentrations in Lake Albert (Figure 9).

Differences in water quality across financial years both within and between Lake Alexandrina and Lake Albert were tested by PERMANOVA. This showed that the water quality in the two lakes was not significantly different in 2005/06 but was significantly different for every following year including 2013/2014. Within Lake Albert water quality varied between the consecutive years 2005/06 and 2006/07, 2008/09 and 2009/10, and 2009/10 and 2010/11. In contrast, water quality in Lake Alexandrina was different between all years except 2007/08 and 2008/09, and 2010/11 and 2011/12. To visualise these sequential shifts in water quality the centroids for the seasonal data of each financial year were plotted for each lake with a line connecting the sequence of years (Figure 10). Periods that were not significantly different are enclosed in ellipses such that by following the sequential line an ellipse crossed prior to reaching a data point encloses periods that were not significantly different (Figure 10). The year 2005/06 for each lake is enclosed

(a)



(b)

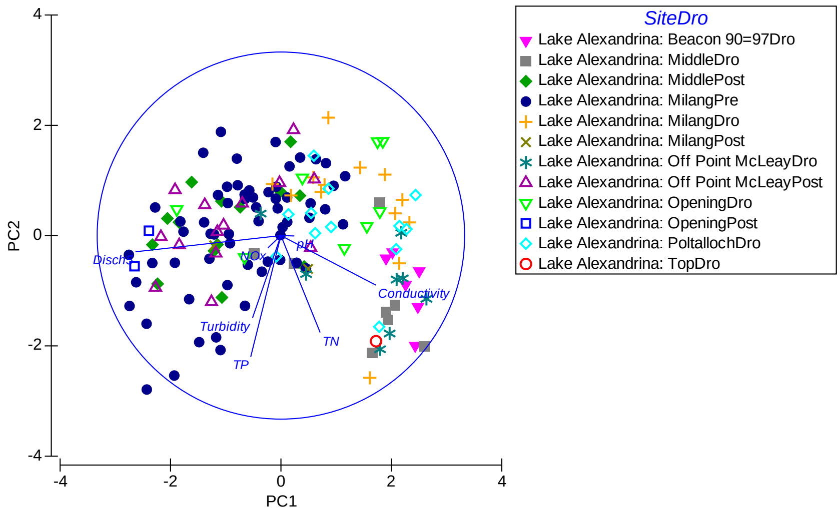


Figure 6 Water quality characteristics of sampling sites from Lake Alexandrina compared through PCA showing (a) pre-, post- and drought periods (b) combined sampling site names and drought stages. Overlays indicate the influence of the selected water quality parameters (see text for definition).

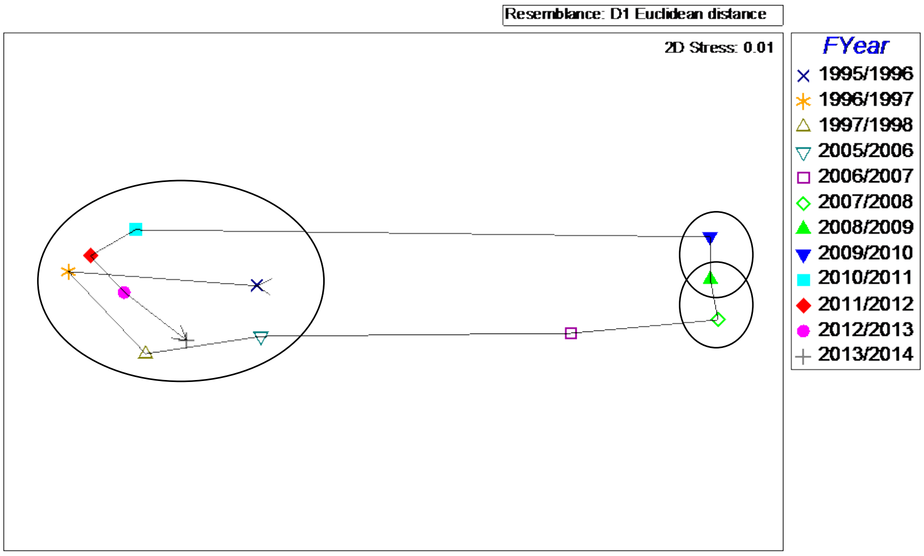


Figure 7 Time sequence of changes in water quality in Lake Alexandrina based on centroids of financial year average seasonal data commencing in 1995/96 prior to the drought. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal water quality characteristics.

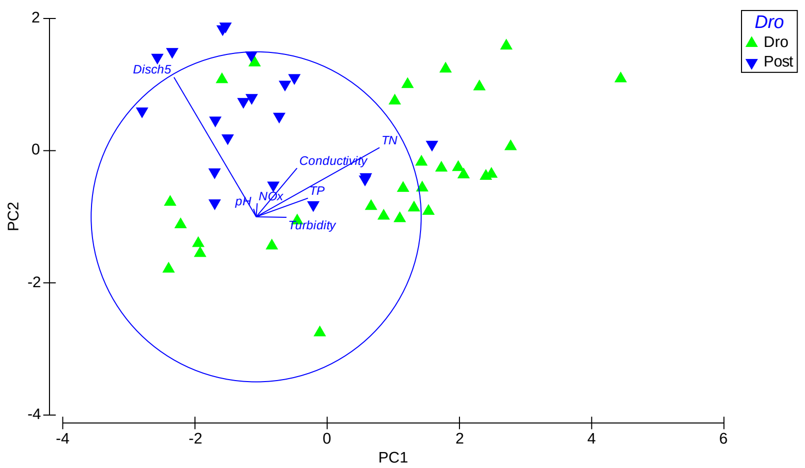
within a single ellipse as the water quality in the two lakes was not significantly different at that time. These results suggest that Lake Alexandrina water quality is approaching what it was early in the drought whereas Lake Albert water quality is still quite different, even though both lakes started with similar water quality in 2005/06, after several years of drought.

Goolwa Channel

The Goolwa Channel, a narrow arm of Lake Alexandrina, is also influenced by inflows from the Southern Mt Lofty Ranges throught Currency Creek and the Finniss River. During the drought the risk of acidification from acid sulfate soils led to the construction of the Currency Creek Regulator in June 2009 and the Goolwa Channel Regulator in August 2009 (Figure 1 and 3d). The Goolwa Channel Regulator was removed in September 2010, and the Currency Creek Regulator in September 2013. In order to assess the influence of reduced flow on acidification and water quality the site upstream of the Goolwa Barrage has been monitored every year since 2005/06, while short term sampling has occurred at a range of other locations over different times since 2009/10.

Water quality changes at all sampling sites were compared using PCA (Figure 11). In general there was a clear distinction between drought and post-drought water quality across all sites (Figure 11a). The Goolwa Barrage site appeared anomalous with results from samples taken during the drought appearing to bridge the drought to post-drought periods indicated by the other sites (Figure 11b). In these analyses the drought period has firmly fixed dates when in practise water flows may have decreased or returned to some sites at different times. The Goolwa Barrage site is situated directly in the Goolwa Channel and perhaps this is why it did not seem to shift to drought water quality conditions until 2007/08. A similar response is seen in Lake Alexandrina samples which bridge the drought and post-drought periods (Figure 6b).

(a)



(b)

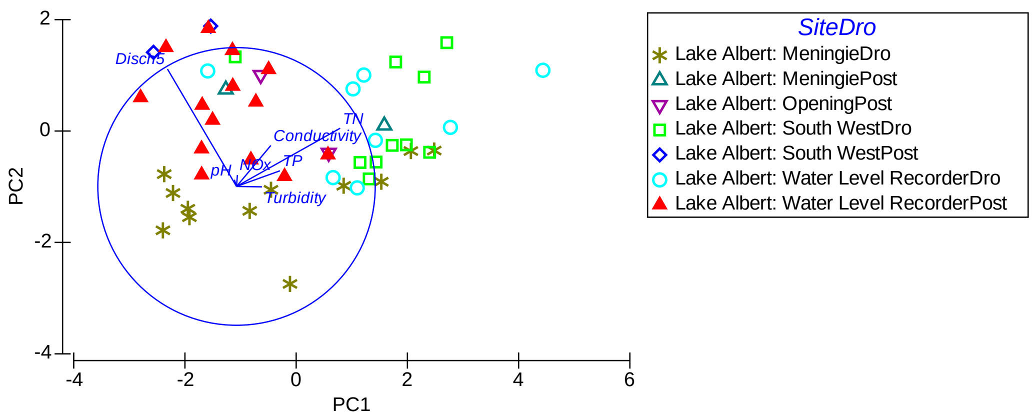


Figure 8 Water quality characteristics of sampling sites from Lake Albert compared through PCA showing (a) pre-, post- and drought periods (b) combined sampling site names and drought stages. Overlays indicate the influence of the selected water quality parameters (see text for definition).

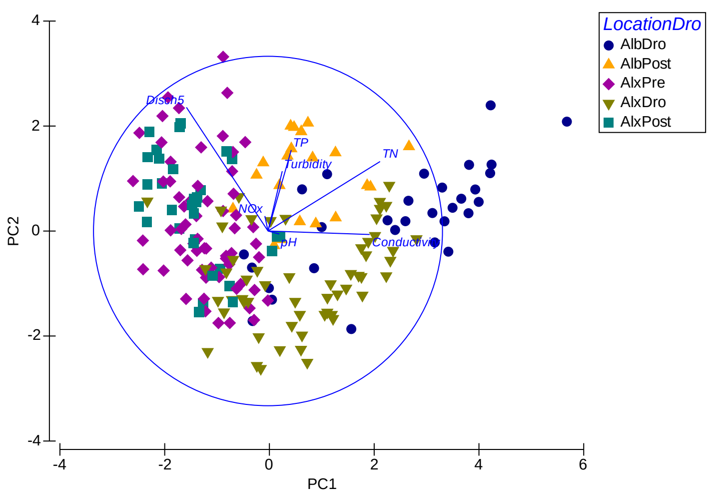


Figure 9 Water quality characteristics of sampling sites from Lake Alexandrina and Lake Albert compared through PCA showing combined sampling site names and drought stages. Overlays indicate the influence of the selected water quality parameters (see text for definition).

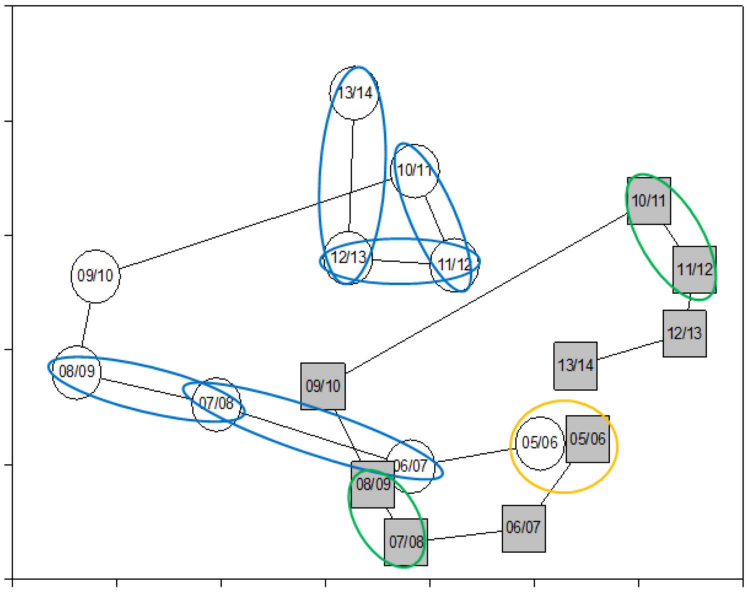
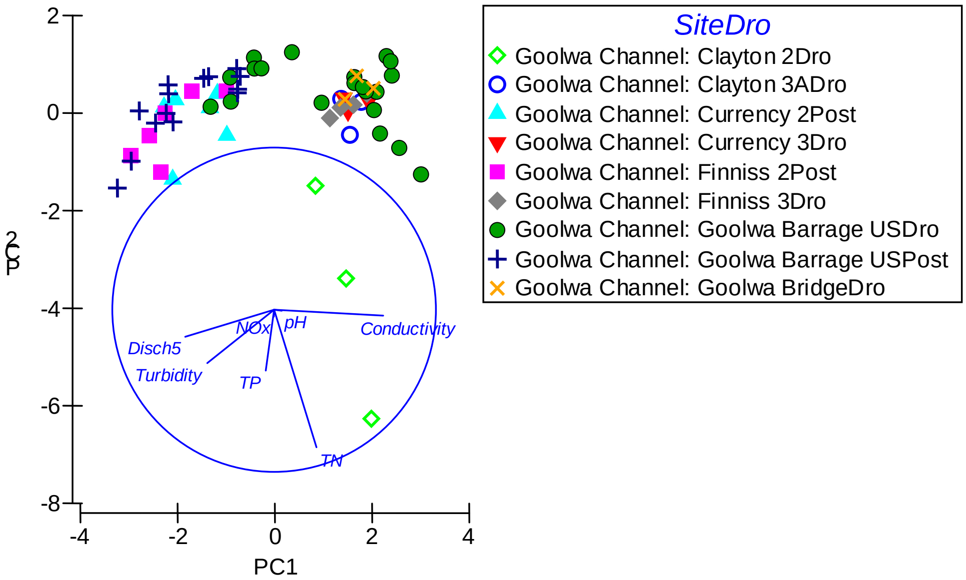


Figure 10 Time sequence of changes in water quality in Lake Alexandrina (filled rectangles) and Lake Albert (circles) based on centroids of financial year average seasonal data commencing 2005/06. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal water quality characteristics.

These changes were investigated more closely using the centroids for the seasonal water quality data across all sites of each financial year plotted with a line connecting the sequence of years (Figure 12). A PERMANOVA tested the significance of differences between financial years and those periods that were not significantly different are shown enclosed in ellipses (Figure 12). During the time sequence 2007/08 to 2009/10 there was no significant difference in water quality but this period was significantly different from preceding and following periods. The time sequence 2010/11 to 2012/13 differs from 2013/14 but was not significantly different from 2005/06, while 2012/13 and 2013/14 were not significantly different from 2005/06 and 2006/07. This suggests that the water quality in the Goolwa Channel has returned to what it was when measurements were initially taken, a similar response as seen in Lake Alexandrina (Figure 7).

The overlay of water quality parameters demonstrates the role of discharge and conductivity in distinguishing between drought and post-drought samples but also suggests a significant change in TN concentration, particularly at the Clayton 2 sampling site (Figure 11a).

(a)



(b)

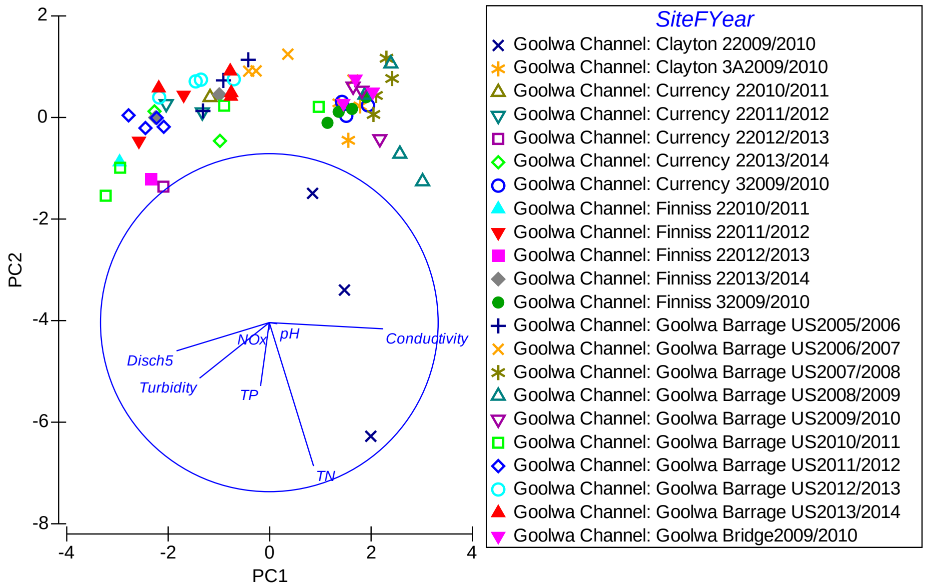


Figure 11 Water quality characteristics of sampling sites from Goolwa Channel compared through PCA showing (a) combined sampling site names and drought stages, (b) sampling site and years of sampling. Overlays indicate the influence of the selected water quality parameters (see text for definition).

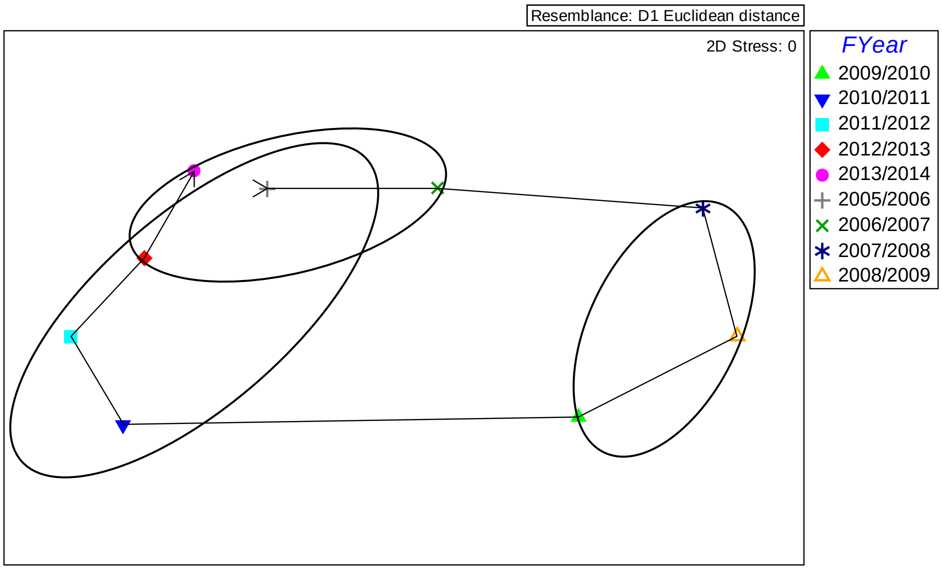


Figure 12 Time sequence of changes in water quality in Goolwa Channel based on centroids of financial year average seasonal data. Ellipses enclose years from 2005/06 onwards that are not significantly different based on PERMANOVA of seasonal water quality characteristics.

Coorong

Apart from an earlier measurement at the Murray Mouth in 2005/06 the analysed sampling set contains water quality data only from 2010/11 and 2013/14 (Figure 13a). This is because the water quality samples were required to be matched with microalgae counts and this significantly reduced the water quality data included for anlayses. A larger water quality dataset was analysed in an earlier report and should be consulted for a more complete overview (Oliver et al 2013).

The Coorong was divided into three sections (Figure 1); Murray Mouth (MM); Coorong North (CN) and Coorong South (CS). Although the restricted data set includes drought and post-drought dates, in general they overlap and show no consistent differences (Figure 13b). PERMANOVA on all data indicated that there were significant differences between all years except for 2005/06 and 2013/14 which were in drought and post-drought periods respectively. Although this suggests that there has been a return to earlier conditions, the comparison is based on limited data and further time periods of monitoring are required to reliably interpret the data.

PERMANOVA contrasting Locations showed that there were significant differences between the Southern Coorong, the Northern Coorong and the Murray Mouth over the sampling period. To visualise this longitudinal sequence the centroids for the seasonal data of each site over all years were plotted with a line connecting the sequence of sites as they occur along the Coorong (Figure 14). Coorong sampling sites and their longitudinal order are listed in Appendix E. Periods that were not significantly different are enclosed in ellipses. Oliver et al (2013) described annual and longitudinal sequences of water quality change in the Coorong using a larger and more extensive data set giving more robust results, but with similar results showing persistent longitudinal variation in water quality.

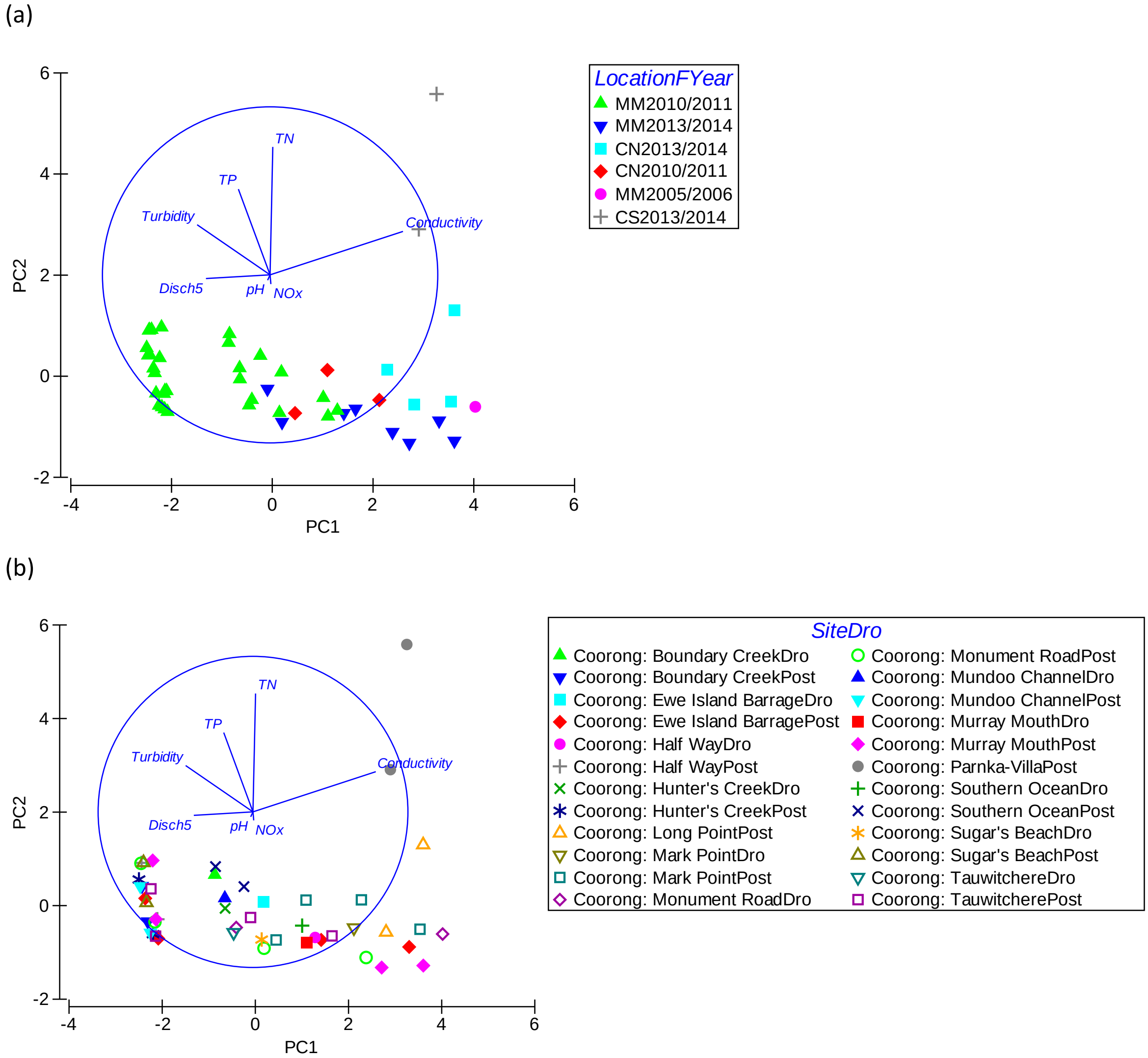


Figure 13 Water quality characteristics of sampling sites from the Coorong compared through PCA showing (a) sampling site and years of sampling (b) combined sampling site names and drought stages. Overlays indicate the influence of the selected water quality parameters (see text for definition).

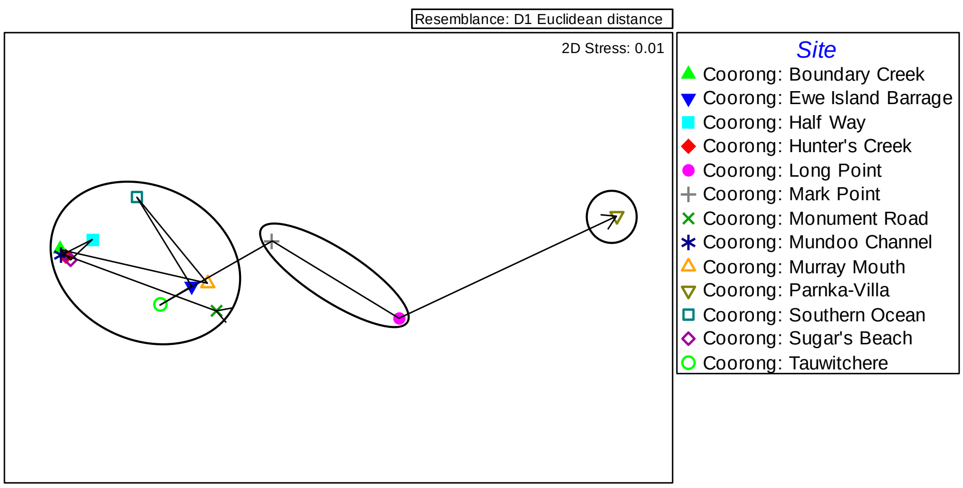


Figure 14 Longitudinal changes in water quality in the Coorong based on centroids of average seasonal data at each site over sampling years. Ellipses enclose sites that are not significantly different based on PERMANOVA.

3.2 Microalgae

3.2.1 SYSTEM SCALE COMPARISONS OF MICROALGAE COMMUNITIES

Hydrological connectivity across the interconnected lake and estuarine system varies significantly in response to river inflows and to water releases over the barrages that separate Lake Alexandrina from the Coorong. Connectivity with the major source of inflow, the Murray River, is expected to diminish across the major locations as travel time increases moving through Lake Alexandrina, Goolwa Channel, Lake Albert, Murray Mouth, Coorong North and Coorong South (Figure 1). An nMDS of the total microalgae data showed distinct differences in community composition across the major locations (Figure 15). A PERMANOVA of pair wise comparisons of locations showed that they were significantly different except for the Coorong North and Coorong South which were combined in Figure 15.

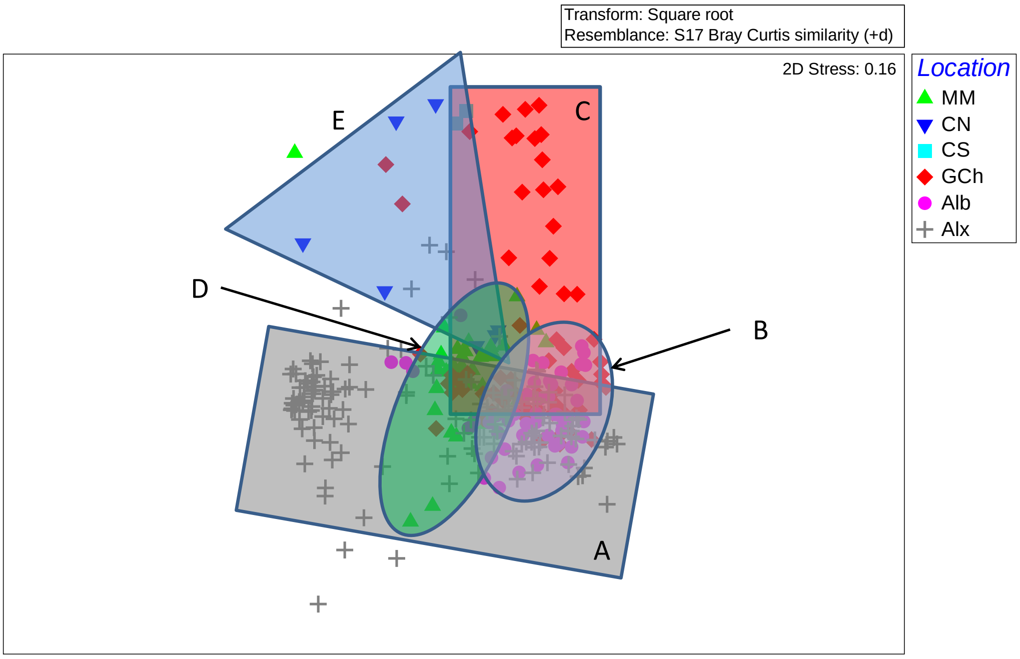


Figure 15 Microalgae community data from sites sampled in A: Lake Alexandrina (Alx), B: Lake Albert(Alb), C: Goolwa Channel (GCh), D) Murray Mouth (MM) and E) Southern (CS) and Northern Coorong (CN) compared though nMDS.

In a previous report (Oliver et al 2013), Lakes Alexandrina and Albert were analysed together as the presence/absence data had suggested they were responding similarly to changing flow conditions. However the use of abundance data in these analyses, and compilation of data over a longer period of time, indicated periods of significant differences between the two lakes and each has been considered separately here (Figure 15).

3.2.2 LAKE ALEXANDRINA

The changes in microalgae community composition displayed using an nMDS (Figure 16a, b) based on seasonal abundance data (Figure 16c) for each financial year from 1982/83 up to 2013/14 (Figure 16b) showed distinct differences in community composition between drought periods (Figure 16d). Comparison with Figure 16a shows that the historical information was entirely from Milang as expected from the data record, but that during later years, when a wider set of sampling sites was used, the Milang site overlapped with the others suggesting is was representative of the lake and that the sampling sites reasonably represented the continuum of variation within the Lake (Figure 16a).

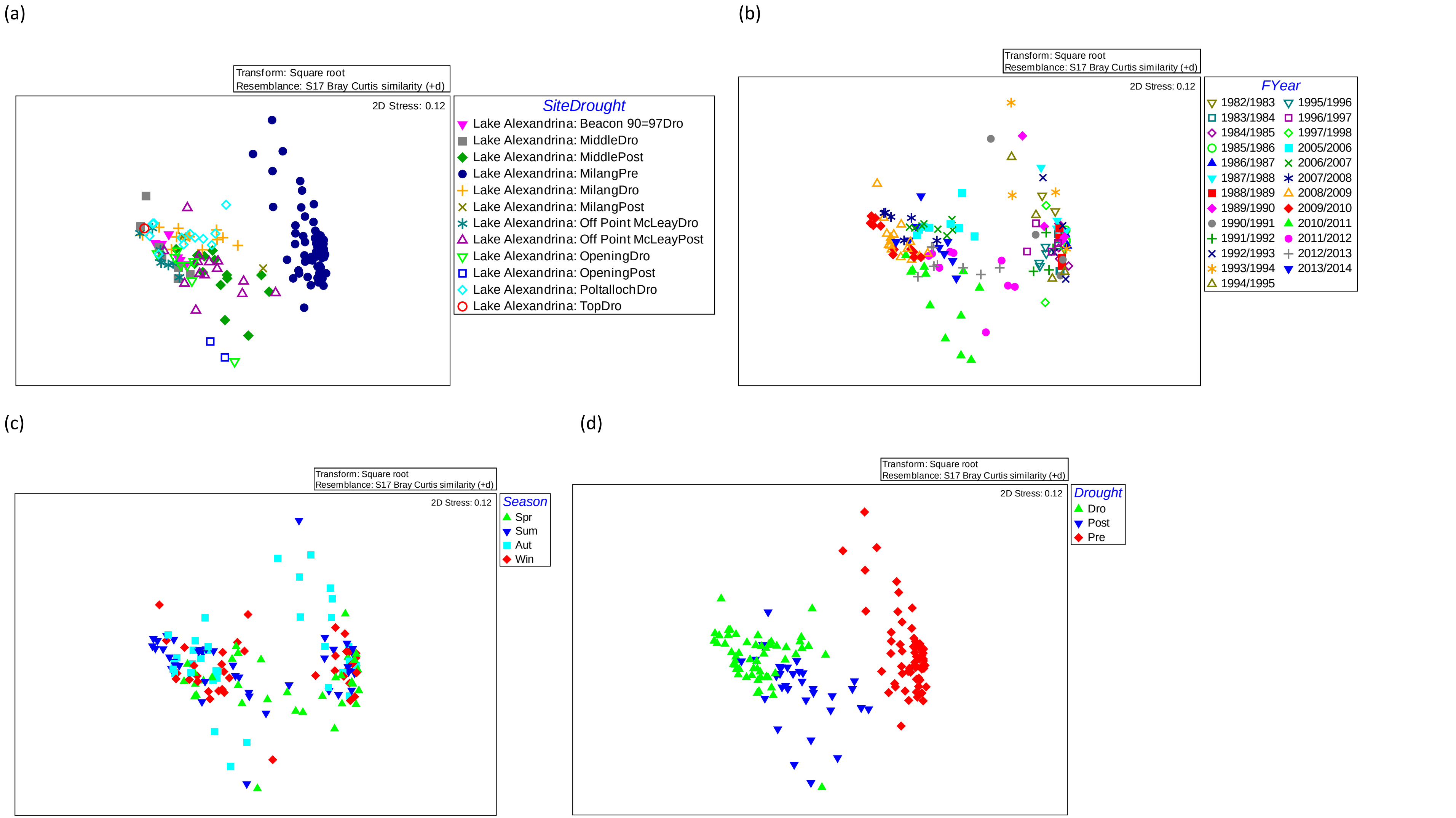
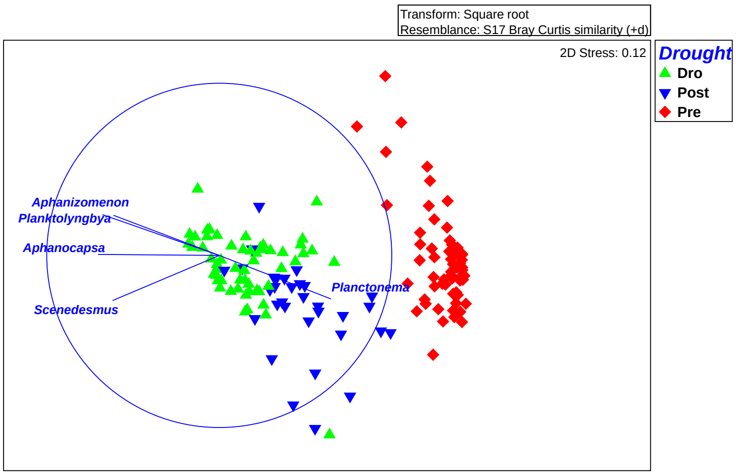


Figure 16 Microalgae community composition changes in Lake Alexandrina analysed using nMDS with re-coding of seasonal average data points to depict (a) Sampling sites and the time sampled in relation to drought indicated by Pre (pre-drought), Dro (drought) and Post (post-drought) (b) sampling years (c) sampling seasons (d) pre-, post- and drought periods.

If there are significant changes in the microalgae community composition over time then the microalgae genera contributing most to the changes can be identified along with associated changes in water quality that may be influencing the microalgae responses. Pearson Correlations between shifts in the community composition and particular microalgae and water quality parameters are shown as overlayed vectors on the nMDS of microalgae composition to demonstrate these associations. These show the strength of the association and the direction. In Figure 17a those microalgae genera aligned with the changes and having a Pearson Correlation >0.65 are shown.

(a)



(b)

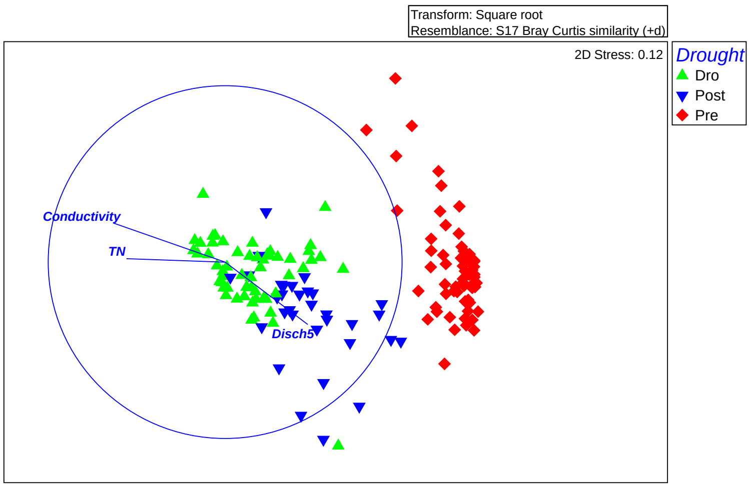


Figure 17 Microalgae community composition changes in Lake Alexandrina analysed using nMDS with overlays of influences from (a) microalgae genera (Pearson Correlation>0.65) (b) water quality parameters (Pearsons Correlation>0.5)

The nMDS indicates that the green microalga *Planctonema* decreases in occurrence during the drought period with an increased occurrence in the pre- and post- drought periods, although the microalgae community composition of the pre- and post- periods are evidently different from each other. The abundance patterns of the green microalga, *Scenedesmus* showed a clear discrimination between the pre-drought and post-drought periods. In contrast, the major genera increasing in abundance in response to the drought were the cyanobacteria *Aphanizomenon*, *Planktolyngbya* and *Aphanocapsa.* These findings match those of earlier reports that were described in the Introduction.

Water quality parameters that aligned with changes in microalgae community composition and having a Pearson Correlation >0.5 are identified on Figure 17b as the average river discharge of the preceding five days (Disch5), Conductivity, and the Total Nitrogen concentration (TN). Conductivity was expected to increase during the drought as river flows declined and evaporation concentrated salts within the Lake. As discussed in relation to water quality (Section 3.1.2) the increase in TN in response to the drought conditions occurred largely in the organic nitrogen component. Although changes in conductivity and TN are associated with changes in microalgae community composition and so may influence, or be influenced by, the community composition, they themselves are most likely to have been affected by the changes in discharge which is considered the primary driver.

PERMANOVA of the microalgae community data demonstrated that sequential pairs of years between 1982/83 to 1997/98 were not significantly different, although some of the non-sequential pairs within the period were different. However, all of these earlier samplings are significantly different from the time series of 2005/06 onwards. In addition there are significant differences between drought and post-drought periods, but also some overlap of communities. To visualise the sequential shift in community composition within Lake Alexandrina centroids were determined for the seasonal data of each financial year and the sequence of years connected with a line (Figure 18). Within the drought and post-drought periods those years from 2005/06 onwards that are not significantly different based on PERMANOVA of seasonal community composition are circled (Figure 18). The shift between the two major groupings of pre-drought vs drought and post-drought data is likely to have been made more abrupt by the fact that microalgae sampling ceased in 1997/98 prior to the drought and was not recommenced until 2005/06, well into the drought period. The time sequence suggests that in 2010/11 and 2011/12 the microalgae community composition was beginning to increase in similarity with the pre-drought community as the data points move in that direction, but in 2012/13 and 2013/14 the similarity appears to decrease again. An analysis of similarity between microalgae communities between the different drought phases indicated that microalgae communities in the pre-drought and drought phases were 7.3% similar, in the drought and post-drought phases they were 36% similar, and in the pre-and post-drought phases they were 15.5% similar.

Another way of displaying these changes over time is to compare the similarity of the average community composition of each financial year with a reference year. In this case 1982/83, the first year of sampling was used as a reference and all following years compared with it (Figure 19). The results showed that on average the years up to 1997/98 were close to 50% similar to 1982/83, but then there was a large shift in similarity with drought samples between 2005/06 and 2009/10 decreasing to be only a few percent similar with 1982/83. Similarity then increased until 2011/12 and then declined in the last two years, reflecting the pattern seen in the nMDS (Figure 18).

A more detailed assessment of the contribution of different microalgae to the changes in composition between the drought phases is presented in Table 2. This lists the microalgae genera that account for ca.90% of the dissimilarity between the three drought phases and their average cell abundances during each of the different phases. The average cell abundance of each of the microalgae genera within each phase is shown as a percentage in Figure 20. These pie charts show the different community compositions within the drought phases of those microalgae genera largely responsible for the changes between phases.

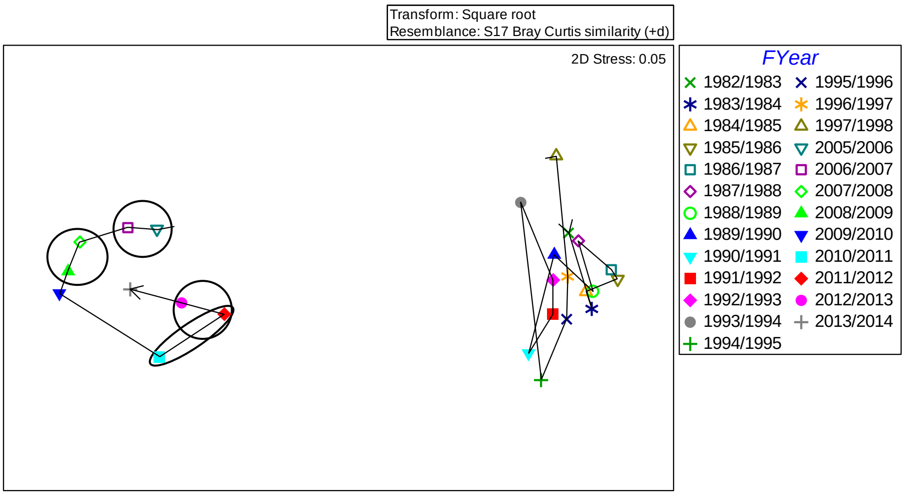


Figure 18 Time sequence of changes in microalgae community composition pre-drought (1982-1998) and from 2005/06 onwards in Lake Alexandrina based on centroids of financial year average seasonal community data. Ellipses enclose years from 2005/06 onwards that are not significantly different based on PERMANOVA of seasonal microalgae community composition.

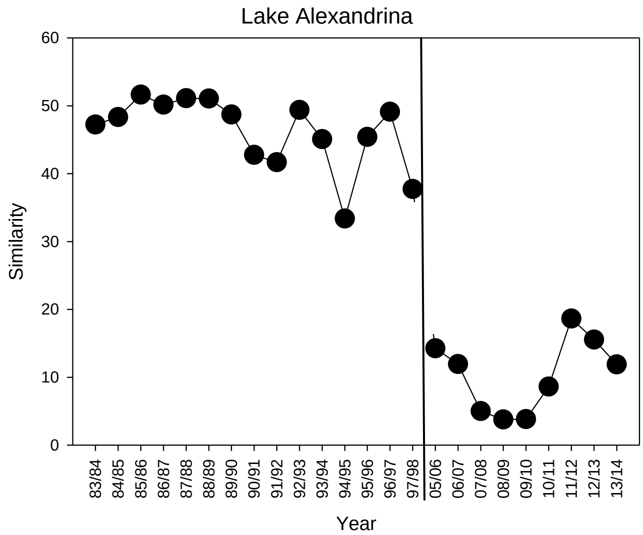


Figure 19 Similarity between microalgae communities in Lake Alexandrina using 1982/83 communities as a reference point. Vertical line indicates the break in monitoring data between 1997/98 and 2005/06

Table 2 Average abundances (cells/mL) and rank abundances of the genera of microalgae contributing 90% of the dissimilarity between drought phases (ie. pre-drought, drought and post-drought) in Lake Alexandrina.

Genera	Pre-drought Average Abundance	Rank Abundance	Drought Average Abundance	Rank Abundance	Post-drought Average Abundance	Rank Abundance
Planktolyngbya	2.65	10	1017.92	1	246.5	1
Aphanocapsa	0	15	422.05	2	163.65	2
Planctonema	148.22	1	37.54	7	72.64	3
Crucigenia	4.23	8	28.78	8	49.5	4
Staurosira	0	15	11.43	12	32.7	8
Aulacoseira	0	15	2.17	17	27.63	9
Scenedesmus	1.46	11	22.98	9	36.31	6
Tetrastrum	0	15	14.39	11	36.11	7
Oocystis	9.18	4	41.41	6	38.04	5
Anabaena	16.65	2	5.34	15	20.1	11
Nodularia	13.65	3	11.12	13	18.67	12
Aphanizomenon	4.57	7	71.41	3	27.14	10
Ankistrodesmus	0.93	13	60.5	4	17.01	13
Cyclotella	1.19	12	5.36	14	11.76	16
Fragilaria	0	15	0	18	14.61	14
Dictyosphaerium	5.46	5		18	8.42	17
Chlorella	3.39	9		18	8.37	18
Chodatella	0	15	2.41	16	13.7	15
Chroomonas	0.43	14		18	8.01	19
Merismopedia		15	16.74	10	1.29	21
Pseudanabaena	4.64	6	55	5	2.47	20

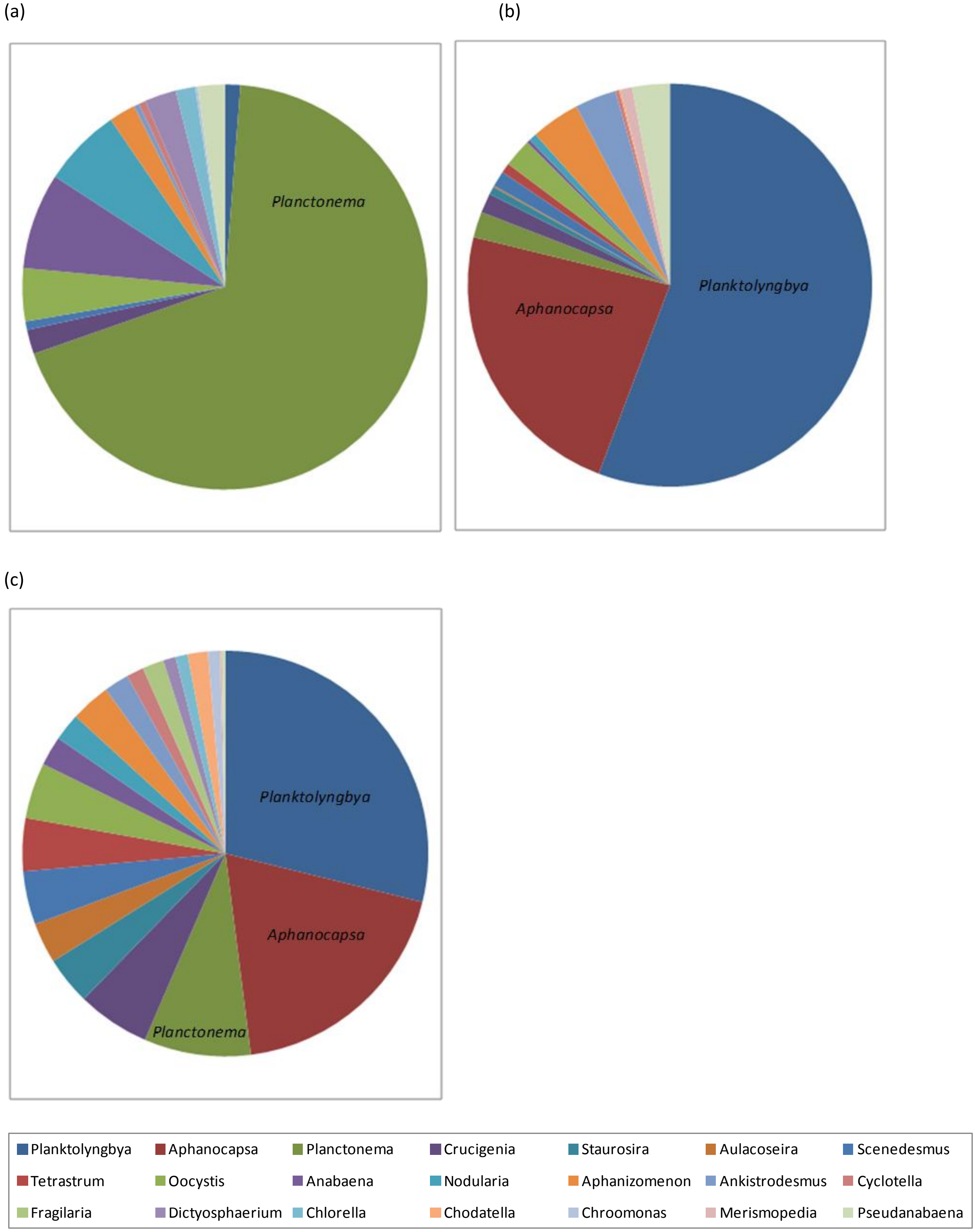


Figure 20 Average percentage abundance of the microalgae genera accounting for 90% of the dissimilarity between pre-drought, drought and post-drought periods in Lake Alexandrina, (a) Pre-drought (b) Drought (c)Post-drought. Note that not all genera occur on all charts and the colour sequence progresses from the top in a clock-wise direction in the order shown across the rows in the legend. The charts are interpreted in conjunction with Table 2 which shows the contribution of each genus in each drought phase. Major genera are shown on each chart.

The results in Table 2 show that there was a substantial decrease in *Planctonema* during the drought and that this did not fully recover following the drought. Conversely, during the drought the increases in *Planktolyngbya* and *Aphanocapsa* dominated the shift in community composition of microalgae responsible for the changes between periods, and these genera remained dominant following the drought.

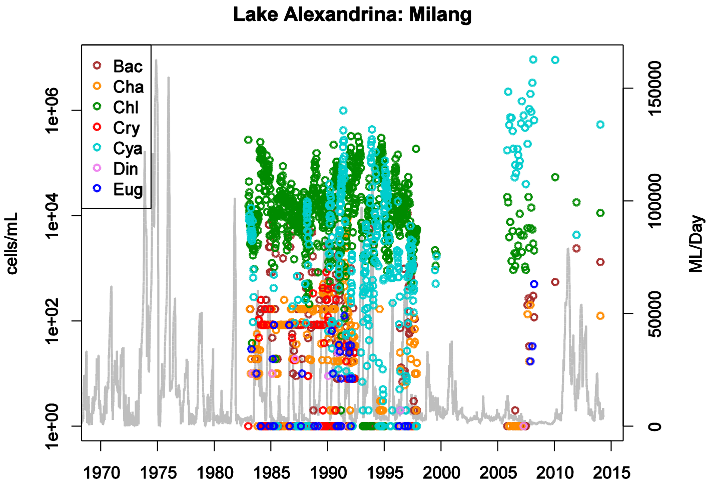
The time sequences of abundances of the major microalgae groups are shown in Figure 21 for three sampling sites in Lake Alexandrina. The Milang site provides a long historic record while the other two sites, Middle and Off Point McLeay, were sampled from August 2008 and captured the end years of the drought and the post-drought period. Prior to the drought at Milang the chlorophytes (green algae), including *Planctonema*, generally either dominated the community or were of a similar abundance to the cyanoabacteria. In comparison between 2008 and 2010, towards the end of the drought, the microalgae community was dominated by cyanobacteria and this dominance continued into the post-drought period although the abundance of cyanobacteria reduced. A comparison across the sites indicates that the overall abundance of chlorophytes prior to the drought was usually greater than 10,000 cells/mL reaching 100,000 at times while in the drought and post-drought phases concentrations remained at around 10,000 cells/mL. But also the community composition of chlorophytes changed, with reductions in *Planctonema* offset by increases in *Crucigenia*, *Scenedesmus*, *Ankistrodesmus*, and *Tetrastrum* (Table 2, Figure 20).

It was possible that some of the community changes within Lake Alexandrina were due to microalgae being carried in by the Murray River. PERMANOVA indicated that only in 1982/83 and 1997/98 were river and lake microalgae communities comparable, in all other years they were significantly different.

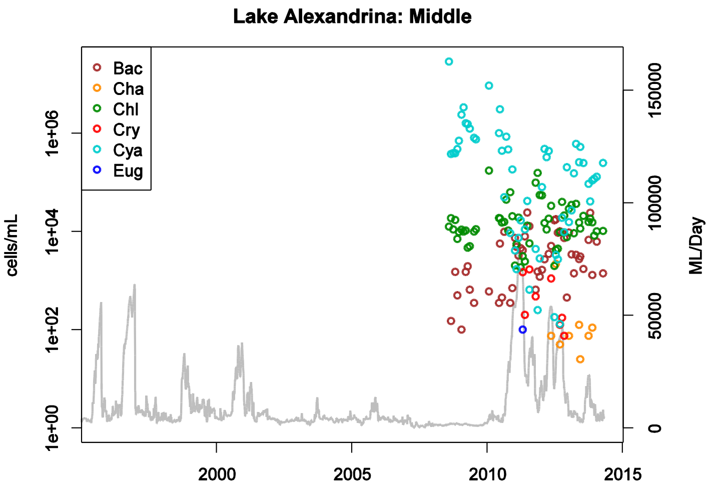
3.2.3 LAKE ALBERT

Microalgae data from Lake Albert has been collected intermittently since 1996/97 but the selected data set commenced from 2005/06 and included samples from different locations fragemented over time. A comparison of Lake Alexandrina and Lake Albert through nMDS from 1982 through to 2014 indicates significant periods of overlap (Figure 22a) across a number of sampling sites (Figure 22b). Sampling is reasonably well spread across the seasons suggesting the data is representative of annual conditions (Figure 22c). The data set includes the early period when Milang was sampled but not Lake Albert and this can be identified as the pre-drought samples in Figure 22d. It would seem from this figure that the drought and post-drought microalgae communities in Lake Alexandrina were closely associated with those in Lake Albert.

(a)



(b)



(c)

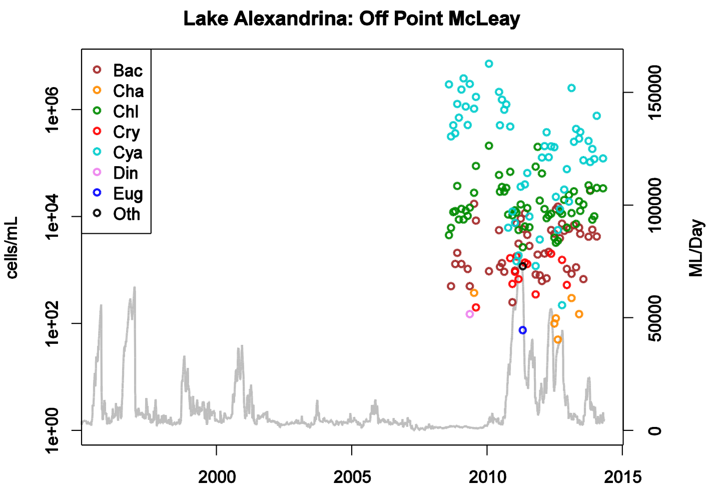


Figure 21 Time series of abundance of major microalgae groups at three sampling sites in Lake Alexandrina, (a) Milang, (b) Middle, (c) Off Point McLeay. Note change of scale on time axes. Microalgae groups are Diatoms (Bac), Charophytes (Cha), Chlorophytes (Chl), Chrysophytes (Cry), Cyanobacteria (Cya), Dinoflagellates (Din), Euglenoids (Eug), and others (oth). The hydrograph of daily river discharge is shown as a grey line.

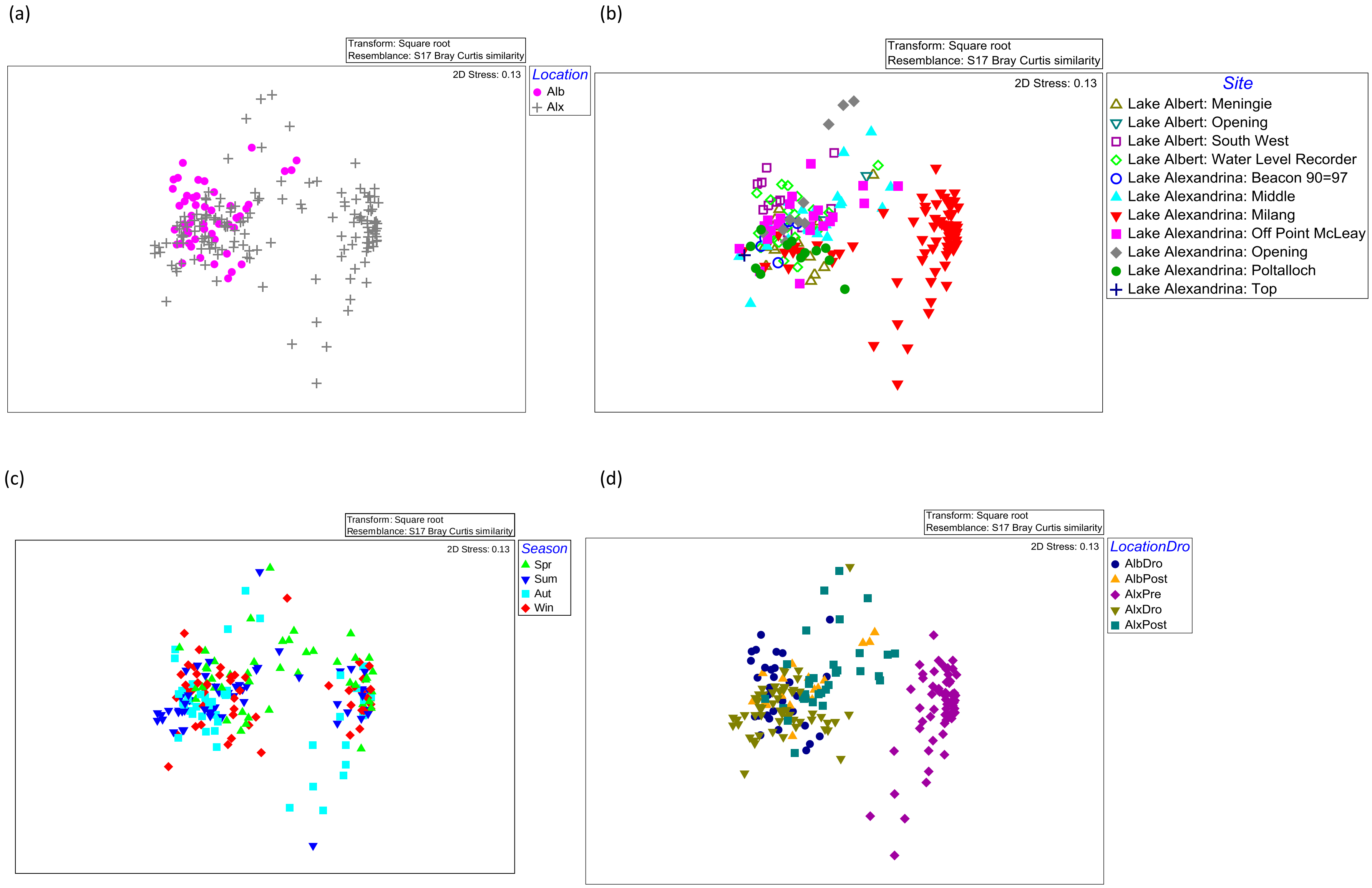


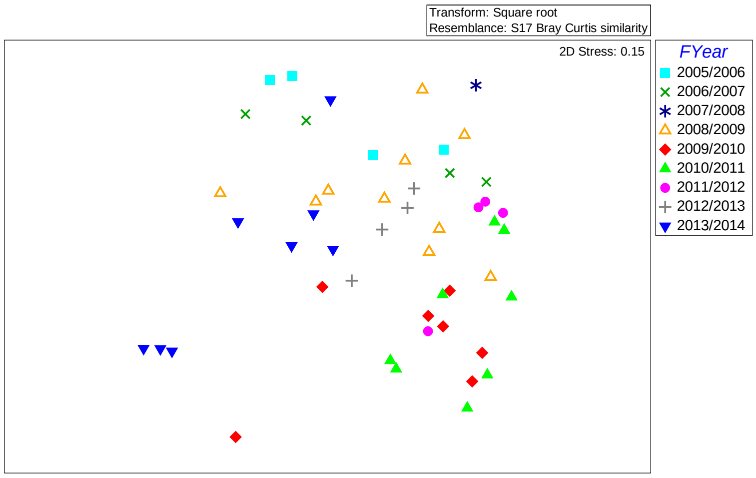
Figure 22 Microalgae community composition changes in Lake Albert and Lake Alexandrina displayed together using nMDS with re-coding of seasonal average data points to depict (a) Sampling locations are Lake Alexandrina (Alex) or Lake Albert (Alb) (b) sampling sites (c) sampling seasons (d) relating sampling locations to pre-drought (Pre), drought (Dro) or post-drought (Post) periods.

To investigate the influence of the different microalgae genera and water quality parameters on these changes within and between the lakes, Pearson Correlations of the influences were overlayed as vectors on the nMDS of microalgae composition. The figures of these results are not shown because they are the same as obtained for Lake Alexandrina alone (Figures 17a, b), presumably because of the large influence of the frequently sampled Milang site. PERMANOVA comparing microalgae communities in the two lakes by years indicated that 2005/06, 2006/07 and 2007/08 were not significantly different while all the following years up to the present were different. These dates are noteworthy in that the Narrung Bund between Lake Albert and Lake Alexandrian was built in March 2008 and this marks the time when the microalgae communities of the lakes diverged. The purpose of the Bund was to enable water to be pumped into and held in Lake Albert to reduce the risk of acidification through exposure of acid sulfate sediments. Although the Bund may have increased the hydrological separation between the lakes the natural transfer of water was reduced prior to its construction as a result of the falling lake levels. The reduced connection between the two lakes prior to the construction of the Bund is demonstrated by their water qualities which were not significantly different in 2005/06 but diverged after that and remained significantly different to the present. The Bund was removed in September 2010 after increased flows raised lake levels but the water quality and microalgae community of Lake Albert continued to remain significantly different from Lake Alexandrina and more similar to drought conditions. This reflects the low rate of water transfer into this terminal lake which is insufficient to flush the basin and to offset evaporative concentration.

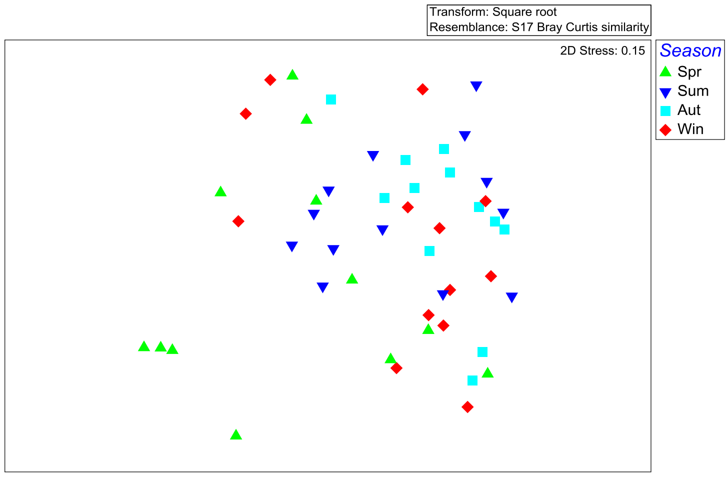
To investigate the changes in Lake Albert itself, the data from 2005/06 to 2013/14 were displayed with an nMDS. The data set contains a reasonable representation of each year except for 2007/08 when only a single sample was taken (Figure 23a). Seasonal samples were reasonably well distributed through the data set (Figure 23b) suggesting a reliable representation of annual conditions. Samples were collected only during the drought and post-drought period and no clear pattern of influence is obvious from the nMDS (Figure 23c). Pearson Correlations were used to assess the influences of particular microalgae genera and water quality parameters on the changes in microalgae community within Lake Albert. A number of microalgae genera had strong influences on the changing community composition (Figure 24a), suggesting that the system shifted from largely cyanobacteria influenced to increasing occurrences of chlorophytes and diatoms, then to a period of increasingly mixed communities. The water quality parameters most strongly associated with these changing microalgae communities were conductivity and NO_X which both generally increased following the hydrological separation of the lakes by falling water levels (Figure 24b).

PERMANOVA was carried out using all years except 2007/08 which only had a single sample, and indicated the periods that were not significantly different from each other as 2005/06-2006/07; 2006/07-08/09, 2006/07-11/12, 2006/07-12/13; 2008/09-12/13; 2009/10-10/11; and 2010/11-11/12. To visualise the sequential shift in community compositions within Lake Albert centroids were determined for the seasonal data of each financial year and are shown in Figure 25 with a line connecting the sequence of years. Periods that are not significantly different are enclosed in ellipses. By following the sequential line the ellipse prior to reaching a data point encloses those periods that are not significantly different.

(a)



(b)



(c)

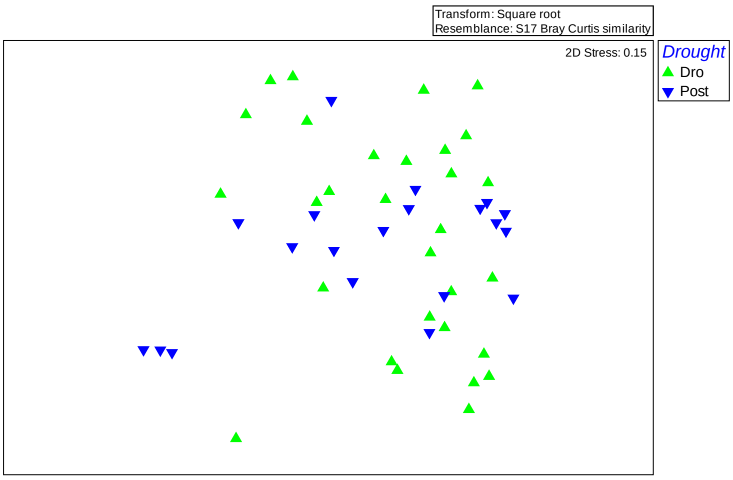
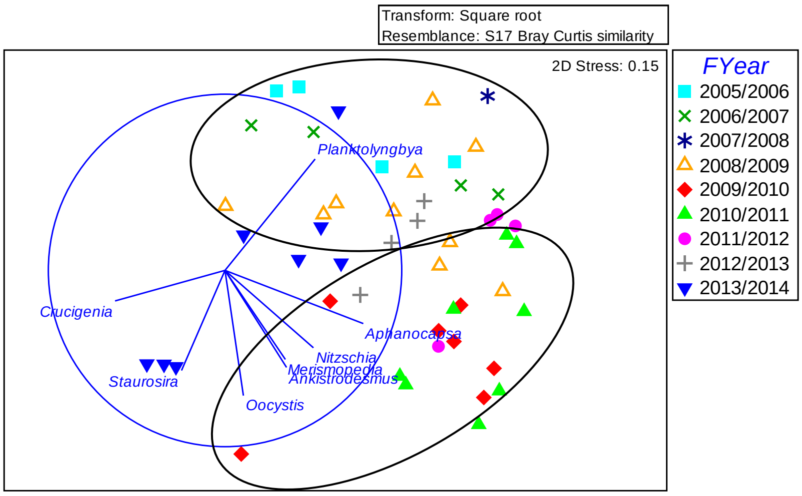


Figure 23 Microalgae community composition changes in Lake Albert analysed using nMDS with re-coding of seasonal average data points to depict (a) financial years (b) seasons (c) drought period (Dro), and post-drought (Post).

(a)



(b)

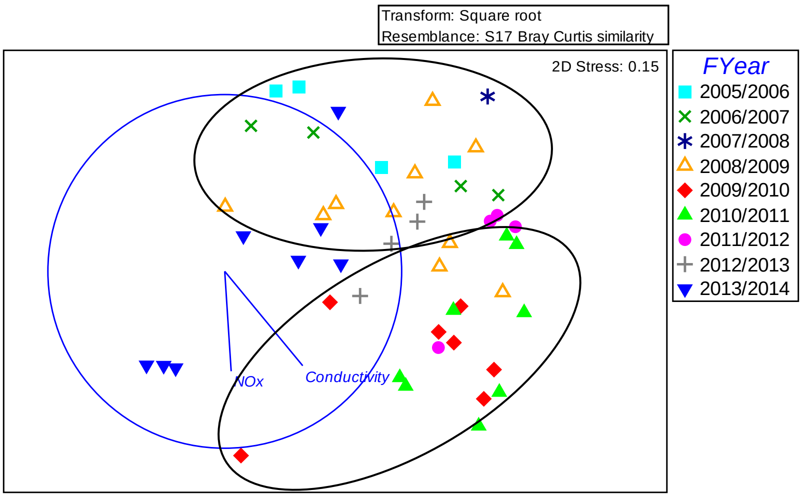


Figure 24 Microalgae community composition changes in Lake Albert analysed using nMDS with overlays of influences from (a) microalgae genera (Pearson Correlation>0.6), (b) water quality parameters (Pearsons Correlation>0.5). The ellipses approximately indicate the periods up to 2008/09 and 2008/09 to 2010/11.

In 2013/14 the Lake appeared to have a different microalgae community to previous years, as well as being significantly different from the microalgae community in Lake Alexandrina, despite the hydrological reconnection following increases in water levels in Lake Alexandrina. However the robustness of this finding requires further assessment as the microalgae sampling in Lake Albert was limited.

Another way of displaying the changes over time is to compare the similarity of each financial year with a reference year. In this case 2005/06, the first year of microalgae data collection in Lake Albert, was used as the reference and all following years compared with it (Figure 26). This shows a reducing similarity in microalgae community composition until 2010/11 and then an increase in similarity until 2012/13 and then a decline again. Note that although in 2012/13 the similarity with the reference year is almost equivalent to that observed in 2006/07 the community composition between 2006/07 and 2013/14 is significantly different (Figure 25). Using the same reference year of 2005/06 the changes in both Lake Alexandrina and Lake Albert can be compared (Figure 26). Microalgae communities in the years 2005/06, 2006/07 and 2007/08 were not significantly different between the lakes while all following years up to the present were significantly different. The pattern of change shown for Lake Alexandrina differs from that in Figure 19

(a)

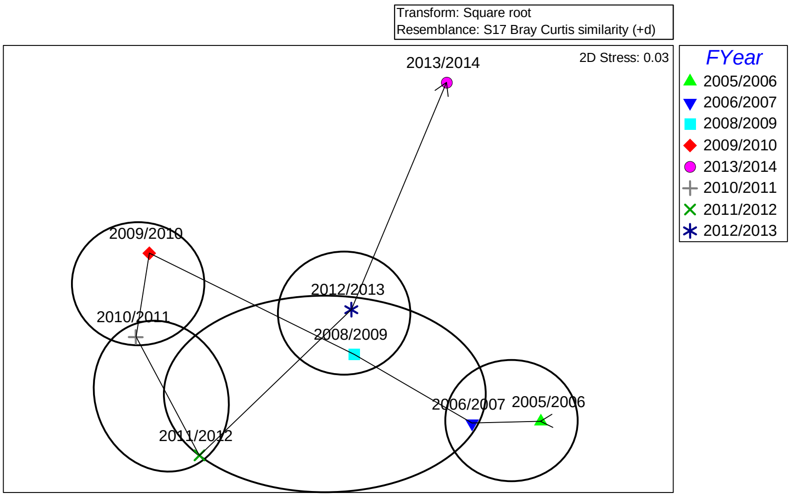


Figure 25 Time sequence of changes in microalgae community composition in Lake Albert based on centroids of financial year average seasonal community data. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal microalgae community composition.

where a different reference year was used, indicating that although these visualisations are useful they are not consistent and will vary depending on the reference year applied.

The actual abundances of the major microalgae groups in Lake Albert are shown for the two longest sampled sites (Figure 27a, b) and a comparison site in Lake Alexandrina (Figure 27c). Other sites from Lake Alexandrina are shown in Figure 21. The "Meningie" site in Lake Albert was sampled from 2005/06 onwards except for a gap during the end of the drought and return of flow periods. This gap period is covered by the sampling from the "Water Level Recorder" site. General patterns across all sites are quite similar at the microalgae group level, with cyanobacteria dominating the communities but with significant contributions from chlorophytes and diatoms. There is an overall decline in cyanobacteria numbers in Lake Alexandrina following the return of flows in 2010, although the cyanobacteria still dominated the microalgae community. Further analyses at this higher microalgae group level would provide an informative contrast with the genera based analyses.

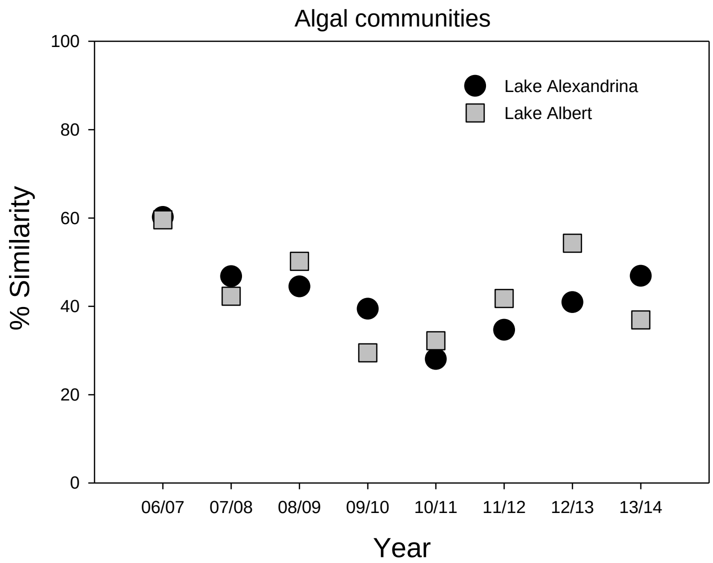
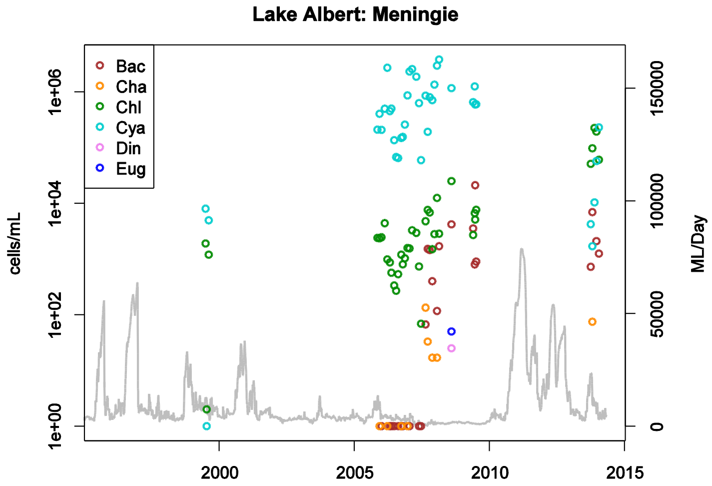
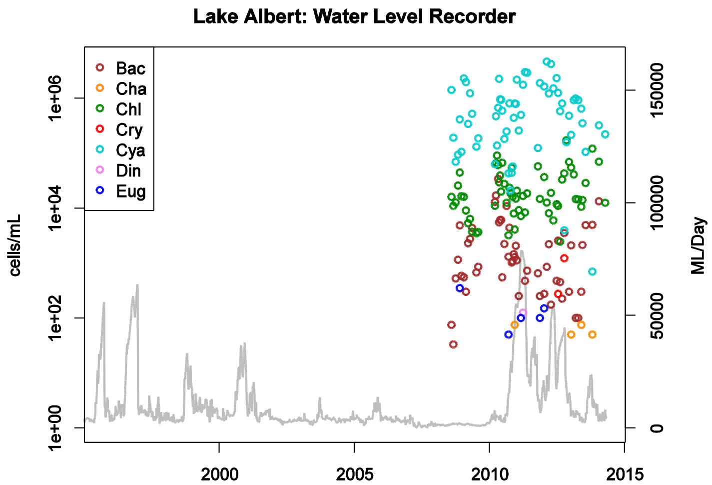


Figure 26 Similarity between microalgae communities in Lake Albert and Lake Alexandrina using 2005/06 as a reference point

(a)



(b)



(c)

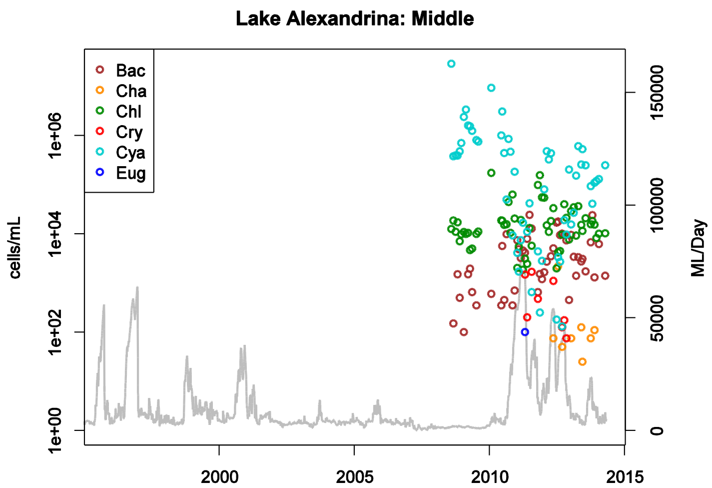


Figure 27 Time series at two sampling sites in Lake Albert (a) Meningie, (b) Water Level Recroder, and one in Lake Alexandrina (c) Middle, of major microalgae group abundances. Bacillariophyceae (Bac, diatoms), Charophyta (Cha), Chlorophyta (Chl, green algae), Cryptophyta (Cry), Cyanophyta (Cya, blue green algae), Dinophyceae (Din) and Euglenophyceae (Eug).

3.2.4 GOOLWA CHANNEL

A comparison of Lake Alexandrina and the Goolwa Channel using nMDS of microalgae communities from 1982 through to 2014 indicated periods of distinct separation in community composition and also periods of overlap (Figure 28a). The Goolwa Channel was not sampled for microalgae when the 1982-1998 historic data was collected at Milang (Figure 28b), but there was some overlap of sampling from 2005/06 onwards (Figure 28c) during the drought and post-drought periods (Figure 28d). Seasonal sampling was relatively evenly spread across the sampling periods (Figure 28d) and analyses were carried out at the level of seasons and financial years using seasonal values as replicates. It can be seen from this set of figures that the Goolwa Channel drought samples differed from all others while the post-drought for Lake Alexandrina and the Goolwa Channel overlaped, but are closer to the Lake Alexandrina drought conditions than to the pre-drought period (Figure 28a). The Goolwa Channel drought samples were from a number of sites suggesting that the microalgae of the channel proper and the creek sites were changing in similar ways (Figure 28c). The period of this major shift was between 2008/09 and 2010/11 and started prior to the construction of the regulators, suggesting that they were not necessarily responsible for the shift in community composition. However, the shift of the microalgae community after 2010/11 back to being more similar to Lake Alexandrina and to drought communities prior to the construction of the regulator suggested that the removal of the separating wall had a marked effect.

Overlays of water quality and microalgae genera on the changes in microalgae community composition using Pearson Correlations suggested that increases in conductivity and reduced turbidity were associated with the drought period in the Goolwa Channel. Increased occurrences of the chlorophyte, *Planctonema* were associated with the pre-drought period, presumably because of the influence of the historical Milang sites on the analyis, while cyanobacteria were associated with the drought and post-drought periods (Figures 29a, b).

The microalgae data from the Goolwa Channel were analysed separately in more detail with the years of sampling and the sampling sites shown in Figures 30a, b and the influences of water quality and microalgae genera in Figures 30c, d. Drought samples collected during the period 2008/09 to 2010/11 were substantially different in microalgae composition as described previously. The correlations in this smaller data set were weaker and the Pearson Correlations were accordingly reduced to demonstrate associations. As was found when the Lake Alexandrina and Goolwa Channel data were analysed together, conductivity and turbidity were the water quality characteristics from the selected set that most strongly associated with alterations in microalgae community composition. Unlike the combined analysis that showed a major influence of the green alga *Planctonema*, presumably because of its occurrence historically at the Milang site, the strongest influences on the microalgae in the Goolwa Channel comprised a shift between cyanobacteria genera during the drought and post-drought periods (Figure 30c).

To visualise the sequential shift in community composition within the Goolwa Channel centroids of the seasonal data for each financial year were determined and the sequence of years connected with a line (Figure 31). Periods that are not significantly different according to a PERMANOVA analysis are enclosed in ellipses. There is a clear shift in microalgae community composition over time especially during 2008/09,

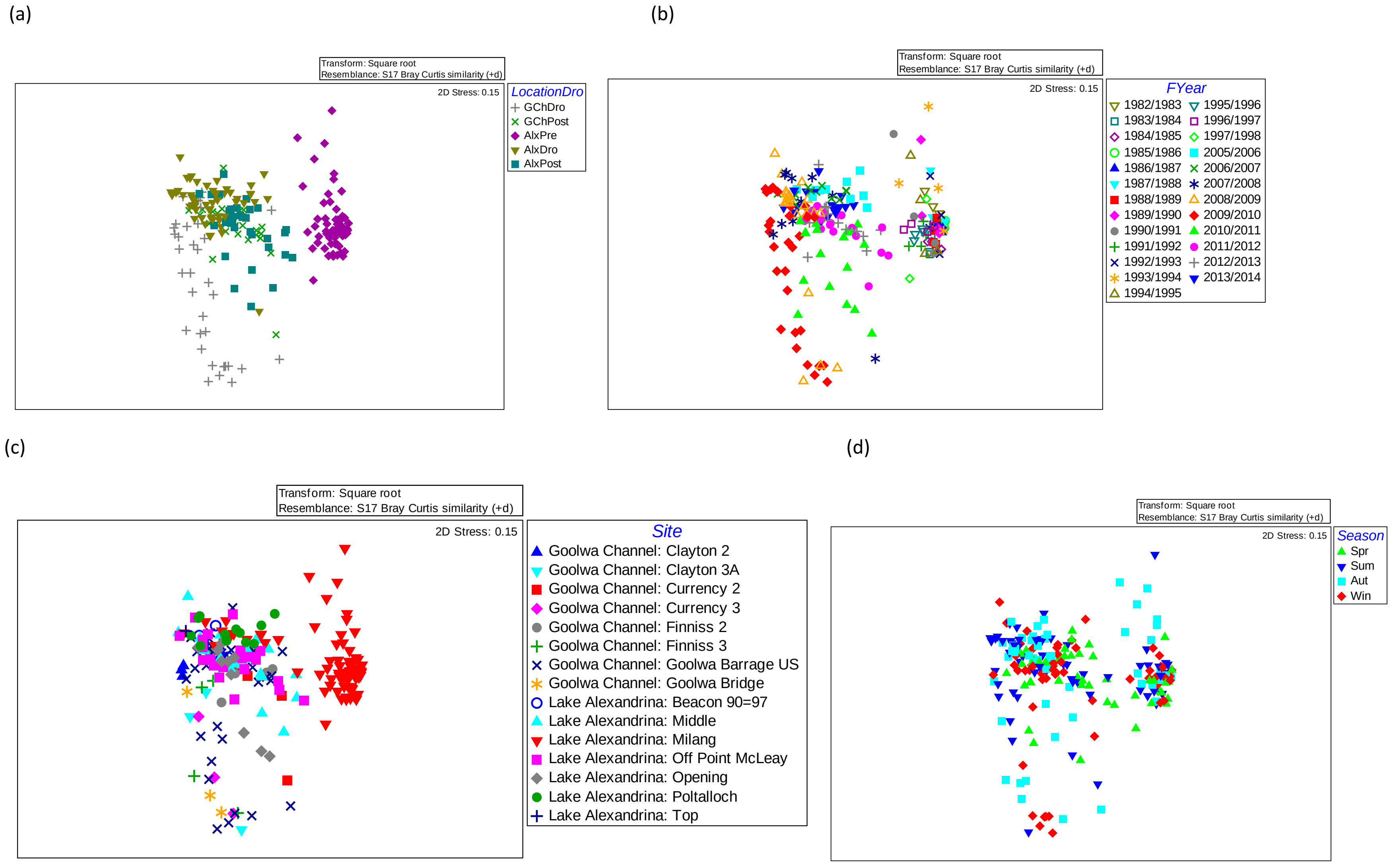
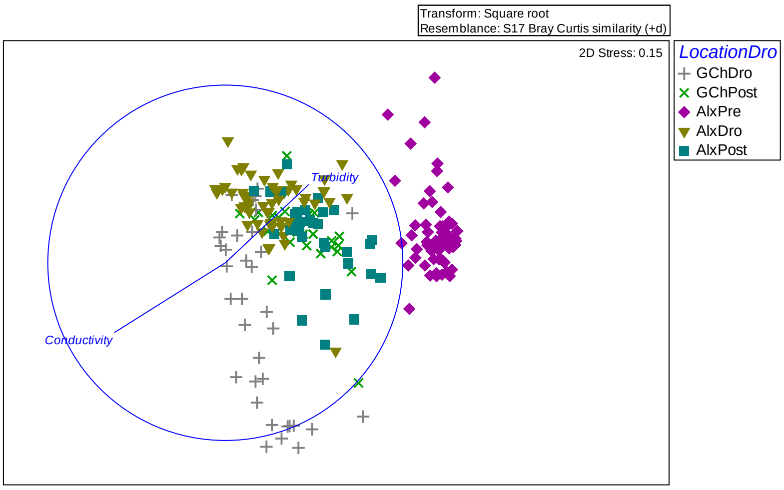


Figure 28 Microalgae community composition changes in Lake Alexandrina and the Goolwa Channel displayed together using nMDS with re-coding of seasonal average data points to depict (a) Sampling sites and the time sampled in relation to drought indicated by Pre (pre-drought), Dro (drought) and Post (post-drought) (b) sampling years (c) sampling sites (d) sampling seasons.

2009/10 and 2010/11, but the post-drought communities of 2011/12 to 2013/14 are not significantly different from the drought communities of 2005/06 to 2007/08. The significant shift in the microalgae community in the latter part of the drought did not seem to be associated with the construction of the regulators, but it would appear that the removal of the Goolwa Channel Regulator influenced the community composition, presumably due to the reconnection with Lake Alexandrina.

The time series of abundance of genera contributing to the microalgae community composition showed the dominance of cyanobacteria in the Goolwa Channel during the period it was sampled (Figure 32a, b, c.). Both Currency Creek and the Finniss River had very similar compositions and abundances of microalgae and these were also similar to data from upstream of the Goolwa Barrage and in the channel itself. However, PERMANOVA indicated that at times river sites were different from the Channel sites and further exploration of the data is warranted to see if these differences reflect detailed changes in water chemistry.

(a)



(b)

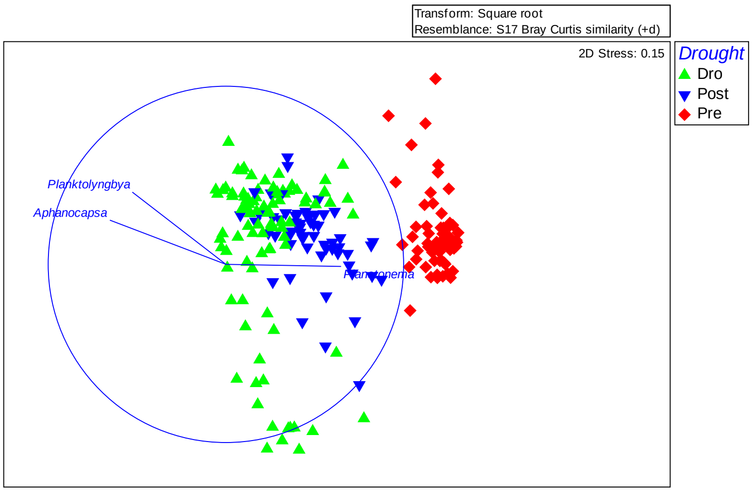


Figure 29 Microalgae community composition changes in Lake Alexandrina and the Goolwa Channel described using nMDS with overlays of influences from (a) water quality parameters (Pearson Correlation>0.5) (b) microalgae genera (Pearson Correlation>0.6)

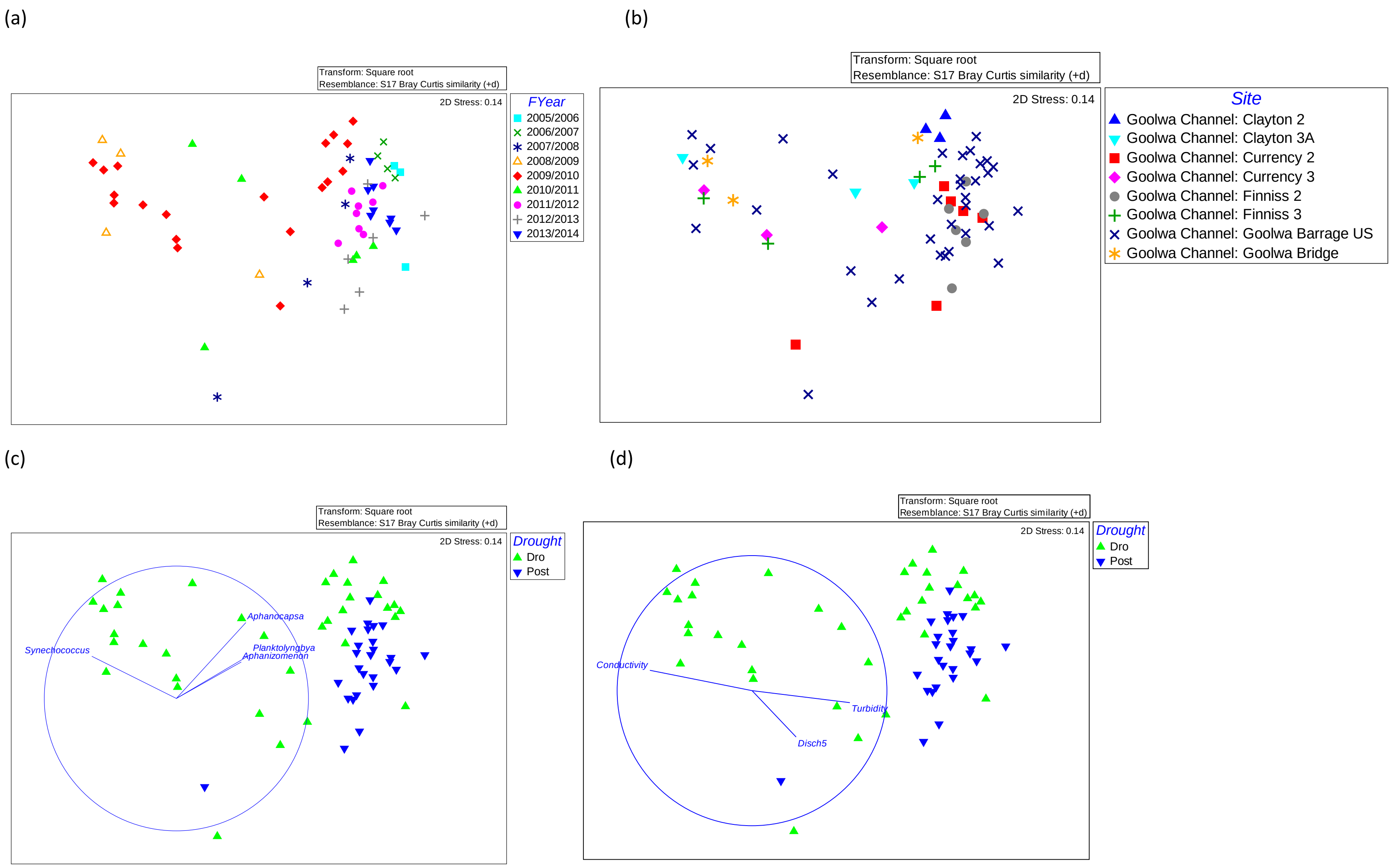


Figure 30 Microalgae community composition changes in Goolwa Channel described using nMDS with re-coding of seasonal average data points to depict (a) financial years (b) Sites. Drought (Dro) and Post-drought (Post) samplings with overlays of influences from (c) microalgae genera (Pearson Correlation>0.55) (d) water quality parameters (Pearsons Correlation>0.45).

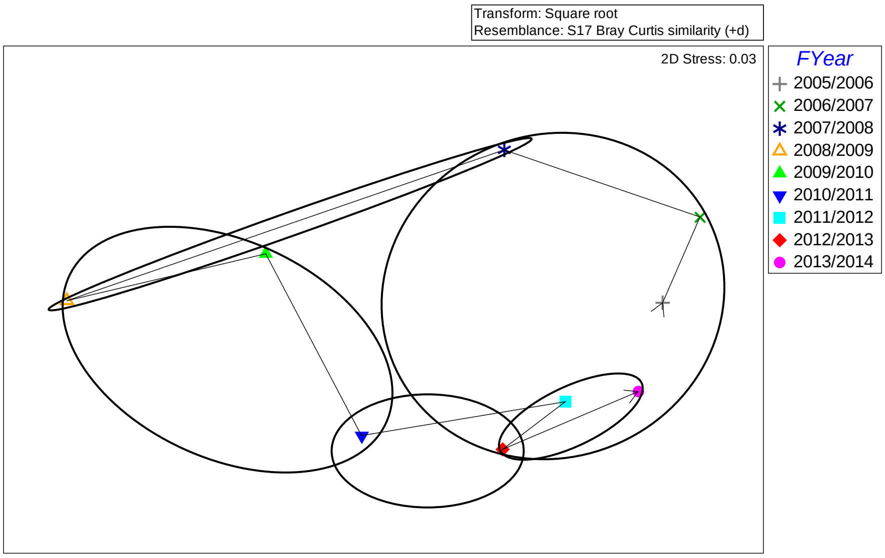
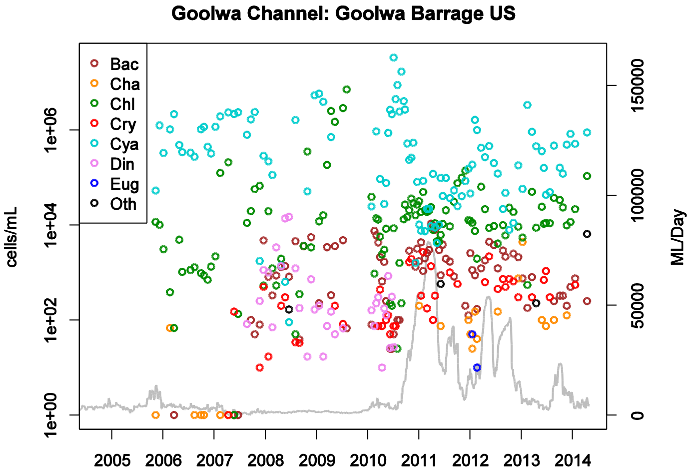


Figure 31 Time sequence of changes in microalgae community composition in Goolwa Channel based on centroids of financial year average seasonal community data. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal microalgae community composition.

(a)



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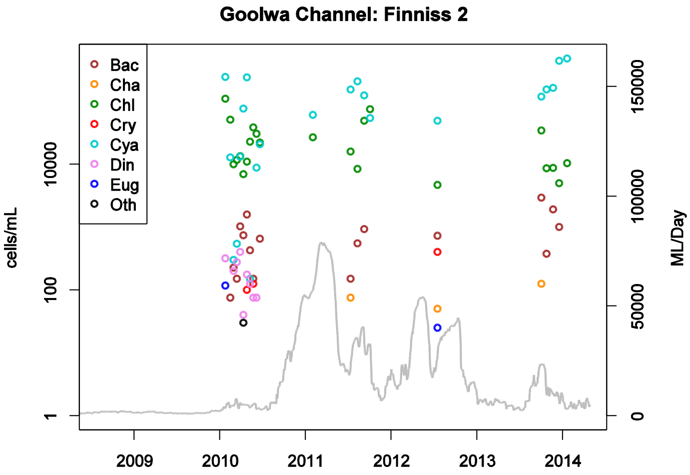


(c)

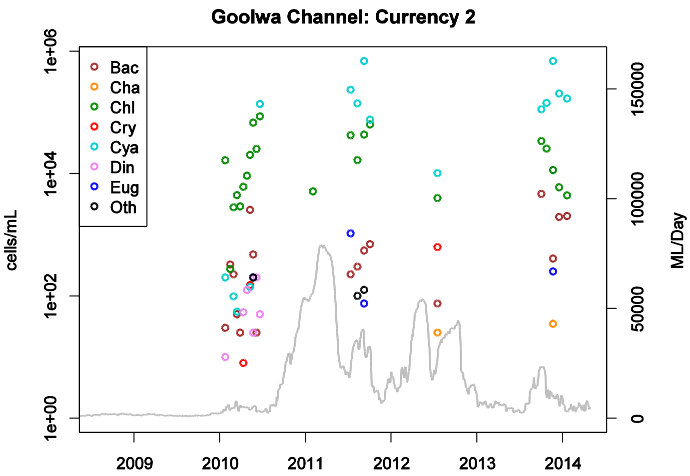


Figure 32 Time series of abundances of major microalgae groups at three sites in the Goolwa Channel (a) Goolwa Barrage Upstream (b) Finniss 2 (c) Currency 2.

3.2.5 COORONG

The available data regarding microalgae in the Coorong commenced from 2010/11 constraining the opportunity for analyses. The sampling effort was not uniform across the three Coorong locations with the

Murray Mouth sampled in 2005/06, 2010/11 and 2012/13; the Northern Coorong in 2010/11 and 2013/14 and the Southern Coorong in 2013/14 (Figure 33a). Only the 2005/2006 data from the Murray Mouth was collected in the period considered to be drought, the rest were in the post-drought period. There was insufficient data to compare across years and PERMANOVA on each of the sampling sites showed that within-site differences were not significant. However comparing across sites (Figure 33b) suggests some major differences along the Coorong with the adjacent sites Parnka-Villa in the Coorong South and Long Point in the Coorong North particularly different from other sites (Figure 33b). Overlays of associated microalgae genera and water quality parameters indicated that shifts were largely associated with changes in the mixtures of microalgae genera, especially cyanobacteria, green algae and dinoflagellates. Of the water quality parameters, increased discharge and turbidity versus increased conductivity influenced a major dimension of the differences between sites, while TN was associated with a second dimension of change. A PERMANOVA confirmed that there were significant differences between sites, and to depict these changes the centroids of the seasonal data at each site were plotted and joined in sequence along the Coorong from north to south (Figure 34). Ellipses enclose samples that are not significantly different. The Murray Mouth and Northern Coorong sites were found to be similar but towards the southern end of the Northern Coorong and into the Southern Coorong significant differences in microalgae communities occurred.

To provide more detail on these changes the percentage contribution of the major microalgae groups to community composition at sampling sites along the Coorong was depicted over time (Figure 35). In 2010/11 sites were similar along the Coorong on each of the sampling occasions. In 2011/12 there was a marked difference between the Murray Mouth section of the Coorong which was dominated by cyanobacteria and the southern end of the Coorong which was dominated by chlorophytes. In 2012/13 there appeared to be a shift in the chlorophyte peak northwards along the Coorong with cyanobacteria appearing at the Parnka-Villa site while Mark Point was dominated by chlorophytes. In 2013/14 there was a complex mixture of microalgae groups along the length of the Coorong. These intricate patterns reflect the complex water mixing and hydrological transport along the Coorong. A model has been devised to describe the longitudinal processes of water movement and salt transport (Webster 2007) and the monitoring data provides an opportunity to align this process model with the statistical assessment of community change.

A further analysis to depict the changes along the Coorong involved identifying the genera of microalgae that at each of the sampling sites contributed 90% of the average total abundance at that site over the monitoring period (Table 3). Major differences are obvious in the distributions of genera with clear changes occurring between Tauwitchere and Mark Point and these are apparent in the pie charts of the percentage distribution of these genera at each site (Figure 36). Further detailed analyses of these trends in conjunction with the hydrodynamic model are warranted.

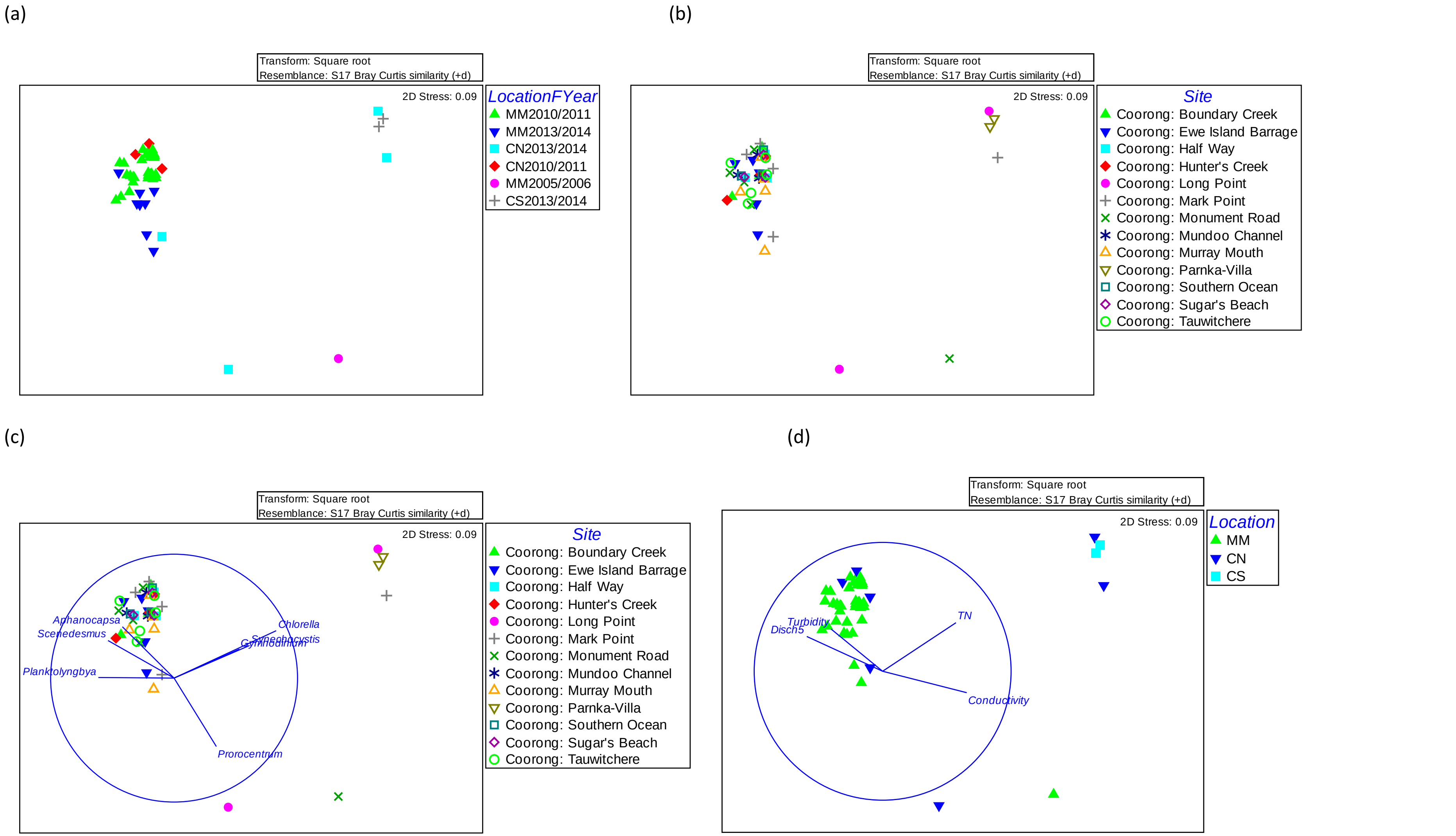


Figure 33 Microalgae community composition changes in the Coorong described using nMDS with re-coding of seasonal average data points to depict (a) Location and financial years of sampling in Murray Mouth (MM), Coorong North (CN) and Coorong South (CS) (b) sampling sites (c) sampling sites with overlays of influences from microalgae genera (Pearson Correlation>0.55), (d) locations with overlays of influences from water quality parameters (Pearsons Correlation>0.5).

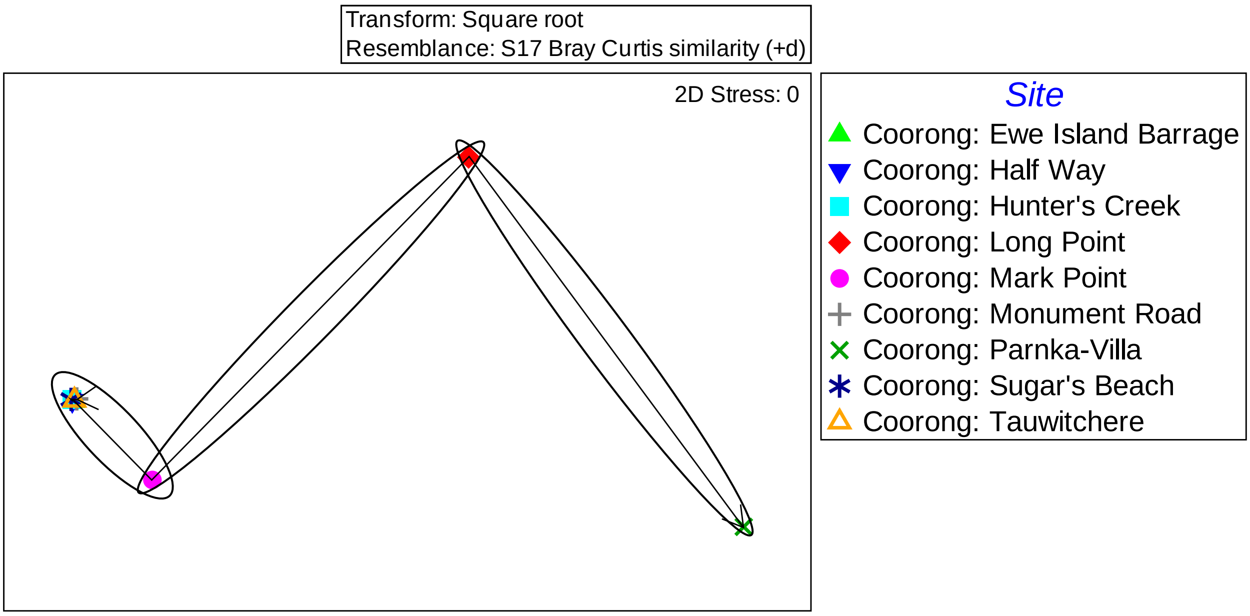


Figure 34 Longitudinal comparisons changes in microalgae community composition in central sites along the Coorong based on centroids of average seasonal community data. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal microalgae community composition.

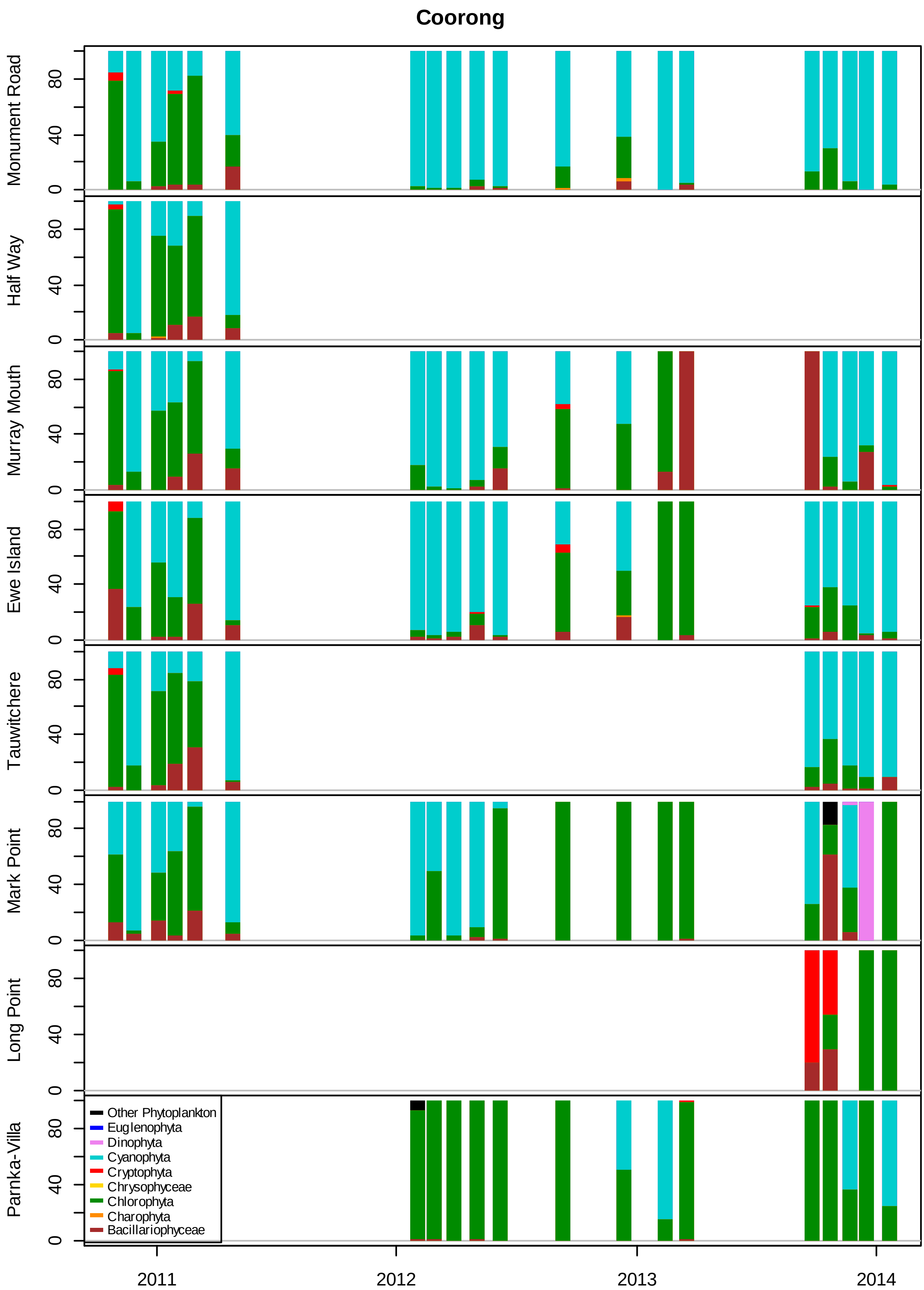


Figure 35 Percent contribution of major microalgae groups to community composition over time at sampling sites along the Coorong, from Monument Road in the Murray Mouth location to Parnka-Villa in the Coorong South location. Each bar is a sampling occasion.

Table 3 Average abundances (cells/mL) of the genera of microalgae contributing 90% of the average total cell abundance at sampling sites along the Coorong over the monitoring period.

Genera	Monument Road	Halfway	Sugar's Beach	Ewe Island	Tauwitchere	Mark Point	Long Point	Parnka Villa
Chlorella	0	0	0	0	0	22476	557500	1219666
Aphanocapsa	32077	33058	40888	21453	33668	31453	0	0
Planktolyngbya	22190	7856	12822	9681	27117	2522	0	0
Coelosphaerium	4691	9433	18166	1270	7800	6270	0	0
Planctonema	4276	4701	8046	3458	3670	0	0	0
Merismopedia	3475	6096	0	0	0	8293	0	0
Tetrastrum	2320	2743	4238	1350	0	0	0	0
Oocystis	0	2930	3047	1252	1987	0	0	0
Staurosira	0	0	3742	1938	2733	0	0	0
Crucigenia	2102	0	0	1896	3166	0	0	0
Ankistrodesmus	0	0	0	0	0	2484	0	0
Cyanogranis	0	0	0	1080	0	0	0	0

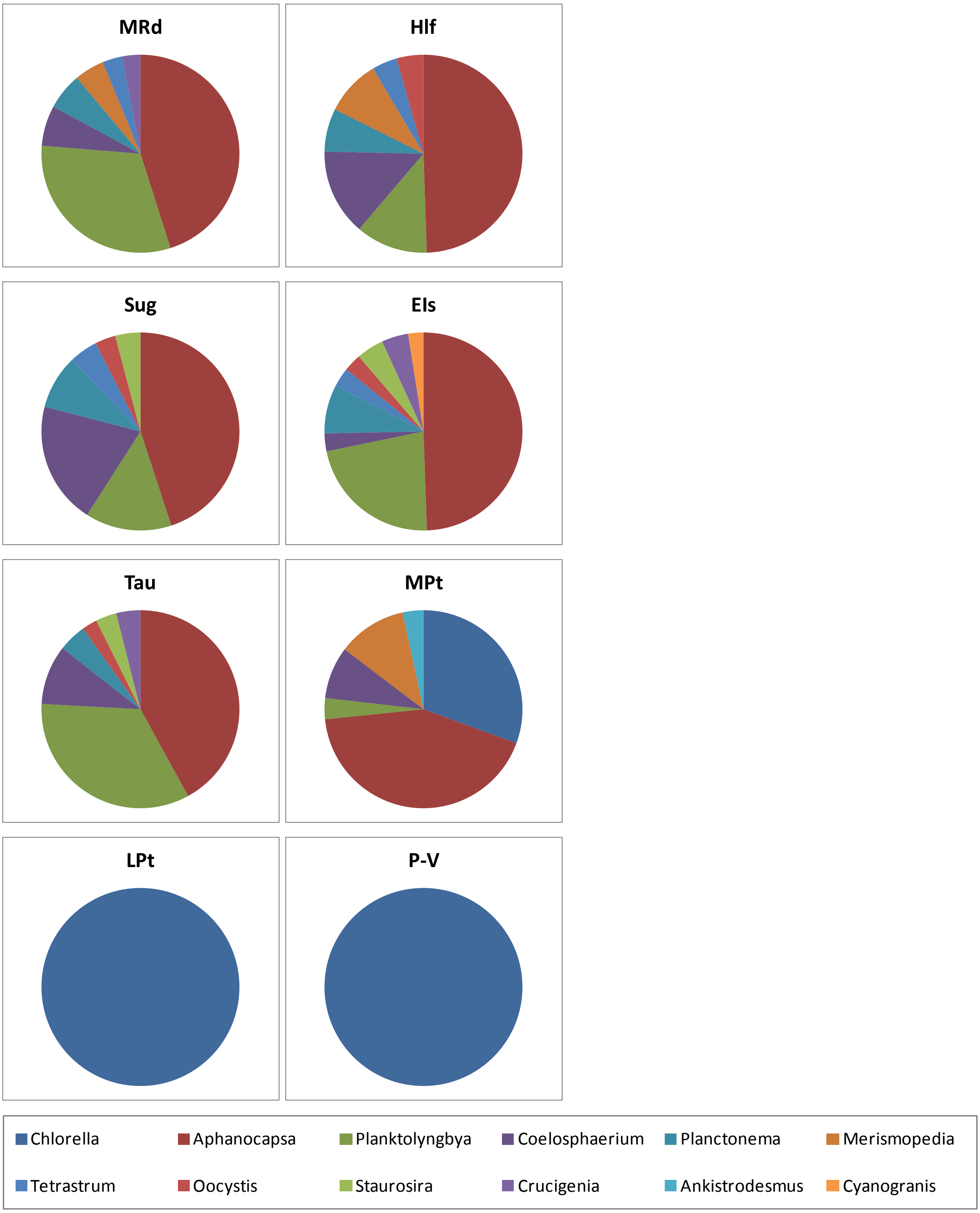


Figure 36 Average percentage abundances of microalgae genera contributing 90% of the total abundance at sampling sites along the Coorong. Monument Road (MRd), Halfway (Hlf), Sugar's Beach (Sug), Ewe Island (EIs), Tauwitchere (Tau), Mark Point (MPt), Long Point (LPt), Parnka-Villa (P-V). Note that not all genera occur on all charts and the colour sequence progresses from the top in a clock-wise direction in the order shown across the rows in the legend. The charts are interpreted in conjunction with Table 3 that shows the contribution of each genus at each site.

3.3 Zooplankton

3.3.1 SYSTEM SCALE COMPARISONS OF ZOOPLANKTON COMMUNITIES

Zooplankton samples have been collected from locations within the CLLMM since 2010/11 (Figure 37a, b). Sites in Lake Alexandrina, Lake Albert, Goolwa Channel, Murray Mouth and Coorong North were sampled each year, while the Coorong South locations were only sampled in 2012/13 and 2013/14. An nMDS of the total zooplankton abundance data shows some distinct differences from the general pattern of overlap of community composition across the major locations (Figure 37a). A PERMANOVA based on this data showed that all pair-wise comparisons of locations were significantly different. A PERMANOVA of financial years within locations indicated that the zooplankton community in Lake Alexandrina, Lake Albert and Goolwa Channel changed significantly between years. In the Murray Mouth and Coorong North locations all years were different except for 2012/13 and 2013/14, while in the Coorong South location there was no significant difference in zooplankton community composition between the two years that were sampled, 2012/13 and 2013/14. Although the total data set describes zooplankton communities across a wide range of sites, each of which may be responding to different environmental conditions, an overlay of zooplankton associated with the changes in community composition identified three particular species with a Pearson Correlation of>0.55, *Filinia pejleri*, *Keratella tropica* and *Stenosomella lacustris*. It cannot be determined from this correlation whether these species are associated with cross-site differences (Figure 37a), annual differences (Figure 37b) or other influences e.g. seasonal effects.

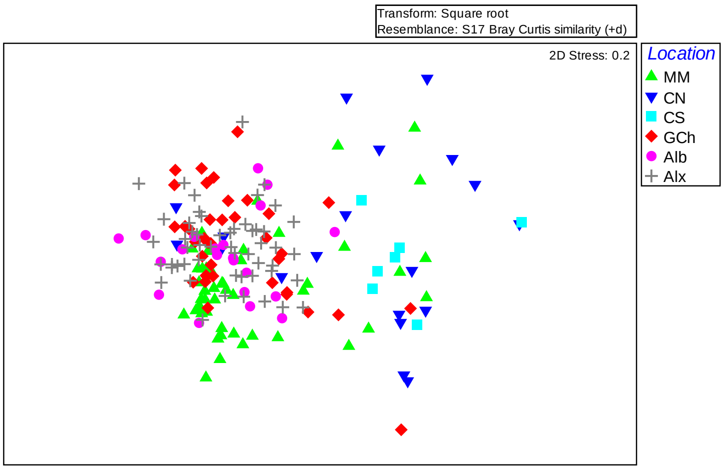
A more detailed assessment of the contribution of particular zooplankton to the differences in community compositions observed across the CLLMM region is presented in Table 4. This lists, for each of the major locations, the percentage abundance over the sampling period of organisms contributing 90% of the average abundance. To help visualise the differences these data are presented in Pie charts of percentage distributions which show clear differences between locations (Figure 38).

Based on the monitoring data from 2010/11 onwards, the Lake Alexandrina/Goolwa Channel sites had a freshwater zooplankton assemblage dominated by River Murray taxa, primarily rotifers and juvenile stages of copepods. Higher diversities in the Goolwa Channel reflected inputs from Currency Creek and the Finniss River, which supported discrete assemblages of riparian/epiphytic/epibenthic/littoral microfauna that appeared in the zooplankton during high flows but which are not 'technically' planktonic, e.g., *Difflugia* and other testate Rhizopoda.

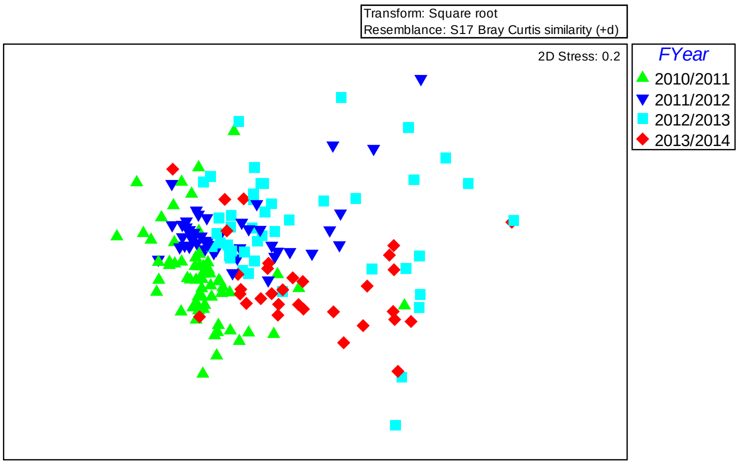
Halotolerant taxa were present in the Lake Albert site. The rotifer *Filinia pejleri* had its greatest density in Lake Albert and *Hexarthra brandorffi* was found only there, while other rotifers, e.g. *Keratella australis* occurred that are known to be tolerant of moderate salinities. An undescribed *Synchaeta* may also be halotolerant.

Based on the monitoring data from 2012/13 onwards, the Southern Coorong contained obligate halophile assemblages. These included the estuarine or inshore marine calanoid *Acartia*, the ostracod *Diacypris* (common in salt lakes in the SE), and a small group of known estuarine/marine rotifers, including *Testudinella obscura,* along with one or more species of *Synchaeta*, and an unidentified contracted species, possibly a proalid. These taxa were also recorded in the southern end of the Northern Coorong where lower salinities during the study period were suggested by the presence of a suite of tintinnid ciliates including the River Murray freshwater tintinnid, *Stenosomella lacustris*. Tintinnids were notably absent from the Southern Coorong samples, possibly due to hypersaline conditions above their tolerances. Species of *Synchaeta* in the Northern Coorong sites appeared to be halotolerant as they occurred also in Southern Coorong sites. The northern sites also contained River Murray freshwater incursion species from either the Goolwa Channel or Lake Alexandrina barrage openings.

(a)



(b)



(c)

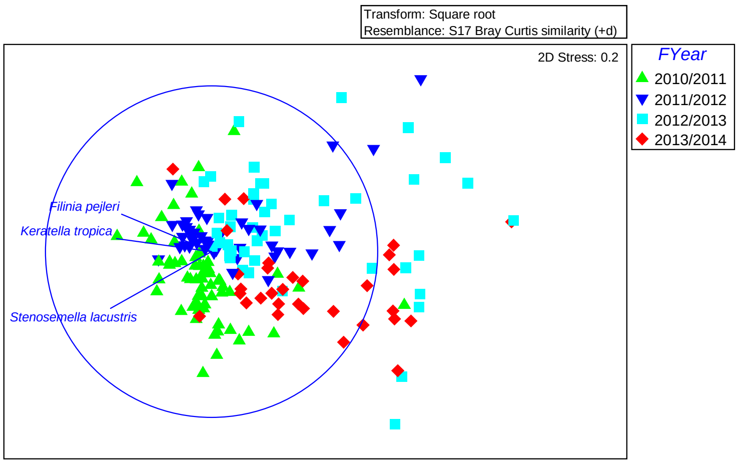


Figure 37 Zooplankton community comparisons analysed using nMDS with re-coding of seasonal average data points to depict (a) the different locations in Lake Alexandrina (Alx), Lake Albert(Alb), Goolwa Channel (GCh), Southern Coorong (CS), Northern Coorong (CN) and Murray Mouth (MM), (b) financial years (c) sampling years with overlays of influences of zooplankton genera (Pearson Correlation>0.55).

Table 4 Average abundances (organisms/L) of the genera of zooplankton contributing 90% of the total abundance at major locations

Species	Lake Alexandrina	Lake Albert	Goolwa	Murray Mouth	Coorong North	Coorong South
Stenosemella lacustris	448.1	775.7	160.5	609.1	62.0	0.0
Filinia pejleri	155.7	594.7	251.2	27.7	36.5	0.0
Synchaeta sp.	129.3	144.0	59.6	12.4	100.3	1.7
Keratella tropica	49.1	43.8	90.7	44.8	23.2	0.0
Difflugia sp.	33.1	0.0	66.1	112.8	0.0	0.0
calanoid nauplii	39.2	51.8	55.1	32.8	25.9	42.3
ciliate	138.5	37.1	66.9	0.0	0.0	0.0
Hexarthra brandorffi	0.0	241.5	0.0	0.0	0.0	0.0
Proalides tentaculatus	39.0	0.0	39.0	0.0	88.2	0.0
Difflugia globulosa	81.1	0.0	52.8	17.6	0.0	0.0
Trichocerca pusilla	45.4	61.4	25.2	15.3	0.0	0.0
Polyarthra dolichoptera	77.8	0.0	22.8	0.0	0.0	0.0
rotifer	23.9	0.0	14.2	0.0	22.4	9.2
Keratella australis	0.0	65.2	0.0	0.0	0.0	0.0
Cothurnia sp.	0.0	0.0	0.0	0.0	47.7	0.0
Hexarthra intermedia	0.0	0.0	45.4	0.0	0.0	0.0
Brachionus angularis	18.0	0.0	23.8	0.0	0.0	0.0
Filinia australiensis	0.0	0.0	23.5	0.0	0.0	0.0
Brachionus diversicornis	0.0	0.0	22.1	0.0	0.0	0.0
Keratella procurva	0.0	0.0	18.8	0.0	0.0	0.0
Difflugia gramen	0.0	0.0	17.9	0.0	0.0	0.0
tintinnids	0.0	0.0	0.0	0.0	14.3	0.0
Epistylis sp.	11.8	0.0	0.0	0.0	0.0	0.0
Filinia longiseta	11.3	0.0	0.0	0.0	0.0	0.0
calanoid copepodites	0.0	0.0	0.0	0.0	0.0	7.7
Acartia sp.	0.0	0.0	0.0	0.0	0.0	5.8
Diacypris sp.	0.0	0.0	0.0	0.0	0.0	3.1
Testudinella obscura	0.0	0.0	0.0	0.0	0.0	2.9
Cyprididae	0.0	0.0	0.0	0.0	0.0	1.8

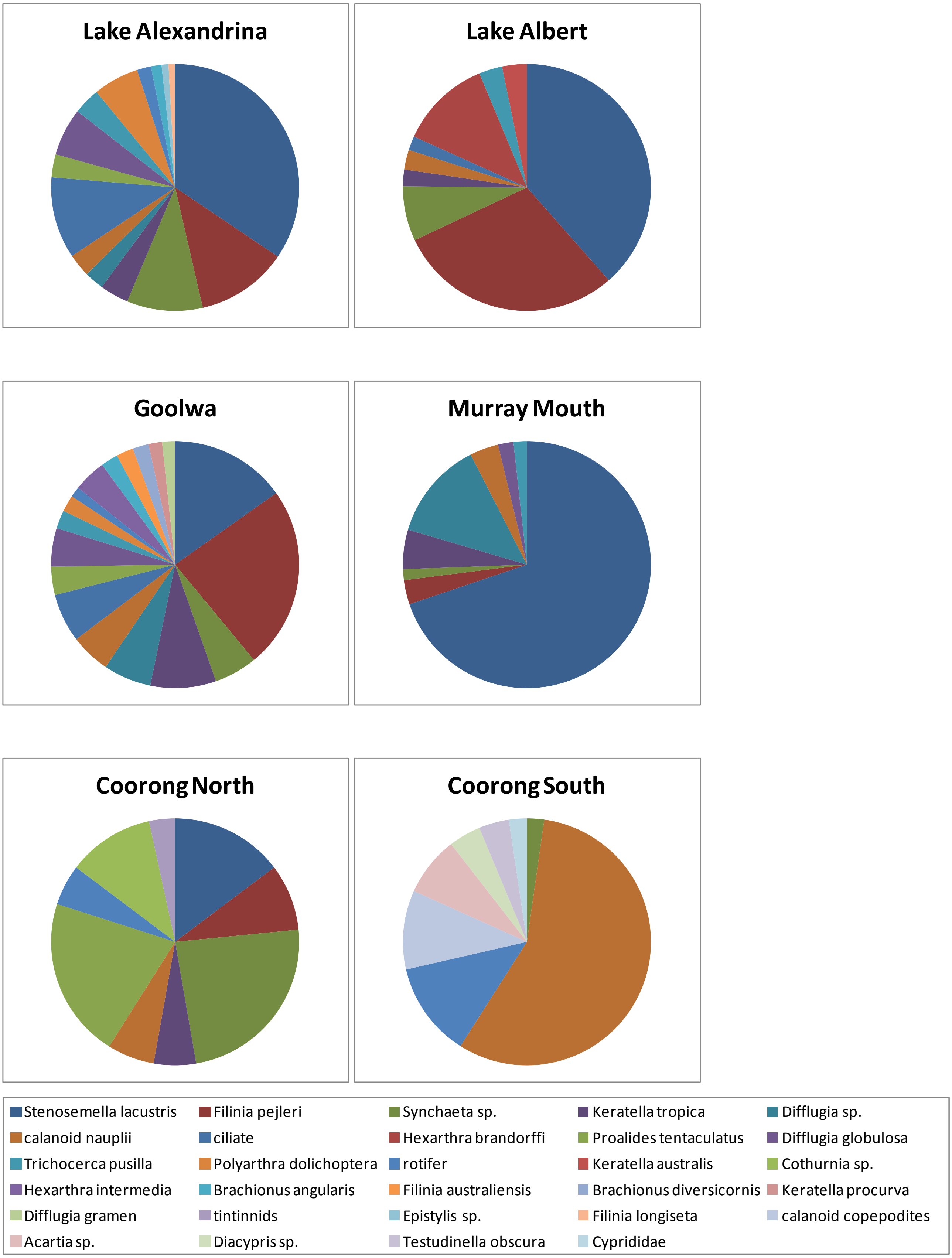


Figure 38 Average percentage abundances of zooplankton accounting for 90% of the total average abundance at the locations shown in the chart titles. See Table 4 for details.

These results reflect a dynamic array of zooplankton communities changing over space and time in response to environmental and biotic interactions. The objective was to describe these changes in community composition, investigate the influences that may be causing them and to assess whether the community had changed in response to the drought and if so whether it had returned to its pre-drought state. Unfortunately, little zooplankton sampling was undertaken during the drought and the few samples taken were restricted to the Murray Mouth and Coorong North locations, so analyses focused more on whether the zooplankton communities were changing over time following the drought.

3.3.2 INDIVIDUAL LOCATIONS AND COMPARISONS

Changes in zooplankton community composition were analysed at all locations and displayed using nMDS based on abundance data. In Lake Alexandrina PERMANOVA indicated that the zooplankton community composition was significantly different between all years (Figure 39a). An overlay of species contributing to the changes with Pearson Correlations of >0.7 suggested that *Polyarthra dolichoptera*, *Brachionus angularis* and *Keratella tropica* were associated with changes in community composition between 2010/11 to 2012/13 while *Synchaeta sp.* was associated with the changing communities between 2012/13 and 2013/14.

In Lake Albert, PERMANOVA indicated that the zooplankton community composition was significantly different between all years (Figure 39b). An overlay of species contributing to the changes with Pearson Correlations of >0.7 identified *Filinia pejleri, Brachionus calyciflorus amphiceros, Asplanchna brightwellii and Brachionus angularis* as associated with changes across all years, decreasing in abundance from 2010/11 onwards.

In the Goolwa Channel, PERMANOVA indicated that the zooplankton community composition was significantly different between all years (Figure 39c). An overlay of species contributing to the changes with Pearson Correlations of >0.7 identified *Filinia pejleri, Trichocerca pusilla, Brachionus diversicornis,* and an unidentified rotifer as associated with community changes between 2010/11 and 2011/12 and also associated with within year variations, while *Keratella tropica* was associated with shifts in community composition between 2011/12 to 2013/14. Care needs to be taken with these interpretations as there appears to be complicated associations between these species in the annual changes at this location.

In the Coorong, PERMANOVA indicated that the zooplankton community composition within each of the three locations, the Murray Mouth, Coorong North and Coorong South was significantly different between all years except 2012/13 and 2013/14 (Figure 39d). An overlay of species contributing to the changes with Pearson Correlations of >0.54 identified *Stenosomella lacustris* and *Keratella tropica* as associated with annual shifts in composition across the years while tintinnids and calanoid nauplii were additionally associated with changes between 2011/12 and 2012/13, and 2012/13 and 2013/14, as well as within year variations. As with the Goolwa Channel, these interpretations should be treated cautiously as there were complicated associations between these species at these sites.

The longitudinal differences in species associations with community composition and some of the complicated associations at locations in the Coorong are likely to reflect in part the longitudinal variation in water quality that existed over the period of zooplankton sampling (Figure 14). The microalgae also showed longitudinal variation in community composition in the Coorong (Figure 34). This possibility was investigated for the zooplankton through PERMANOVA of average seasonal data at the sampling sites along the Coorong. Significant differences were found between some sites and when collated they indicated that over the sampling period the Coorong South zooplankton communities were significantly different from those of the Coorong North and Murray Mouth which were not significantly different from each other. To visualise this, centroids of the seasonal zooplankton community data at each site over the sampling period were plotted and joined with a line showing the sequence of sites along the Coorong (Figure 40). Ellipses enclose those sites not significantly different from each other. This pattern mirrors the longitudinal variation observed for the microalgae and for water quality.

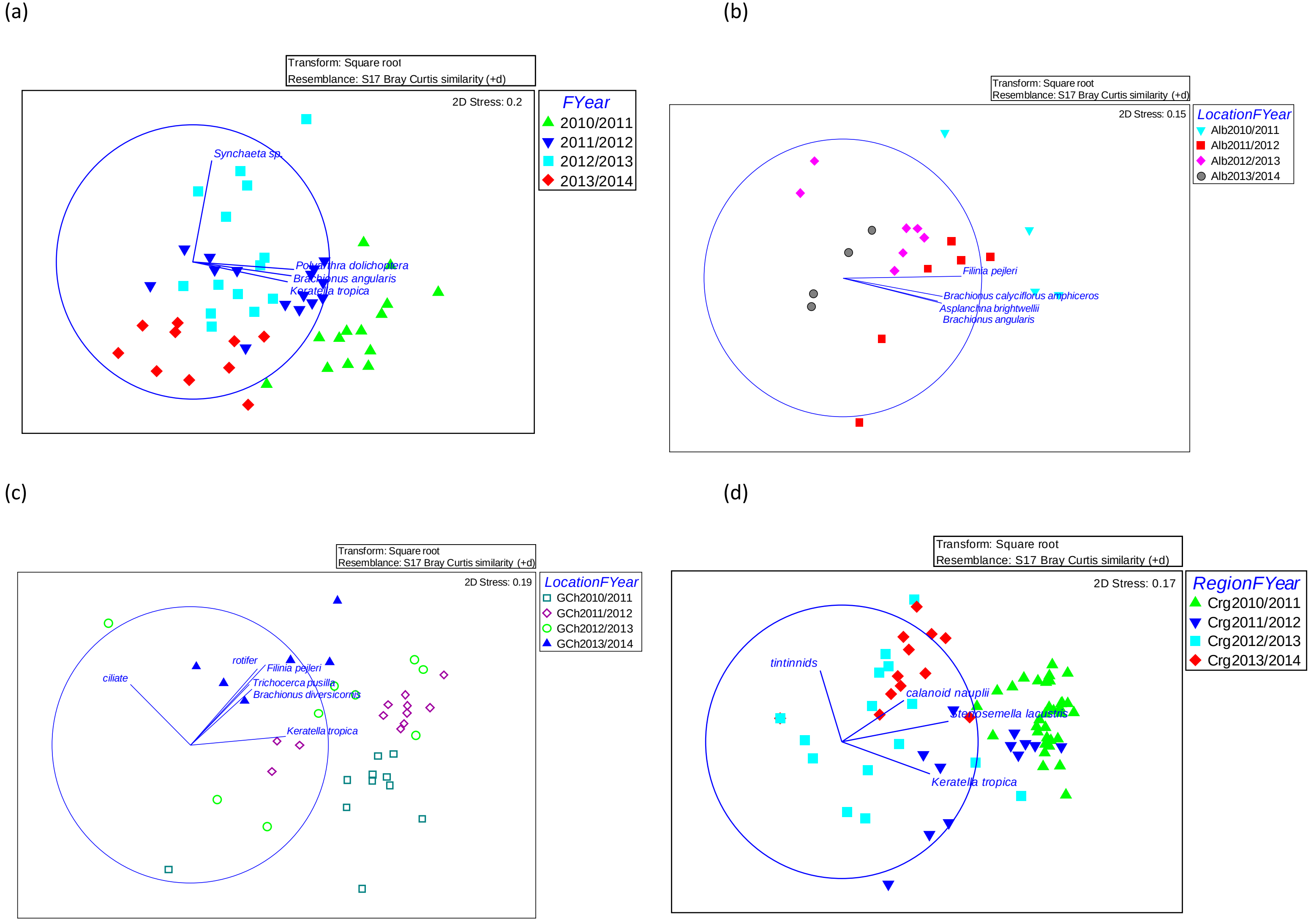


Figure 39 Zooplankton community composition changes displayed using nMDS showing locations and financial years of sampling with overlays of influences from zooplankton species for (a) Lake Alexandrina (Pearson Correlation>0.7), (b) Lake Albert (Pearson Correlation>0.7) (c) Goolwa Channel (Pearson Correlation>0.6) (d) Coorong (Pearson Correlation>0.54).

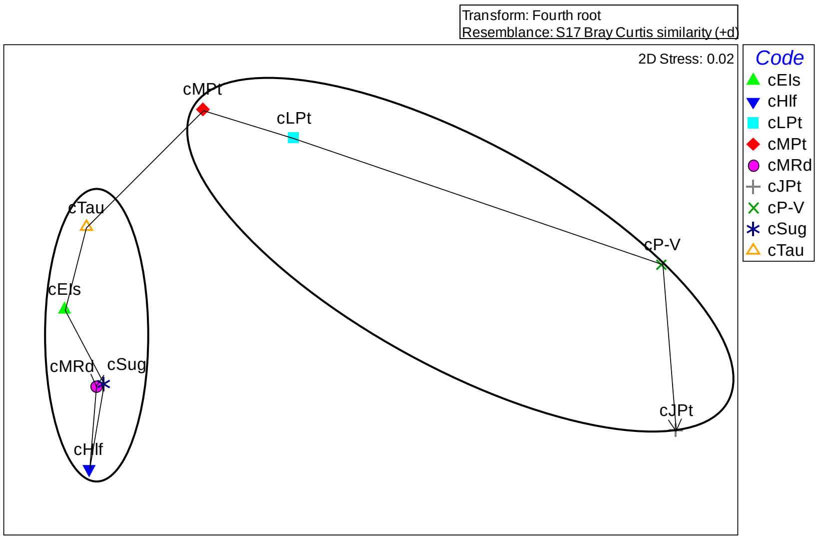


Figure 40 Time sequence of changes in zooplankton community composition in central sites along the Coorong based on centroids of financial year average seasonal community data. Ellipses enclose years that are not significantly different based on PERMANOVA of seasonal zooplankton community composition. Sites are Monument Road (cMRd), Halfway (cHlf), Sugar's Beach (cSug), Ewe Island (cEIS), Tauwitchere (cTau), Mark Point (cMPt), Long Point (cLPt), Parnka-Villa (cP-V), Jack Point (cJPt).

Changes in the zooplankton community composition included contributions from protists, and this was particularly influential in data from along the Coorong (Figure 41). However, it may not be appropriate including protists with the zooplankton when analysing community composition as they are microscopic and often very numerous, reducing the relative influence of the larger, and less numerous zooplankton (Figures 41, 42). The combined protist and zooplankton data was fourth root transformed to minimise this effect but further analyses are required to test these influences. The protists are small and difficult to identify and consequently are not identified with the same taxonomic resolution as the other plankton. Rhizopoda and Ciliophora were the major groups in the Coorong (Figure 43) with few other contributors so the sensitivity of community composition analysis is reduced, but further analyses are warranted.

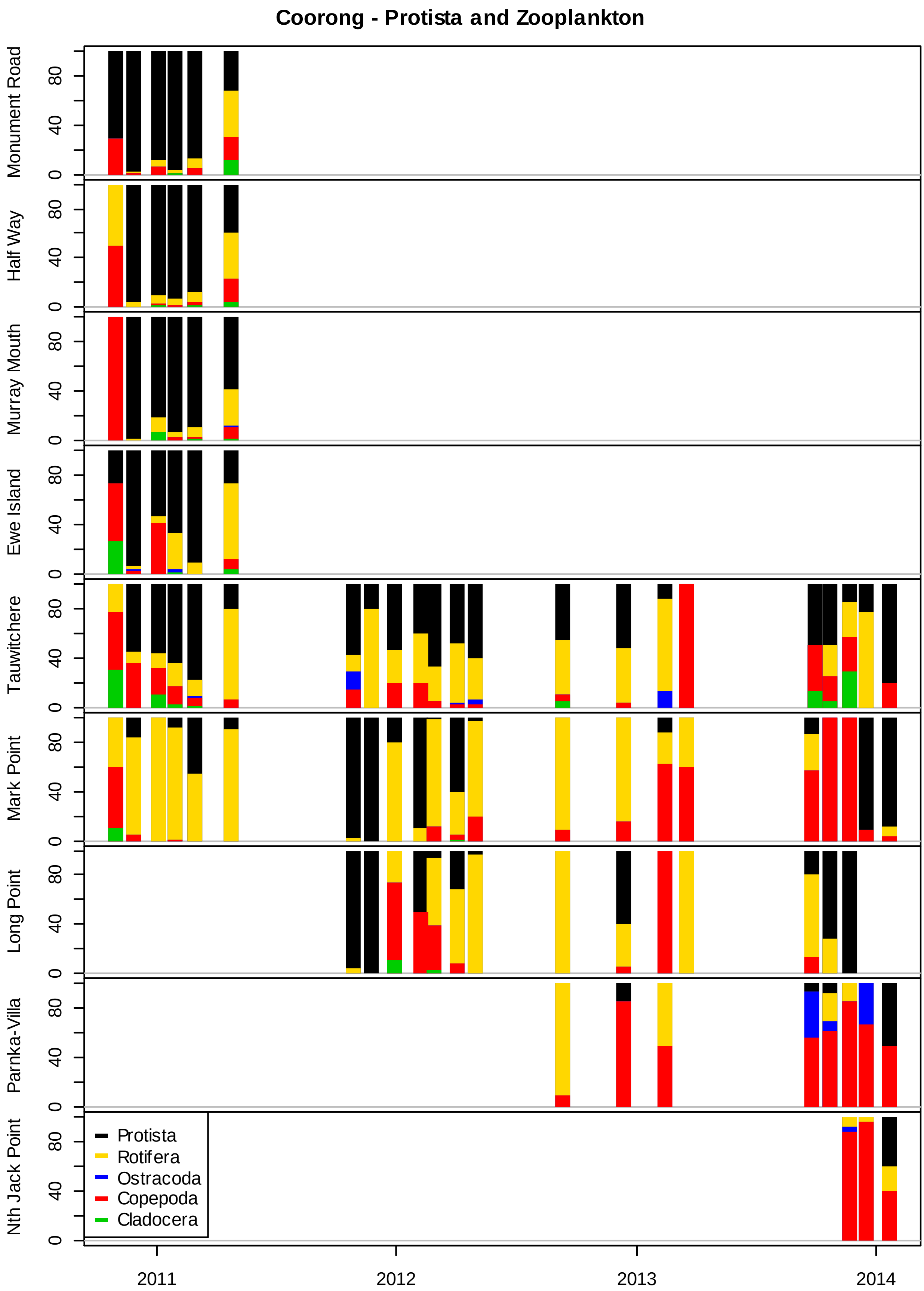


Figure 41 Percent contribution of major zooplankton groups including protista to community composition over time at sampling sites along the Coorong, from Monument Road in the Murray Mouth location to Parnka-Villa in the Coorong South location.

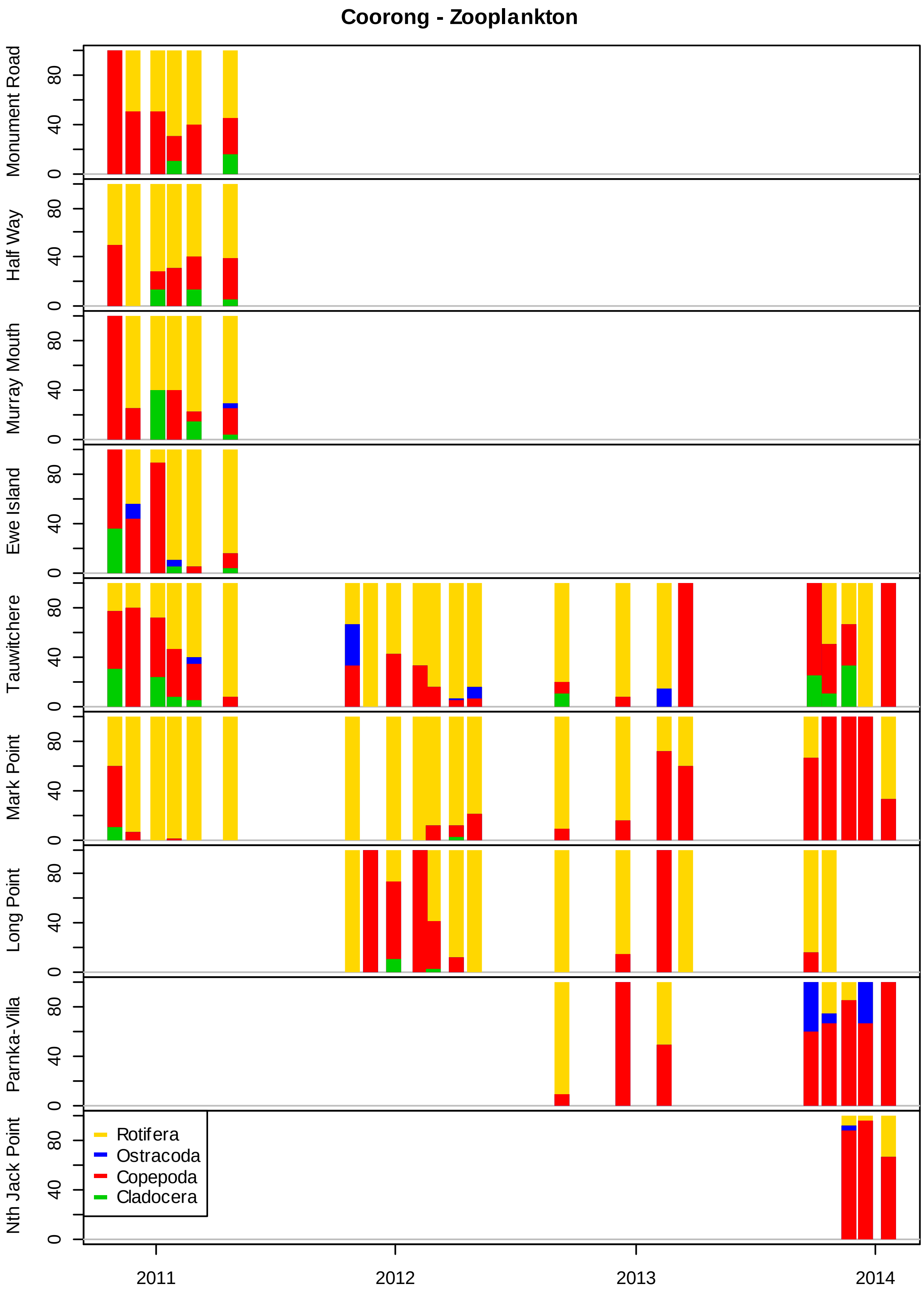


Figure 42 Percent contribution of major zooplankton groups to community composition over time at sampling sites along the Coorong, from Monument Road in the Murray Mouth location to Parnka-Villa in the Coorong South location.

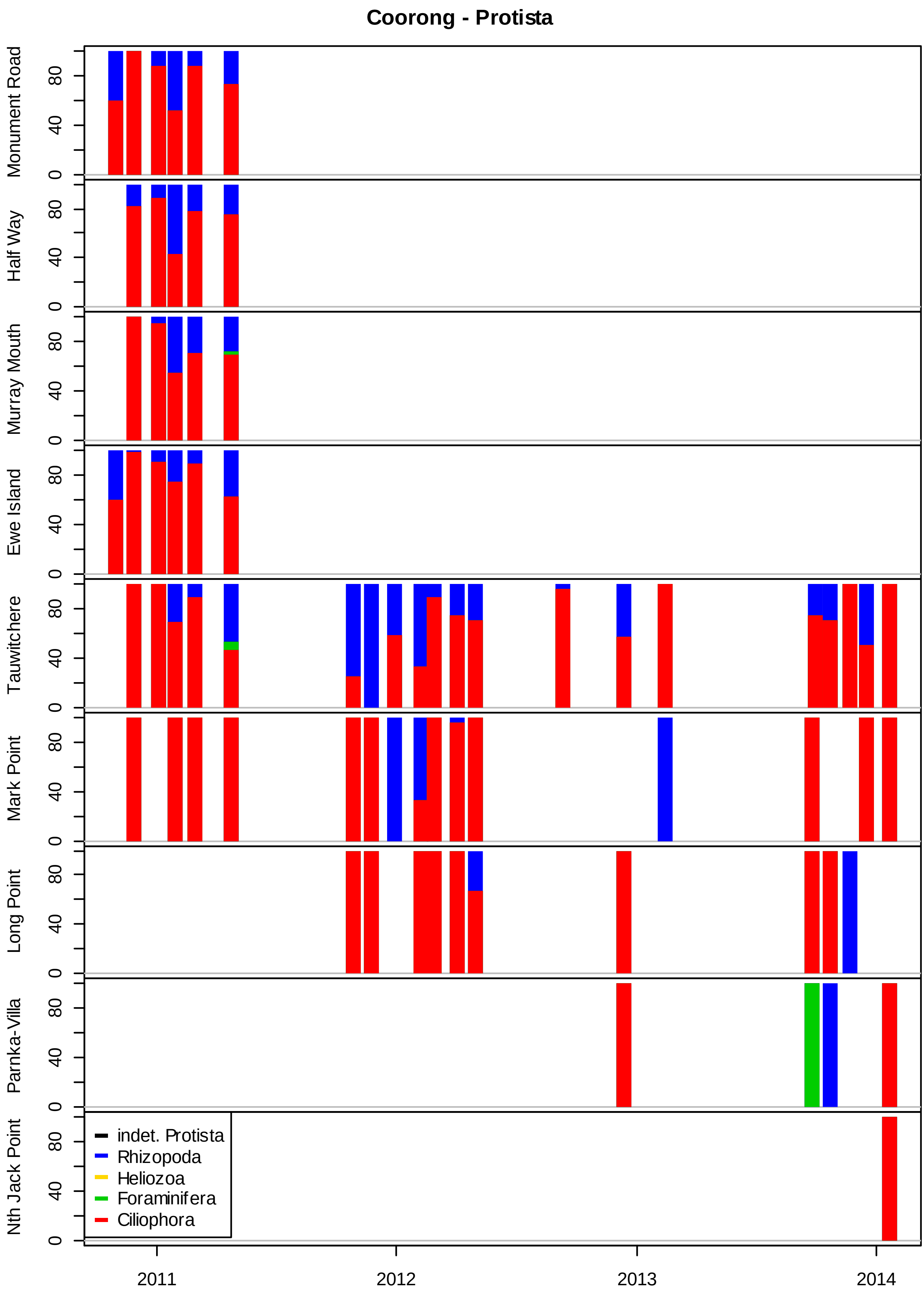


Figure 43 Percent contribution of major protist groups to community composition over time at sampling sites along the Coorong, from Monument Road in the Murray Mouth location to Parnka-Villa in the Coorong South location.

4 Conclusions

4.1 Contrast with previous analyses

The results presented here have built on, and significantly extended the findings of the previous report on changes in water quality and planktonic communities in the CLLMM (Oliver et al 2013). In the earlier report a major effort was focused on identifying and analysing data sets that were informative about water quality changes. That report provided the first overview of the annual sequences of water quality through the drought period and identified that in Lake Albert and the Coorong water quality had not returned to pre-drought conditions. Flow, conductivity and major nutrients were shown to be major influences on the water quality shifts. Also identified was the longitudinal variation in water quality along the Coorong, and the remarkable stability of that gradient. However, in the previous report changes in the community compostion of microalgae and zooplankton were investigated using presence/absence data. The approach was used because of uncertainty about the reliability of the abundance data, and also because it simplified the analyses. However, presence/absence data reduces the sensitivity and detail of community composition analyses and there was concern that dominant microalgae, previously reported in the literature as having significant influences on community composition, had not been identified in the first report, presumably precluded by the over-simplified presence/absence categorisation. A prime example of this was *Planctonema*, a dominant genus of green microalgae that was not identified in the previous report as influencing microalgae community composition despite having been recorded as undergoing change (Geddes 1988; Baker 2000; Aldridge et al 2010). Consequently, a focus of this study was to analyse the abundance data for both microalgae and zooplankton. This involved checking the total database for consistency of taxonomic nomenclature and providing suitable taxonomic collations for reliable statistical analyses, major tasks in themselves (Appendices C and D).

Analytical sensitivity is important in identifying the organisms primarily responsible for changes in community composition and the environmental parameters driving these changes. In the previous report the shifts in community composition were not always strongly associated with water quality and flow conditions, despite the clear roles of flow, conductivity and major nutrients in determining the changes in water quality. It was suspected that the presence/absence analyses were not always sufficiently sensitive to demonstrate the principal environmental associations.

As water quality was extensively assessed in the first report the focus in this report was on analysing the microalgae and zooplankton abundance data, but the selection of these parameters significantly reduced the number of sites being analysed as there has been far less microalgae and zooplankton monitoring than water quality monitoring. It was possible that this reduced data set might not be sufficient to significantly demonstrate water quality changes observed in the previous report, so reducing the ability to interpret changes in water quality and to associate them with changes in microalgae and zooplankton. However, as shown in the next section, analyses of the reduced water quality data set produced patterns similar to those previously observed (Oliver et al 2013).

4.2 Water Quality

The analyses showed that water quality in at all sites changed significantly in response to the drought and that the major changes were influenced by the reductions in water delivery and resulting shifts in conductivity. In Lake Alexandrina TP, TN and turbidity changes also influenced water quality, but these effects were largely within the pre-drought, drought or post-drought periods, rather than between periods (Figure 6). In contrast, in Lake Albert the reduced flows were responsible for changes in water quality between the drought and post-drought periods (Figure 7). However, during the drought period water quality changed within Lake Albert as a function of the sampling location with lower TN and conductivity at

Meningie and increasing concentrations at both the South West site and the Water Level Recorder (Figure 8). Time series data could now be investigated to assess what is driving these differences. The Narrung Bund was built in March 2008 and physically separated Lakes Alexandrina and Albert, although water levels were maintained in Lake Albert with water pumped from Lake Alexandrina. Despite this the water quality in Lake Albert was significantly different from that in Lake Alexandrina from 2005/06 onwards, the divergence beginning before the building of the Bund. With the return of substantial river flows in 2010/11 the water quality in Lake Alexandrina returned to pre-drought conditions (Figures 7 and 9) while in Lake Albert water quality remained significantly different from Lake Alexandrina, even after the removal of the Bund in September 2010 (Figures 9 and 10). The differences were due to higher conductivities and higher TP and TN concentrations in Lake Albert. The most recent monitoring in 2013/14 shows the water quality in Lake Albert still to be significantly different from Lake Alexandrina. The differences are considered to be a function of the poor water exchange between Lake Alexandrina and Lake Albert and the evaporative concentration of material within Lake Albert, which being a terminal lake can only be flushed through the opening to Lake Alexandrina.

The Goolwa Channel is part of Lake Alexandrina but was isolated from it between August 2009 and September 2010 by the Goolwa Channel regulator. The regulator seemed to have little direct influence on the water quality which moved to drought conditions in 2007/08 prior to its installation, presumably because of reduced connectivity with Lake Alexandrina as water levels declined during the drought (Figures 11 and 12). Although the drought throughout the Murray-Darling Basin catchment was officially considered to commence in 2000/01, low flows through Lake Alexandrina and the Goolwa Channel maintained water quality at these sites and in Lake Albert until 2007/08.

With the removal of the Goolwa Channel regulator in 2010/11 there was a large shift in water quality that coincided with the period of increased inflows. It is possible that if the regulator had not been removed water quality would have remained in the drought state. Despite the removal of the regulator the water quality in the Goolwa Channel did not return to earlier conditions until 2012/13, unlike Lake Alexandrina which was returned to pre-drought conditions by the 2010/11 flows. The lag in the Goolwa Channel could be due to the influence of inflows from the Southern Mt Lofty Ranges through Currency Creek and Finniss River, but further analyses are required to investigate this suggestion. It was thought that pH would have a significant influence on the conditions within the Goolwa Channel because of the exposed acid sulfate soils, but this was not evident in the overall data analyses (Figure 11).Focused analyses of specific sites might provide further information on the impacts of pH.

Analyses of water quality changes in the Coorong were described in Oliver et al (2013) and are not detailed in this report as the data selection focused on microalgae and zooplankton did not provide a long period of water quality coverage. As observed in the previous report, water quality varied along the length of the Coorong, influenced by flow and conductivity, with significant differences between the Southern Coorong, Northern Coorong and the Murray Mouth locations (Figure 14). These gradients are well documented (Webster 2007; Brookes et al 2009) so it is reassuring to see these parameters identified by the multivariate analyses.

4.3 Microalgae

It was expected that the microalgae would change in association with water quality, but this was not always the case. In Lake Alexandrina there were major shifts in microalgae community composition in response to the drought and these were associated strongly with the changes in flow and conductivity (Figure 17), the major parameters that had influenced water quality. However, while water quality appeared to return to pre-drought conditions following the 2010/11 river inflows, the microalgae community composition did not and still remained significantly different from the pre-drought conditions in the most recent 2013/14 monitoring (Figure 18 and 19). Prior to the drought the dominant genera of microalgae in Lake Alexandrina were the green algae, *Planctonema*, *Oocystis* and *Dictyosphaerium* and the cyanobacteria *Anabaena* and *Nodularia*. In general *Planctonema* dominated the community but at times cyanobacteria co-dominated and occasionally dominated (Figures 20 and 21). During the drought there was a fundamental shift in the microalgae community composition with a major decline in *Planctonema* and *Anabaena*, but increases in the green algae *Ankistrodesmus* and *Oocystis* and the cyanobacteria, *Planktolyngbya*, *Aphanocapsa* and *Aphanizomenon* (Table 2). Despite increases and decreases in both green microalgae and cyanobacteria there was an overall decline in green microalgae and a significant increase in the numbers of cyanobacteria so that they dominated the community (Figure 21). Following the return of flows in 2010/11 *Planktolyngbya*, *Aphanocapsa* and *Aphanizomenon* still dominated the system althought overall abundance declined. Major shifts in microalgae community composition have been recorded previously (Geddes 1988; Baker 2000; Aldridge et al 2010), but usually based on limited data sets. The collation of the CLLMM monitoring data through this project dramatically demonstrates the scale of this change, not only over time, but also across sites in the Lake (Figure 21). The fundamental shift caused by the drought has changed the community composition from one recorded for at least a decade before the drought, to one that has continued for the last nine years of monitoring that included drought and post-drought periods. This large shift in primary producers at the base of the foodweb is expected to have influenced the magnitude and trophic linkages of the aquatic foodwebs within Lake Alexandrina. If data were available to include higher trophic groups such as macroinveterbrates or fish in these analyses then such linkages could be investigated.

Lake Albert is a terminal lake connected to Lake Alexandrina through a single opening with constricted hydrological exchange. Despite the drought the microalgae communities were similar in the two lakes between 2005/06 and 2007/08, but then diverged becoming significantly different. This was different from water quality which became significantly different between the two lakes after 2005/05 (Figure 12). Interestingly there appears to have been a lag in the response of the microalgae to the change in water quality. The divergence in water quality occurred before the construction of the Narrung Bung in 2007/08, but the divergence in microalgae community composition occurred at this time. It is not possible to say whether this change was due to the Bung or would have happened anyway due to the reduced hydrological connections between the two lakes as a result of water level decline. Water quality continued to change in Lake Albert despite pumping in of water from Lake Alexandrina, presumably a result of evaporative concentration of materials within the water column of the terminal lake, as flushing was not possible. The shift in microalgae compostion in Lake Albert was associated with increased salinity and nitrogen concentrations (Figure 24).

The Narrung Bund was removed in September 2010 when river flows returned to the system, but both water quality (Figure 10) and microalgae community composition (Figure 22 and 25) remained significantly different between the lakes and from previous periods within the lakes. Despite the removal of the bund, Lake Albert has not equilibrated with Lake Alexandrina again reflecting the poor hydrological connectivity.

The Goolwa Channel is an arm of Lake Alexandrina and the microalgae community remained similar between these locations until 2008/09 when a significant shift occurred and the community composition in the Channel diverged from that of the Lake (Figures 28 and 31). This occurred prior to the installation of the Goolwa Channel regulator in 2009/10. The regulator was removed in 2010/11 but the difference in microalgae community composition continued until 2011/12. This might reflect the influence of inflows from Currency Creek and the Finniss River. The two sites then returned to being similar to each other, although both were different from the pre-drought community associated with Lake Alexandrina.

During the period from 2005/06 onwards cyanobacteria mainly dominated the community in the Goolwa Channel, although at times green microalgae made major contributions (Figure 32). The water quality attributes most closely associated with the changes in community composition were discharge, conductivity and turbidity (Figure 30d), but it was conductivity that was most strongly associated with the community differences between Lake Alexandrina and the Goolwa Channel (Figure 29b). There was an expectation that pH might play an influential role due to the exposure of acid sulfate sediments by falling water levels, but this was not observed, perhaps because all of the Channel monitoring sites were collated in the analyses. It is likely that pH played a role at particular locations and further site specific analyses are warranted.

The analyses of microalgae community change in the Coorong was curtailed by the limited period of monitoring, which only commenced in 2010/11. Although there was no clear time series in the short data set, there was a clear spatial signal showing longitudinal variation in microalgae communities along the Coorong. The Southern Coorong communities were significantly different from the Northern Coorong, and these significantly different from the Murray Mouth communities (Figure 34). The spatial changes in microalgae community composition aligned with changes in water quality that occurred along the Coorong (Figure 14). The major water quality changes were associated with discharge, conductivity and turbidity (Figure 33). The distinct changes in microalgae community composition along the Coorong (Figure 35) and the average community compositions at sites (Figure 36) show a complex mixture of groups changing over space and time. At Long Point and Parnka Villa in the Southern Coorong a single genera of green microalgae appeared to dominate the community at all times (Table 4). These complex patterns are driven by changing water quality conditions that are influenced by the relative supplies of freshwater over the barrages and marine water through the Murray Mouth. A hydrodynamic model has been constructed to describe these interactions and their influence on water quality, particularly conductivity, along the Coorong. There is now an opportunity to apply the model to assess short term changes and to associate these with the microalgae community composition. This would further enhance the value of the hydrodynamic modelling tool for testing management strategies.

4.4 Zooplankton

Zooplankton monitoring occurred at sites across the CLLMM from 2010/11, the year which marked the return of flows to the system. Consequently it was not possible to determine whether zooplankton communities were similar to pre-drought conditions. However, as data was collected from most locations any shifts in community structure in the future can be compared with conditions immediately post-drought. Continued monitoring will be important in describing time series of changes, and determing whether or not a persistent core of community composition types is finally established that could be considered as an appropriate state for the system. Unlike the analyses for microalgae, where the pre-drought conditions are known and could be considered a suitable management target, the continued monitoring of zooplankton will be required to inform on the pathway of change towards an unknown environmental state.

The zooplankton monitoring data demonstrated significant differences in community composition across all the major CLLMM locations; Lake Alexandrina, Lake Albert, the Goolwa Channel, the Murray Mouth, Coorong North and Coorong South. In all locations except the Coorong South there were annual shifts in the zooplankton community composition. At each of the locations the changes in community composition were associated with different zooplankton species, indicating the importance of local conditions and the diversity across the sites. Interpretation of these shifts requires more information on the traits of these particular species. Further detailed analyses of the data are required to link changing environmental conditions, including associations with particular microalgae, with the shifts in zooplankton community composition.

Zooplankton communities varied along the Coorong just as was observed for microalgae and water quality (Figure 40). These differences were largely associated with *Stenosomella lacustris* which was important in 2010/11, *Keratella tropica* important in 2011/12, calanoid nauplii and tintinnids in 2012/13, and calanoid nauplii in 2013/14. These changes mostly occurred in the Northern Coorong and are thought to be associated with changing flows over the barrages. More focused analyses are required to investigate these links.

4.5 Final comments

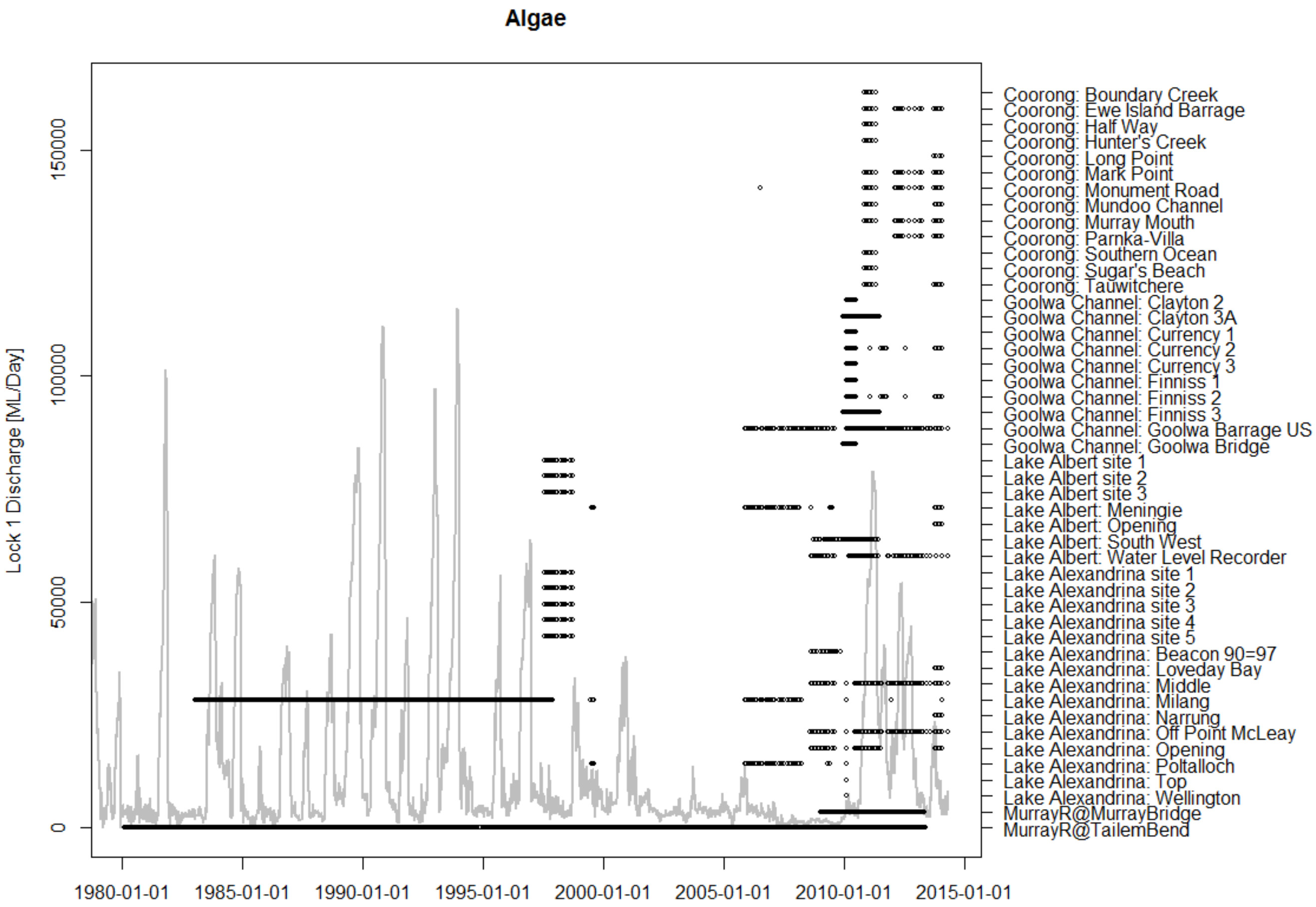
Changes in water quality, microalgae and zooplankton are closely connected and they play a pivotal role in determining the quantity and form of the food resources available to support aquatic food webs. Major shifts in these conditions, as observed during the drought, are expected to affect the foodweb connections and the capacity of the CLLMM system to sustain higher trophic levels. A reduction in microorganism abundance means less food to support the consumers that depend on them, while changes in community composition mean that suitable food resources are not available for particular consumers. The impacts of these changes are potentially debilitating to ecosystems, reducing the supply of organic carbon and constraining the flux of energy through the foodwebs leading to reductions in consumer populations. In the Lakes and the Goolwa Channel the water quality has returned to conditions reminiscent of those prior to the drought, but the microalgae have not. It is suspected that the zooplankton communities also have not returned to pre-drought conditions as they are still undergoing large annual changes and are not showing a tendency to reduce to a conservative set of frequently observed community compositions. However, this might reflect the short period of zooplankton sampling.

A large environmental perturbation like a sustained drought is expected to impact on a region, but the expectation is that on the relief of such a pressure the system will move back to its prior condition. The aquatic components of the CLLMM have not, and it remains to be seen if they will under current conditions, or if increased system manipulation will be required. The drought has influenced river management and there is likely to be tighter regulation perhaps leading to reduced flows to the CLLMM. The indications are that under such a scenario the CLLMM will remain a cyanobacteria dominated system offering poor resources for the aquatic organisms that were once a vital part of its ecology. Continued monitoring is required to observe the changes within the system and to assess their responses to future management actions. Further analysis of the monitoring data is required, building on the connections identified through the multivariate analyses to focus on quantifying the water quality and environmental conditions responsible for the changes in community composition of microalgae and zooplankton. This information is required to provide management targets that could be used to assess the volumes and delivery patterns of environmental flows required to meet the identified outcomes.

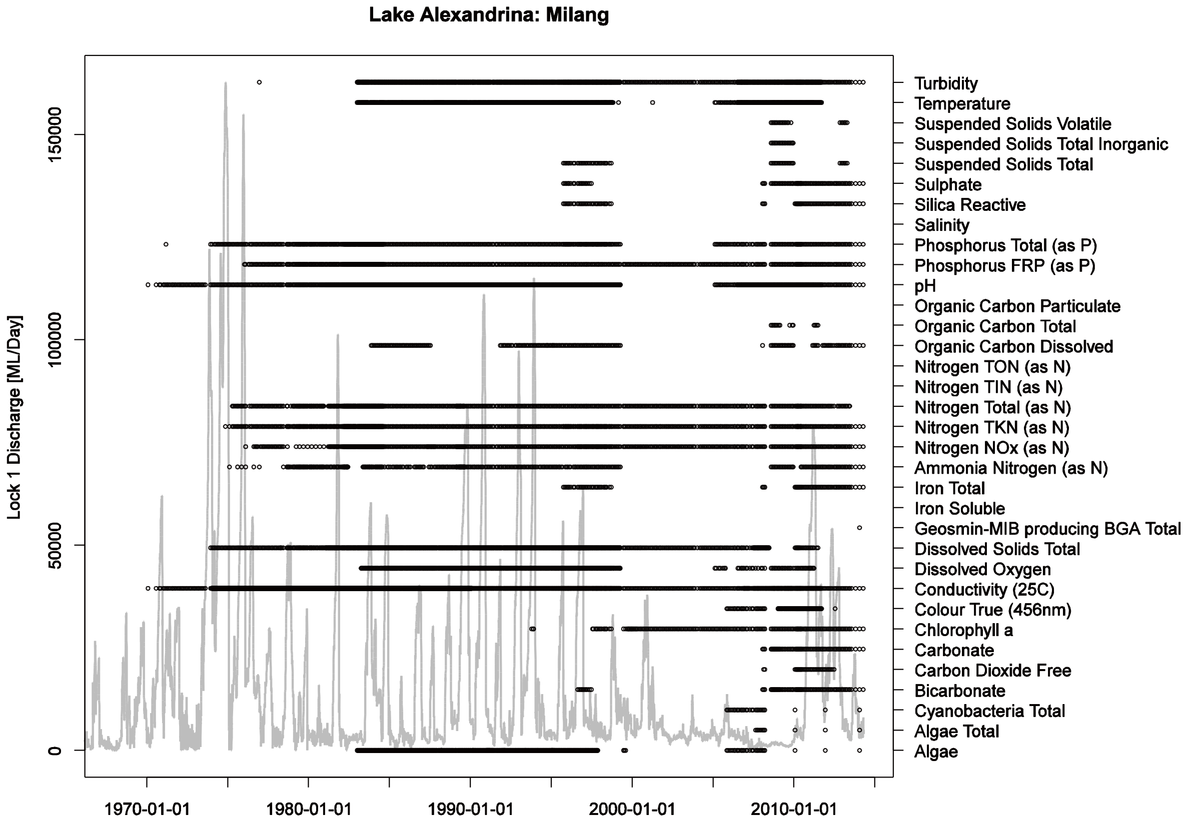
5 Recommendations

1. The analyses of the CLLMM monitoring data has demonstrated that the system has not returned to conditions that are thought to have prevailed prior to the Millenium Drought. It is recommended that monitoring be continued to ensure that the changing water quality and shifts in community composition of microalgae and zooplankton are logged for future assessments of environmental condition. Few other variables could provide such detailed and interpretable information on the changing status of the system over space and time.
2. Building on the multivariate analyses it would be useful to undertake more detailed assessments of the influence of flow conditions on water quality, microalgae and zooplankton. This would involve assessing the hydrological characteristics of the flow patterns including flow peaks, flow frequencies, flow durations, interflood periods etc. Associating these characteristics with responses in the biota provides a basis for assessing environmental flow requirements and identifies flow management targets.
3. The multivariate analyses have identified links between water quality, microalgae and zooplankton, but it was not possible within the project to try and quantify these relationships using multivariate techniques akin to multiple regression approaches. These techniques should be tested to begin developing statistical models describing the interactions identified.
4. The multivariate analyses have laid a foundation for extending the comparisons of changing physicochemical and biological conditions to other attributes and other organisms where corresponding data is available. For example, if fish census data were available then this could be linked through the multivariate analyses with water quality and the communities of microalgae and zooplankton. This would improve understanding of the links between trophic levels.
5. The multivariate analyses have described general relationships between water quality, microalgae and zooplankton. This information provides the foundation for more focused statistical and process modelling of the interactions between these components. One opportunity is to utilise the hydrodynamic model that has been constructed for the Coorong and to compare the model predictions with the statistical relationships.
6. The multivariate analyses identified time periods and locations when significant interactions or changes were occurring. This information can be used to focus statistical analyses on critical parts of the monitoring time series constructed through the project data collation activities. This focus provides opportunites to select and apply other statistical and analytical techniques to appropriately constrained data sets, and to address specific questions identified from the data sets. For example, the changing nitrogen concentrations in Lake Albert that are, in part, responsible for the difference in water quality from Lake Alexandrina during and following the drought. Or the influence of pH on microbiota within the Currency Creek and Finniss River.

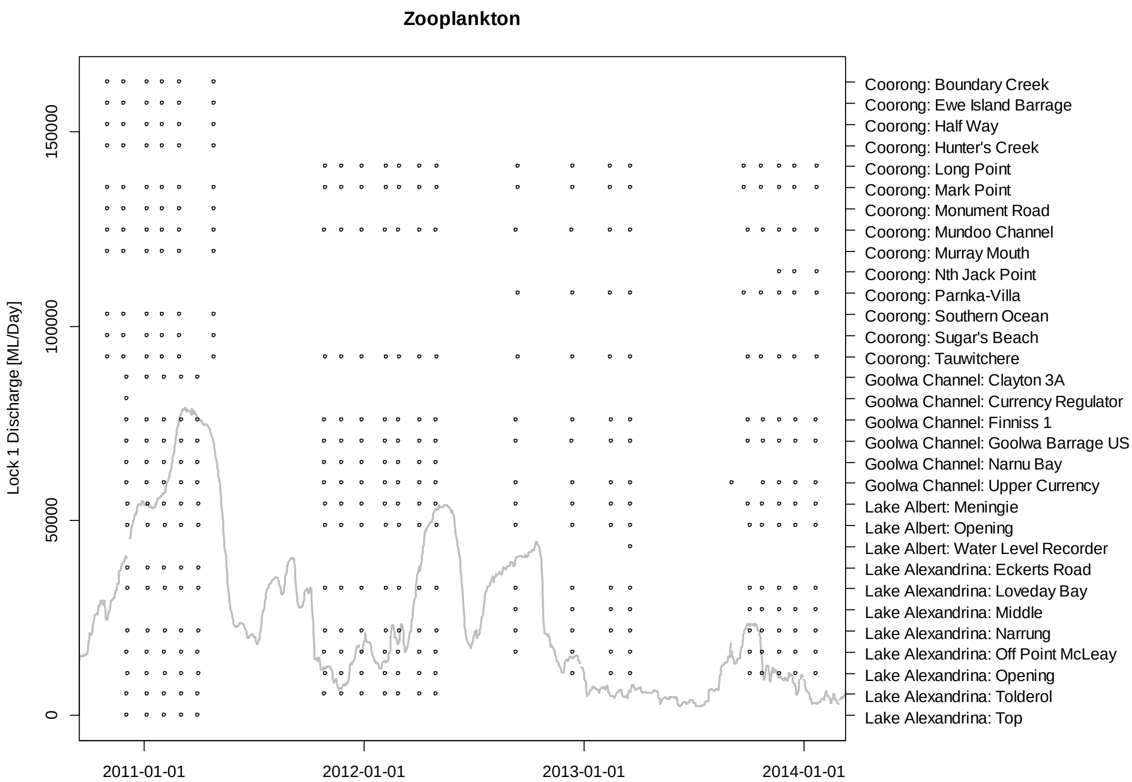
Appendix A Examples of sampling patterns in CLLMM monitoring programs



Apx Figure 5-1 Microalgae sampling dates for sites listed on the right hand axis. Daily Murray River discharge at Lock 1 shown as a continuous line (data sourced from SA Water).



Apx Figure 5-2 Water quality sampling dates at Milang for parameters listed on the right hand axis. Daily Murray River discharge at Lock 1 shown as a continuous line (data sourced from SA Water).



Apx Figure 5-3 Zooplankton sampling dates for sites listed on the right hand axis. Daily Murray River discharge at Lock 1 shown as a continuous line (data sourced from SA Water).

Appendix B Standardised sampling site names

B.1 Sampling site names consolidated and standardised for this report listed against original sampling site names in the SA EPA database exactly as recorded

Original Name	Standard Name	Code	Location	Region	Original Name	Standard Name	Code	Location	Region
Coorong - Bonneys	Coorong: Bonneys	Bon	CN	Crg	C-0 u/s Goolwa Barr.	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
Coorong sub-lagoon 5 (Bonney's)	Coorong: Bonneys	Bon	CN	Crg	EPA - Goolwa Barrage (upstream)	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
Coorong: Bonneys	Coorong: Bonneys	Bon	CN	Crg	GCW-06	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
EPA - Bonneys	Coorong: Bonneys	Bon	CN	Crg	GCW06	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
Boundary Creek	Coorong: Boundary Creek	BCk	MM	Crg	goolwa	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
C-8 Boundary Ck	Coorong: Boundary Creek	BCk	MM	Crg	Goolwa Barrage	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
Coorong: Boundary Creek	Coorong: Boundary Creek	BCk	MM	Crg	Goolwa Channel: Goolwa Barrage US	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
C-9 Ewe Is.	Coorong: Ewe Island Barrage	EIs	MM	Crg	Lake Alexandrina Goolwa Barrage US	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
Coorong - Ewe Island Barrage	Coorong: Ewe Island Barrage	EIs	MM	Crg	Lake Alexandrina: Goolwa Barrage (Upstream)	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
Coorong: Ewe Island Barrage	Coorong: Ewe Island Barrage	EIs	MM	Crg	Us Goolwa Barrage	Goolwa Channel: Goolwa Barrage US	GBU	GCh	GCh
EPA - Ewe Island Barrage	Coorong: Ewe Island Barrage	EIs	MM	Crg	EPA - Goolwa Bridge	Goolwa Channel: Goolwa Bridge	GBr	GCh	GCh
Ewe Island	Coorong: Ewe Island Barrage	EIs	MM	Crg	Goolwa Channel: Goolwa Bridge	Goolwa Channel: Goolwa Bridge	GBr	GCh	GCh

C-2 Half Way	Coorong: Half Way	Hlf	MM	Crg	GCW-08	Goolwa Channel: Narnu Bay	NBa	GCh	GCh
Coorong: Half Way	Coorong: Half Way	Hlf	MM	Crg	GCW08	Goolwa Channel: Narnu Bay	NBa	GCh	GCh
Half Way	Coorong: Half Way	Hlf	MM	Crg	Goolwa Channel: Narnu Bay	Goolwa Channel: Narnu Bay	NBa	GCh	GCh
Coorong sub-lagoon 8 (Hamilla Downs)	Coorong: Hamilla Downs	Ham	CS	Crg	Hindmarsh Island (Narnu)	Goolwa Channel: Narnu Bay	NBa	GCh	GCh
Coorong: Hamilla Downs	Coorong: Hamilla Downs	Ham	CS	Crg	Goolwa Channel: Off Clayton	Goolwa Channel: Off Clayton	ClO	GCh	GCh
C-6 Hunter's Ck	Coorong: Hunter's Creek	HCk	MM	Crg	Currency Creek Ballast Stone Winery	Goolwa Channel: Upper Currency	CuU	GCh	GCh
Coorong: Hunter's Creek	Coorong: Hunter's Creek	HCk	MM	Crg	GCW-10	Goolwa Channel: Upper Currency	CuU	GCh	GCh
Hunter's Creek	Coorong: Hunter's Creek	HCk	MM	Crg	GCW-10 [Currency Ck]	Goolwa Channel: Upper Currency	CuU	GCh	GCh
C12	Coorong: Long Point	LPt	CN	Crg	GCW10	Goolwa Channel: Upper Currency	CuU	GCh	GCh
Coorong - Long Point	Coorong: Long Point	LPt	CN	Crg	Goolwa Channel: Upper Currency	Goolwa Channel: Upper Currency	CuU	GCh	GCh
Coorong sub-lagoon 3 (Long Point)	Coorong: Long Point	LPt	CN	Crg	Goolwa Channel: Upper Finniss	Goolwa Channel: Upper Finniss	FiU	GCh	GCh
Coorong: Long Point	Coorong: Long Point	LPt	CN	Crg	Lake Albert site 1	Lake Albert site 1	St1	Alb	Alb
EPA - Long Point	Coorong: Long Point	LPt	CN	Crg	Lake Albert site 2	Lake Albert site 2	St2	Alb	Alb
Long Point	Coorong: Long Point	LPt	CN	Crg	Lake Albert site 3	Lake Albert site 3	St3	Alb	Alb
Long Pt	Coorong: Long Point	LPt	CN	Crg	albert	Lake Albert: Meningie	Men	Alb	Alb
C-11 Mark Point	Coorong: Mark Point	MPt	CN	Crg	EPA - Lake Albert : Meningie	Lake Albert: Meningie	Men	Alb	Alb
C11	Coorong: Mark Point	MPt	CN	Crg	Lake Albert - Meningie	Lake Albert: Meningie	Men	Alb	Alb
Coorong - Mark Point	Coorong: Mark Point	MPt	CN	Crg	Lake Albert Meningie	Lake Albert: Meningie	Men	Alb	Alb
Coorong sub-lagoon 2 (Mark Point)	Coorong: Mark Point	MPt	CN	Crg	Lake Albert: Meningie	Lake Albert: Meningie	Men	Alb	Alb
Coorong: Mark Point	Coorong: Mark Point	MPt	CN	Crg	LAlbert Meningie	Lake Albert: Meningie	Men	Alb	Alb

EPA - Mark Point	Coorong: Mark Point	MPt	CN	Crg	Meningie	Lake Albert: Meningie	Men	Alb	Alb
Mark Point	Coorong: Mark Point	MPt	CN	Crg	ZOO-09	Lake Albert: Meningie	Men	Alb	Alb
Mark Pt	Coorong: Mark Point	MPt	CN	Crg	ZOO09	Lake Albert: Meningie	Men	Alb	Alb
Coorong sub-lagoon 6 (McGrath Flat North)	Coorong: McGrath Flat North	MGF	CN	Crg	Lake Albert	Lake Albert: Opening	Opn	Alb	Alb
Coorong: McGrath Flat North	Coorong: McGrath Flat North	MGF	CN	Crg	Lake Albert: Nurra Nurra	Lake Albert: Opening	Opn	Alb	Alb
C-1 d/s Goolwa Barr.	Coorong: Monument Road	MRd	MM	Crg	LAlbert opening	Lake Albert: Opening	Opn	Alb	Alb
Coorong - Monument Road	Coorong: Monument Road	MRd	MM	Crg	ZOO-08	Lake Albert: Opening	Opn	Alb	Alb
Coorong: Monument Road	Coorong: Monument Road	MRd	MM	Crg	ZOO08	Lake Albert: Opening	Opn	Alb	Alb
EPA - Coorong Monument Road	Coorong: Monument Road	MRd	MM	Crg	EPA - Lake Albert : Opening	Lake Albert: Opening	Opn	Alb	Alb
Goolwa Barrage Downstream	Coorong: Monument Road	MRd	MM	Crg	Lake Albert - Opening	Lake Albert: Opening	Opn	Alb	Alb
Lake Alexandrina-Goolwa Barrage D/S 426525	Coorong: Monument Road	MRd	MM	Crg	Lake Albert: Opening	Lake Albert: Opening	Opn	Alb	Alb
Lake Alexandrina: Goolwa Barrage (Downstream)	Coorong: Monument Road	MRd	MM	Crg	Lake Albert - South West	Lake Albert: South West	S-W	Alb	Alb
C-7 Mundoo	Coorong: Mundoo Channel	MCh	MM	Crg	Lake Albert: South West	Lake Albert: South West	S-W	Alb	Alb
C7	Coorong: Mundoo Channel	MCh	MM	Crg	EPA- Lake Albert - Middle	Lake Albert: Water Level Recorder	WLR	Alb	Alb
Coorong - Mundoo Channel	Coorong: Mundoo Channel	MCh	MM	Crg	Lake Albert - Middle	Lake Albert: Water Level Recorder	WLR	Alb	Alb
Coorong: Mundoo Channel	Coorong: Mundoo Channel	MCh	MM	Crg	Lake Albert - Water Level Recorder	Lake Albert: Water Level Recorder	WLR	Alb	Alb
Mundoo Channel	Coorong: Mundoo Channel	MCh	MM	Crg	Lake Albert: Water Level Recorder	Lake Albert: Water Level Recorder	WLR	Alb	Alb
C-5 Murray Mouth	Coorong: Murray Mouth	MRM	MM	Crg	Water level rec	Lake Albert: Water Level Recorder	WLR	Alb	Alb

Coorong - Murray Mouth	Coorong: Murray Mouth	MRM	MM	Crg	Lake Alexandrina site 1	Lake Alexandrina site 1	St1	Alx	Alx
Coorong: Murray Mouth	Coorong: Murray Mouth	MRM	MM	Crg	Lake Alexandrina site 2	Lake Alexandrina site 2	St2	Alx	Alx
EPA - Murray Mouth	Coorong: Murray Mouth	MRM	MM	Crg	Lake Alexandrina site 3	Lake Alexandrina site 3	St3	Alx	Alx
Murray Mouth	Coorong: Murray Mouth	MRM	MM	Crg	Lake Alexandrina site 4	Lake Alexandrina site 4	St4	Alx	Alx
Coorong sub-lagoon 4 (Noonameena)	Coorong: Noonameena	Nnm	CN	Crg	Lake Alexandrina site 5	Lake Alexandrina site 5	St5	Alx	Alx
Coorong: Noonameena	Coorong: Noonameena	Nnm	CN	Crg	Lake Alexandrina at Beacon 90	Lake Alexandrina: Beacon 90=97	Bcn	Alx	Alx
Coorong sub-lagoon 10 (Jack Point)	Coorong: Nth Jack Point	JPt	CS	Crg	Lake Alexandrina: Beacon 90=97	Lake Alexandrina: Beacon 90=97	Bcn	Alx	Alx
Coorong: North Jack Point	Coorong: Nth Jack Point	JPt	CS	Crg	Lake Alexandrina: Beacon 97	Lake Alexandrina: Beacon 90=97	Bcn	Alx	Alx
Coorong: Nth Jack Point	Coorong: Nth Jack Point	JPt	CS	Crg	Lake Alexandrina: Boggy Lake	Lake Alexandrina: Top	Top	Alx	Alx
EPA - Nth Jack Point	Coorong: Nth Jack Point	JPt	CS	Crg	ZOO-02	Lake Alexandrina: Top	Top	Alx	Alx
Morella Basin - North Jack Point	Coorong: Nth Jack Point	JPt	CS	Crg	ZOO02	Lake Alexandrina: Top	Top	Alx	Alx
Nth Jack Pt	Coorong: Nth Jack Point	JPt	CS	Crg	Lake Alexandrina: Eckerts Road	Lake Alexandrina: Eckerts Road	ERd	Alx	Alx
Nth Jack Pt	Coorong: Nth Jack Point	JPt	CS	Crg	ZOO-05	Lake Alexandrina: Eckerts Road	ERd	Alx	Alx
Coorong: Parnka-Villa	Coorong: Parnka-Villa	P-V	CS	Crg	ZOO05	Lake Alexandrina: Eckerts Road	ERd	Alx	Alx
Coorong sub-lagoon 7 (Parnka Point)	Coorong: Parnka-Villa	P-V	CS	Crg	EPA - Lake Alexandrina Islands	Lake Alexandrina: Islands	Isl	Alx	Alx
Coorong: Parnka Point	Coorong: Parnka-Villa	P-V	CS	Crg	Lake Alexandrina: Islands	Lake Alexandrina: Islands	Isl	Alx	Alx
Parnka Point	Coorong: Parnka-Villa	P-V	CS	Crg	Coorong - Jockwar Road	Lake Alexandrina: Opening	Opn	Alx	Alx
C-4 Sthn Ocean	Coorong: Southern Ocean	Ocn	MM	Crg	Jockwar Rd	Lake Alexandrina: Opening	Opn	Alx	Alx
Coorong: Southern	Coorong: Southern Ocean	Ocn	MM	Crg	Lake Alexandrina:	Lake Alexandrina: Opening	Opn	Alx	Alx

Ocean					Jockwar Road				
Southern Ocean	Coorong: Southern Ocean	Ocn	MM	Crg	Murray River Wellington	Lake Alexandrina: Opening	Opn	Alx	Alx
Coorong sub-lagoon 11 (South of Policeman Point)	Coorong: Sth of Policeman Point	Pol	CS	Crg	ZOO-03	Lake Alexandrina: Opening	Opn	Alx	Alx
Coorong: Sth of Policeman Point	Coorong: Sth of Policeman Point	Pol	CS	Crg	ZOO03	Lake Alexandrina: Opening	Opn	Alx	Alx
Coorong sub-lagoon 12 (Sth of Salt Creek)	Coorong: Sth Salt Creek	Sal	CS	Crg	Lake Alex Loveday Bay	Lake Alexandrina: Loveday Bay	LBa	Alx	Alx
Coorong: South Salt Creek	Coorong: Sth Salt Creek	Sal	CS	Crg	Lake Alexandrina: Loveday Bay	Lake Alexandrina: Loveday Bay	LBa	Alx	Alx
Coorong: Sth Salt Creek	Coorong: Sth Salt Creek	Sal	CS	Crg	Loveday Bay	Lake Alexandrina: Loveday Bay	LBa	Alx	Alx
EPA - Sth Salt Creek	Coorong: Sth Salt Creek	Sal	CS	Crg	ZOO-04	Lake Alexandrina: Loveday Bay	LBa	Alx	Alx
Coorong sub-lagoon 9 (Stony Well)	Coorong: Stony Well	Sto	CS	Crg	ZOO-04 [Loveday Bay]	Lake Alexandrina: Loveday Bay	LBa	Alx	Alx
Coorong: Stony Well	Coorong: Stony Well	Sto	CS	Crg	ZOO04	Lake Alexandrina: Loveday Bay	LBa	Alx	Alx
C-3 Sugar's Bch	Coorong: Sugar's Beach	Sug	MM	Crg	EPA - Lake Alexandrina Middle	Lake Alexandrina: Middle	Mid	Alx	Alx
Coorong: Sugar's Beach	Coorong: Sugar's Beach	Sug	MM	Crg	Lake Alexandrina: Middle	Lake Alexandrina: Middle	Mid	Alx	Alx
Sugar's Beach	Coorong: Sugar's Beach	Sug	MM	Crg	LAlex Mid	Lake Alexandrina: Middle	Mid	Alx	Alx
C-10Tauwitch Barr	Coorong: Tauwitchere	Tau	MM	Crg	EPA - Lake Alexandrina Milang	Lake Alexandrina: Milang	Mil	Alx	Alx
C10	Coorong: Tauwitchere	Tau	MM	Crg	L Alex/Milang	Lake Alexandrina: Milang	Mil	Alx	Alx
Coorong - Tauwitchere Barrage	Coorong: Tauwitchere	Tau	MM	Crg	Lake Alexandrina Milang	Lake Alexandrina: Milang	Mil	Alx	Alx
Coorong - Tauwitcherie	Coorong: Tauwitchere	Tau	MM	Crg	Lake Alexandrina: Milang	Lake Alexandrina: Milang	Mil	Alx	Alx
Coorong sub-lagoon 1(Tauwitchere)	Coorong: Tauwitchere	Tau	MM	Crg	milang	Lake Alexandrina: Milang	Mil	Alx	Alx
Coorong: Tauwitchere	Coorong: Tauwitchere	Tau	MM	Crg	Milang	Lake Alexandrina: Milang	Mil	Alx	Alx

EPA - Tauwitcherie	Coorong: Tauwitchere	Tau	MM	Crg
Tauwitchere	Coorong: Tauwitchere	Tau	MM	Crg
Tauwitcherie	Coorong: Tauwitchere	Tau	MM	Crg
Tauwitcherie Barrage	Coorong: Tauwitchere	Tau	MM	Crg
Coorong - Villa de Yumpa	Coorong: Parnka-Villa	P-V	CS	Crg
Coorong: Villa de Yumpa	Coorong: Parnka-Villa	P-V	CS	Crg
EPA - Villa de Yumpa	Coorong: Parnka-Villa	P-V	CS	Crg
Villa de Yumpa	Coorong: Parnka-Villa	P-V	CS	Crg
Clayton 1	Goolwa Channel: Clayton 1	Cl1	GCh	GCh
Goolwa Channel: Clayton 1	Goolwa Channel: Clayton 1	Cl1	GCh	GCh
EPA - Lake Alexandrina: Clayton (east of regulator)	Goolwa Channel: Clayton 2	Cl2	GCh	GCh
Goolwa Channel: Clayton 2	Goolwa Channel: Clayton 2	Cl2	GCh	GCh
Lake Alexandrina: Clayton (east of regulator)	Goolwa Channel: Clayton 2	Cl2	GCh	GCh
Clayton 3A	Goolwa Channel: Clayton 3A	C3A	GCh	GCh
EPA - Clayton 3A	Goolwa Channel: Clayton 3A	C3A	GCh	GCh
Goolwa Channel: Clayton 3A	Goolwa Channel: Clayton 3A	C3A	GCh	GCh
Lake Alexandrina: Clayton (west of regulator)	Goolwa Channel: Clayton 3A	C3A	GCh	GCh
Clayton 3B	Goolwa Channel: Clayton 3B	C3B	GCh	GCh

Lake Albert - Narrung	Lake Alexandrina: Narrung	Nar	Alx	Alx
Lake Alexandrina: Narrung	Lake Alexandrina: Narrung	Nar	Alx	Alx
Narrung Narrows	Lake Alexandrina: Narrung	Nar	Alx	Alx
ZOO-07	Lake Alexandrina: Narrung	Nar	Alx	Alx
ZOO-07 [Narrung Narrows]	Lake Alexandrina: Narrung	Nar	Alx	Alx
ZOO07	Lake Alexandrina: Narrung	Nar	Alx	Alx
EPA - Lake Alexandrina Point	Lake Alexandrina: Off Point McLeay	PML	Alx	Alx
EPA - Lake Alexandrina: Off Point McLeay	Lake Alexandrina: Off Point McLeay	PML	Alx	Alx
Lake Alexandrina: Off Point McLeay	Lake Alexandrina: Off Point McLeay	PML	Alx	Alx
EPA - Lake Alexandrina Opening	Lake Alexandrina: Opening	Opn	Alx	Alx
Lake Alexandrina: Opening	Lake Alexandrina: Opening	Opn	Alx	Alx
Lake Alex Point Sturt	Lake Alexandrina: Off Point McLeay	PSt	Alx	Alx
Lake Alexandrina: Point Sturt	Lake Alexandrina: Off Point McLeay	PSt	Alx	Alx
LAlex Points	Lake Alexandrina: Off Point McLeay	PSt	Alx	Alx
ZOO-01	Lake Alexandrina: Off Point McLeay	PSt	Alx	Alx
ZOO01	Lake Alexandrina: Off Point McLeay	PSt	Alx	Alx
Lake Alexandrina: Point Sturt 1	Lake Alexandrina: Point Sturt 1	PS1	Alx	Alx
Lake Alexandrina:	Lake Alexandrina: Point Sturt 2	PS2	Alx	Alx

Goolwa Channel: Clayton 3B	Goolwa Channel: Clayton 3B	C3B	GCh	GCh
Clayton 3C	Goolwa Channel: Clayton 3C	C3C	GCh	GCh
Goolwa Channel: Clayton 3C	Goolwa Channel: Clayton 3C	C3C	GCh	GCh
GCW-01	Goolwa Channel: Clayton 3A	C3A	GCh	GCh
GCW01	Goolwa Channel: Clayton 3A	C3A	GCh	GCh
Goolwa Channel: Clayton Jetty	Goolwa Channel: Clayton 3A	C3A	GCh	GCh
EPA - Currency 1	Goolwa Channel: Currency 1	Cu1	GCh	GCh
Goolwa Channel: Currency 1	Goolwa Channel: Currency 1	Cu1	GCh	GCh
Currency Creek - Currency 2	Goolwa Channel: Currency 2	Cu2	GCh	GCh
EPA - Currency 2	Goolwa Channel: Currency 2	Cu2	GCh	GCh
Goolwa Channel: Currency 2	Goolwa Channel: Currency 2	Cu2	GCh	GCh
Lake Alexandrina: Currency 2	Goolwa Channel: Currency 2	Cu2	GCh	GCh
EPA - Currency 3	Goolwa Channel: Currency 3	Cu3	GCh	GCh
Goolwa Channel: Currency 3	Goolwa Channel: Currency 3	Cu3	GCh	GCh
Lake Alexandrina: Currency 3	Goolwa Channel: Currency 3	Cu3	GCh	GCh
GCW-05	Goolwa Channel: Currency Regulator	CuR	GCh	GCh
GCW05	Goolwa Channel: Currency Regulator	CuR	GCh	GCh

Point Sturt 2				
Lake Alexandrina: Point Sturt 3	Lake Alexandrina: Point Sturt 3	PS3	Alx	Alx
Lake Alexandrina: Point Sturt 4	Lake Alexandrina: Point Sturt 4	PS4	Alx	Alx
Lake Alexandrina: Point Sturt 5	Lake Alexandrina: Point Sturt 5	PS5	Alx	Alx
Lake Alexandrina: Point Sturt 6	Lake Alexandrina: Point Sturt 6	PS6	Alx	Alx
Lake Alexandrina: Point Sturt 7	Lake Alexandrina: Point Sturt 7	PS7	Alx	Alx
Lake Alexandrina: Point Sturt 8	Lake Alexandrina: Point Sturt 8	PS8	Alx	Alx
EPA - Lake Alexandrina Poltalloch	Lake Alexandrina: Poltalloch	Pol	Alx	Alx
Lake Alexandrina Poltalloch Plains	Lake Alexandrina: Poltalloch	Pol	Alx	Alx
Lake Alexandrina: Poltalloch	Lake Alexandrina: Poltalloch	Pol	Alx	Alx
Lake Alexandrina: Poltalloch plains	Lake Alexandrina: Poltalloch	Pol	Alx	Alx
poltalloch	Lake Alexandrina: Poltalloch	Pol	Alx	Alx
Poltalloch	Lake Alexandrina: Poltalloch	Pol	Alx	Alx
Lake Alex Tolderol	Lake Alexandrina: Tolderol	Tol	Alx	Alx
Lake Alexandrina: Tolderol	Lake Alexandrina: Tolderol	Tol	Alx	Alx
ZOO-06	Lake Alexandrina: Tolderol	Tol	Alx	Alx
ZOO06	Lake Alexandrina: Tolderol	Tol	Alx	Alx
EPA - Lake Alexandrina Top	Lake Alexandrina: Top	Top	Alx	Alx

Goolwa Channel: Currency Regulator	Goolwa Channel: Currency Regulator	CuR	GCh	GCh	Lake Alexandrina: Top	Lake Alexandrina: Top	Top	Alx	Alx
EPA - Finniss 1	Goolwa Channel: Finniss 1	Fi1	GCh	GCh	EPA - Lake Alexandrina Wellington	Lake Alexandrina: Wellington	Wel	MRD	MRD
Finniss River	Goolwa Channel: Finniss 1	Fi1	GCh	GCh	Lake Alexandrina: Wellington	Lake Alexandrina: Wellington	Wel	MRD	MRD
GCW-03	Goolwa Channel: Finniss 1	Fi1	GCh	GCh	MurrayR@Wellington	Lake Alexandrina: Wellington	Wel	MRD	MRD
GCW-03 [Finniss R]	Goolwa Channel: Finniss 1	Fi1	GCh	GCh	Murray Bridge No1 PS	MurrayR@Murray Bridge	MBr	MRD	MRD
GCW03	Goolwa Channel: Finniss 1	Fi1	GCh	GCh	murray_bridge	MurrayR@Murray Bridge	MBr	MRD	MRD
Goolwa Channel: Finniss 1	Goolwa Channel: Finniss 1	Fi1	GCh	GCh	MurrayR@MurrayBridge	MurrayR@Murray Bridge	MBr	MRD	MRD
EPA - Finniss 2	Goolwa Channel: Finniss 2	Fi2	GCh	GCh	River Murray Murray Bridge Sample Pump	MurrayR@Murray Bridge	MBr	MRD	MRD
Finniss River - Finniss 2	Goolwa Channel: Finniss 2	Fi2	GCh	GCh	River Murray Murray Bridge Surface	MurrayR@Murray Bridge	MBr	MRD	MRD
Goolwa Channel: Finniss 2	Goolwa Channel: Finniss 2	Fi2	GCh	GCh	MurrayR@TailemBend	MurrayR@TailemBend	Tlm	MRD	MRD
Lake Alexandrina: Finniss 2	Goolwa Channel: Finniss 2	Fi2	GCh	GCh	River Murray Tailem Bend Sample Pump	MurrayR@TailemBend	Tlm	MRD	MRD
EPA - Finniss 3	Goolwa Channel: Finniss 3	Fi3	GCh	GCh	River Murray Tailem Bend Surface	MurrayR@TailemBend	Tlm	MRD	MRD
Goolwa Channel: Finniss 3	Goolwa Channel: Finniss 3	Fi3	GCh	GCh	tailem	MurrayR@TailemBend	Tlm	MRD	MRD
Lake Alexandrina: Finniss 3	Goolwa Channel: Finniss 3	Fi3	GCh	GCh	Tailem Bend	MurrayR@TailemBend	Tlm	MRD	MRD
					Tailem Bend No1 PS	MurrayR@TailemBend	Tlm	MRD	MRD

Appendix C Microalgae nomenclature

Original Taxa	Genera	Group	Original Taxa	Genera	Group
Achnanthidium	Achnanthidium	Bacillariophyceae	Ulothrix	Ulothrix	Chlorophyta
Amphipleura	Amphipleura	Bacillariophyceae	Chrysomonadales	Chrysomonadales	Chrysophyceae
Amphiprora	Amphiprora	Bacillariophyceae	Chrysophyceae	Chrysophyceae	Chrysophyceae
Amphiprora (= Entomoneis)	Amphiprora	Bacillariophyceae	Chroomonas	Chroomonas	Cryptophyta
Asterionella	Asterionella	Bacillariophyceae	CRYPTOMONADACEAE	Cryptomonadaceae	Cryptophyta
Asterionellopsis	Asterionellopsis	Bacillariophyceae	Cryptomonas	Cryptomonas	Cryptophyta
Attheya	Attheya	Bacillariophyceae	Cryptophyceae	Cryptophyceae	Cryptophyta
Aulacoseira	Aulacoseira	Bacillariophyceae	Anabaena	Anabaena	Cyanophyta
Aulacoseira distans	Aulacoseira	Bacillariophyceae	Anabaena (coiled) spp.	Anabaena	Cyanophyta
Aulacoseira granulata	Aulacoseira	Bacillariophyceae	Anabaena (straight) spp.	Anabaena	Cyanophyta
Bacillaria	Bacillaria	Bacillariophyceae	Anabaena aphanizomenoides	Anabaena	Cyanophyta
BACILLARIOPHYCEAE	Bacillariophyceae	Bacillariophyceae	Anabaena bergii	Anabaena	Cyanophyta
Centric Bacillariophyceae	Centric	Bacillariophyceae	Anabaena bergii var. limnetica	Anabaena	Cyanophyta
Chaetoceros	Chaetoceros	Bacillariophyceae	Anabaena circinalis	Anabaena	Cyanophyta
Cocconeis	Cocconeis	Bacillariophyceae	Anabaena crassa	Anabaena	Cyanophyta
Coscinodiscus	Coscinodiscus	Bacillariophyceae	Anabaena flos-aquae var. 1	Anabaena	Cyanophyta
Cyclotella	Cyclotella	Bacillariophyceae	Anabaena flos-aquae var. 2	Anabaena	Cyanophyta
Cyclotella large spp.	Cyclotella	Bacillariophyceae	Anabaena planktonica	Anabaena	Cyanophyta
Cyclotella small spp.	Cyclotella	Bacillariophyceae	Anabaena solitaria	Anabaena	Cyanophyta
Cymatopleura	Cymatopleura	Bacillariophyceae	Anabaena spiroides var. 1	Anabaena	Cyanophyta
Cymbella	Cymbella	Bacillariophyceae	Anabaena spiroides var. 2	Anabaena	Cyanophyta
Diatoma	Diatoma	Bacillariophyceae	Anabaena spiroides var. 4	Anabaena	Cyanophyta
Fragilaria	Fragilaria	Bacillariophyceae	Anabaenopsis	Anabaenopsis	Cyanophyta
Gyrosigma	Gyrosigma	Bacillariophyceae	Anabaenopsis elenkinii	Anabaenopsis	Cyanophyta

Leptocylindrus	Leptocylindrus	Bacillariophyceae	Anabaenopsis tanganyikae	Anabaenopsis	Cyanophyta
Melosira	Melosira	Bacillariophyceae	Aphanizomenon	Aphanizomenon	Cyanophyta
Melosira varians	Melosira	Bacillariophyceae	Aphanizomenon gracile	Aphanizomenon	Cyanophyta
Navicula	Navicula	Bacillariophyceae	Aphanizomenon ovalisporum	Aphanizomenon	Cyanophyta
Nitzschia	Nitzschia	Bacillariophyceae	Aphanocapsa	Aphanocapsa	Cyanophyta
Pennate Bacillariophyceae	Pennate	Bacillariophyceae	Aphanothece	Aphanothece	Cyanophyta
Pseudo-nitzschia	Pseudo-nitzschia	Bacillariophyceae	Arthrospira	Arthrospira	Cyanophyta
Rhizosolenia	Rhizosolenia	Bacillariophyceae	CHROOCOCCALES	Chroococcales	Cyanophyta
Rhopalodia	Rhopalodia	Bacillariophyceae	Chroococcus	Chroococcus	Cyanophyta
Skeletonema	Skeletonema	Bacillariophyceae	Coelosphaerium	Coelosphaerium	Cyanophyta
Staurosira	Staurosira	Bacillariophyceae	Cuspidothrix issatschenkoi	Cuspidothrix	Cyanophyta
Stephanodiscus	Stephanodiscus	Bacillariophyceae	Cyanodictyon	Cyanodictyon	Cyanophyta
Surirella	Surirella	Bacillariophyceae	Cyanogranis	Cyanogranis	Cyanophyta
Synedra	Synedra	Bacillariophyceae	Cyanophyceae	Cyanophyceae	Cyanophyta
Tabellaria	Tabellaria	Bacillariophyceae	Cylindrospermopsis	Cylindrospermopsis	Cyanophyta
Closterium	Closterium	Charophyta	Cylindrospermopsis raciborskii	Cylindrospermopsis	Cyanophyta
Closterium large spp.	Closterium	Charophyta	Cylindrospermum	Cylindrospermum	Cyanophyta
Cosmarium	Cosmarium	Charophyta	Geitlerinema	Geitlerinema	Cyanophyta
Elakatothrix	Elakatothrix	Charophyta	Lemmermanniella	Lemmermanniella	Cyanophyta
Mougeotia	Mougeotia	Charophyta	Limnothrix	Limnothrix	Cyanophyta
Spirogyra	Spirogyra	Charophyta	Lyngbya	Lyngbya	Cyanophyta
Staurastrum	Staurastrum	Charophyta	Merismopedia	Merismopedia	Cyanophyta
Actinastrum	Actinastrum	Chlorophyta	Microcystis	Microcystis	Cyanophyta
Ankistrodesmus	Ankistrodesmus	Chlorophyta	Microcystis aeruginosa	Microcystis	Cyanophyta
Ankistrodesmus sp.	Ankistrodesmus	Chlorophyta	Microcystis flos-aquae	Microcystis	Cyanophyta
Ankistrodesmus sp. (small cells)	Ankistrodesmus	Chlorophyta	Microcystis wesenbergii	Microcystis	Cyanophyta
Ankyra	Ankyra	Chlorophyta	Nodularia	Nodularia	Cyanophyta
Asterococcus	Asterococcus	Chlorophyta	Nodularia spumigena	Nodularia	Cyanophyta
Botryococcus	Botryococcus	Chlorophyta	Nodularia spumigena.1	Nodularia	Cyanophyta
Carteria	Carteria	Chlorophyta	Oscillatoria	Oscillatoria	Cyanophyta
Chlamydomonadaceae	Chlamydomonadaceae	Chlorophyta	Phormidium	Phormidium	Cyanophyta

Chlamydomonas	Chlamydomonas	Chlorophyta	Phormidium broad spp.	Phormidium	Cyanophyta
Chlorella	Chlorella	Chlorophyta	Phormidium narrow sp.	Phormidium	Cyanophyta
CHLOROCOCCALES	Chlorococcales	Chlorophyta	Phormidium narrow spp.	Phormidium	Cyanophyta
Chlorophyceae	Chlorophyceae	Chlorophyta	Planktolyngbya	Planktolyngbya	Cyanophyta
CHLOROPHYCEAE	Chlorophyceae	Chlorophyta	Planktolyngbya contorta	Planktolyngbya	Cyanophyta
CHLOROPHYTA	Chlorophyta	Chlorophyta	Planktolyngbya minor	Planktolyngbya	Cyanophyta
Chodatella (Lagerheimia)	Chodatella	Chlorophyta	Planktolyngbya subtilis	Planktolyngbya	Cyanophyta
Closteriopsis	Closteriopsis	Chlorophyta	Planktothrix	Planktothrix	Cyanophyta
Coelastrum	Coelastrum	Chlorophyta	Planktothrix perornata f. attenuata	Planktothrix	Cyanophyta
Crucigenia	Crucigenia	Chlorophyta	Pseudanabaena	Pseudanabaena	Cyanophyta
Dictyosphaerium	Dictyosphaerium	Chlorophyta	Romeria	Romeria	Cyanophyta
Didymocystis	Didymocystis	Chlorophyta	Snowella	Snowella	Cyanophyta
Dimorphococcus	Dimorphococcus	Chlorophyta	Spirulina	Spirulina	Cyanophyta
Eudorina	Eudorina	Chlorophyta	Synechococcus	Synechococcus	Cyanophyta
Franceia	Franceia	Chlorophyta	Synechocystis	Synechocystis	Cyanophyta
Golenkinia	Golenkinia	Chlorophyta	Trichodesmium	Trichodesmium	Cyanophyta
Kirchneriella	Kirchneriella	Chlorophyta	Amphidinium	Amphidinium	Dinophyta
Micractinium	Micractinium	Chlorophyta	Ceratium	Ceratium	Dinophyta
Monoraphidium	Monoraphidium	Chlorophyta	DINOPHYCEAE	Dinophyceae	Dinophyta
Nephrocytium	Nephrocytium	Chlorophyta	Dinophysis	Dinophysis	Dinophyta
Oedogonium	Oedogonium	Chlorophyta	Dinophysis acuminata	Dinophysis	Dinophyta
Oocystis	Oocystis	Chlorophyta	Glenodinium	Glenodinium	Dinophyta
Oocystis sp.	Oocystis	Chlorophyta	Gymnodinium	Gymnodinium	Dinophyta
Oocystis sp. (large cells)	Oocystis	Chlorophyta	Gyrodinium	Gyrodinium	Dinophyta
Oocystis sp. (small cells)	Oocystis	Chlorophyta	Katodinium	Katodinium	Dinophyta
Pandorina	Pandorina	Chlorophyta	Peridinium	Peridinium	Dinophyta
Pediastrum	Pediastrum	Chlorophyta	Prorocentrum	Prorocentrum	Dinophyta
Planctonema	Planctonema	Chlorophyta	Prorocentrum minimum	Prorocentrum	Dinophyta
Pseudodidymocystis	Pseudodidymocystis	Chlorophyta	Protoperidinium	Protoperidinium	Dinophyta
Pteromonas	Pteromonas	Chlorophyta	Euglena	Euglena	Euglenophyta
Pyramimonas	Pyramimonas	Chlorophyta	Euglenophyceae	Euglenophyceae	Euglenophyta

Scenedesmus	Scenedesmus	Chlorophyta	Phacus	Phacus	Euglenophyta
Schroederia	Schroederia	Chlorophyta	Strombomonas	Strombomonas	Euglenophyta
Sphaerellopsis	Sphaerellopsis	Chlorophyta	Trachelomonas	Trachelomonas	Euglenophyta
Sphaerocystis	Sphaerocystis	Chlorophyta	Mallomonas	Mallomonas	Other Phytoplankton
Tetraedron	Tetraedron	Chlorophyta	Phytoflagellates	Phytoflagellates	Other Phytoplankton
Tetraspora	Tetraspora	Chlorophyta	Phytoplankton Other	Phytoplankton	Other Phytoplankton
Tetrastrum	Tetrastrum	Chlorophyta	Synura	Synura	Other Phytoplankton

Appendix D Zooplankton nomenclature

Original Taxa	Genera	Group
Alona rectangula	Alona	Cladocera
Alona sp.	Alona	Cladocera
Bosmina meridionalis	Bosmina	Cladocera
Ceriodaphnia cornuta	Ceriodaphnia	Cladocera
Ceriodaphnia sp.	Ceriodaphnia	Cladocera
Chydorus sp.	Chydorus	Cladocera
Daphnia carinata	Daphnia	Cladocera
Daphnia lumholtzi	Daphnia	Cladocera
Daphnia projecta	Daphnia	Cladocera
Diaphanosoma unguiculatum	Diaphanosoma	Cladocera
Ilyocryptus sp.	Ilyocryptus	Cladocera
Moina micrura	Moina	Cladocera
Pleuroxus inermis	Pleuroxus	Cladocera
Acartia sp.	Acartia	Copepoda
Boeckella triarticulata	Boeckella	Copepoda
Calamoecia ampulla	Calamoecia	Copepoda
calanoid copepodites	calanoid copepodites	Copepoda
calanoid nauplii	calanoid nauplii	Copepoda
cyclopoid copepodites	cyclopoid copepodites	Copepoda
cyclopoid nauplii	cyclopoid nauplii	Copepoda
Gladioferens pectinatus	Gladioferens	Copepoda
Gladioferens spinosus	Gladioferens	Copepoda
harpacticoid adult	harpacticoid adult	Copepoda
harpacticoid copepodites	harpacticoid copepodites	Copepoda
harpacticoid nauplii	harpacticoid nauplii	Copepoda
bdelloid	Bdelloid	Rotifera
Brachionus angularis	Brachionus	Rotifera
Brachionus angularis bidens	Brachionus	Rotifera
Brachionus baylyi	Brachionus	Rotifera
Brachionus bennini	Brachionus	Rotifera
Brachionus bidentatus	Brachionus	Rotifera
Brachionus budapestinensis	Brachionus	Rotifera
Brachionus calyciflorus	Brachionus	Rotifera
Brachionus calyciflorus amphiceros	Brachionus	Rotifera
Brachionus caudatus austrogenitus	Brachionus	Rotifera
Brachionus diversicornis	Brachionus	Rotifera
Brachionus falcatus	Brachionus	Rotifera
Brachionus keikoa	Brachionus	Rotifera
Brachionus leydigii	Brachionus	Rotifera
Brachionus lyratus	Brachionus	Rotifera
Brachionus nilsoni	Brachionus	Rotifera
Brachionus novaezealandiae	Brachionus	Rotifera
Brachionus quadridentatus cluniorbicularis	Brachionus	Rotifera
Brachionus quadridentatus quadridentatus	Brachionus	Rotifera
Brachionus sericus	Brachionus	Rotifera
Brachionus sp.	Brachionus	Rotifera
Brachionus urceolaris	Brachionus	Rotifera
Cephalodella forficula	Cephalodella	Rotifera
Cephalodella gibba	Cephalodella	Rotifera
Cephalodella sp.	Cephalodella	Rotifera

Cypretta	Cypretta	Ostracoda	Cephalodella ventripes	Cephalodella	Rotifera
Cyprididae	Cyprididae	Ostracoda	Collotheca pelagica	Collotheca	Rotifera
Diacypris sp.	Diacypris	Ostracoda	Colurella adriatica	Colurella	Rotifera
Limnocythere sp.	Limnocythere	Ostracoda	Colurella sp.	Colurella	Rotifera
ostracod	Ostracod	Ostracoda	Colurella uncinata	Colurella	Rotifera
Reticypris sp.	Reticypris	Ostracoda	Conochilus dossuarius	Conochilus	Rotifera
Arcella bathystoma	Arcella	Protista	Conochilus sp.	Conochilus	Rotifera
Arcella discoides	Arcella	Protista	Dicranophorus epicharis	Dicranophorus	Rotifera
Arcella hemisphaerica	Arcella	Protista	Encentrum sp.	Encentrum	Rotifera
Arcella megastoma	Arcella	Protista	Euchlanis sp.	Euchlanis	Rotifera
Arcella sp.	Arcella	Protista	Filinia australiensis	Filinia	Rotifera
Arcella vulgaris	Arcella	Protista	Filinia brachiata	Filinia	Rotifera
Centropyxis aculeata	Centropyxis	Protista	Filinia grandis	Filinia	Rotifera
Centropyxis cassis	Centropyxis	Protista	Filinia longiseta	Filinia	Rotifera
Centropyxis discoides	Centropyxis	Protista	Filinia opoliensis	Filinia	Rotifera
Centropyxis ecornis	Centropyxis	Protista	Filinia passa	Filinia	Rotifera
Centropyxis platystoma	Centropyxis	Protista	Filinia pejleri	Filinia	Rotifera
Centropyxis sp.	Centropyxis	Protista	Filinia terminalis	Filinia	Rotifera
ciliate	Ciliate	Protista	flosculariid	Flosculariid	Rotifera
Cothurnia sp.	Cothurnia	Protista	Habrotrocha sp.	Habrotrocha	Rotifera
Cyclopyxis sp.	Cyclopyxis	Protista	Hexarthra brandorffi	Hexarthra	Rotifera
Cyphoderia ampulla	Cyphoderia	Protista	Hexarthra intermedia	Hexarthra	Rotifera
Didinium sp.	Didinium	Protista	Hexarthra mira	Hexarthra	Rotifera
Difflugia acuminata	Difflugia	Protista	Keratella australis	Keratella	Rotifera
Difflugia amphora	Difflugia	Protista	Keratella cochlearis	Keratella	Rotifera
Difflugia ampullula	Difflugia	Protista	Keratella procurva	Keratella	Rotifera
Difflugia australis	Difflugia	Protista	Keratella quadrata	Keratella	Rotifera
Difflugia avellana	Difflugia	Protista	Keratella sp.	Keratella	Rotifera
Difflugia corona	Difflugia	Protista	Keratella tropica	Keratella	Rotifera
Difflugia elegans	Difflugia	Protista	Lecane bulla	Lecane	Rotifera
Difflugia globulosa	Difflugia	Protista	Lecane closterocerca	Lecane	Rotifera
Difflugia gramen	Difflugia	Protista	Lecane hamata	Lecane	Rotifera
Difflugia lanceolata	Difflugia	Protista	Lecane ludwigii	Lecane	Rotifera

Difflugia limnetica	Difflugia	Protista	Lecane luna	Lecane	Rotifera
Difflugia lithophila	Difflugia	Protista	Lecane monostyla	Lecane	Rotifera
Difflugia longicollis	Difflugia	Protista	Lecane sp.	Lecane	Rotifera
Difflugia manicata	Difflugia	Protista	Lepadella sp.	Lepadella	Rotifera
Difflugia minutissima	Difflugia	Protista	Lindia torulosa	Lindia	Rotifera
Difflugia oblonga	Difflugia	Protista	Lophocharis sp.	Lophocharis	Rotifera
Difflugia parva	Difflugia	Protista	Microcodides sp.	Microcodides	Rotifera
Difflugia sp.	Difflugia	Protista	Notommata sp.	Notommata	Rotifera
Epistylis sp.	Epistylis	Protista	Philodina sp.	Philodina	Rotifera
Euglypha sp.	Euglypha	Protista	Polyarthra dolichoptera	Polyarthra	Rotifera
Euplotes sp.	Euplotes	Protista	Polyarthra sp.	Polyarthra	Rotifera
Foraminifera	Foraminifera	Protista	Pompholyx complanata	Pompholyx	Rotifera
Halteria sp.	Halteria	Protista	Proales daphnicola	Proales	Rotifera
Hyalosphenia sp.	Hyalosphenia	Protista	Proales sp.	Proales	Rotifera
Lesquereusia spiralis	Lesquereusia	Protista	Proalides tentaculatus	Proalides	Rotifera
Netzelia tuberculata	Netzelia	Protista	Rotaria neptunia	Rotaria	Rotifera
Paradileptus elephantinus	Paradileptus	Protista	Rotaria sp.	Rotaria	Rotifera
protist	Protist	Protista	rotifer	Rotifer	Rotifera
Stenosemella lacustris	Stenosemella	Protista	Synchaeta oblonga	Synchaeta	Rotifera
Stentor sp.	Stentor	Protista	Synchaeta pectinata	Synchaeta	Rotifera
tintinnids	Tintinnids	Protista	Synchaeta sp.	Synchaeta	Rotifera
Trinema sp.	Trinema	Protista	Synchaeta tremula	Synchaeta	Rotifera
Zivkovicia sp.	Zivkovicia	Protista	Synchaeta triophthalma	Synchaeta	Rotifera
Anuraeopsis coelata	Anuraeopsis	Rotifera	Testudinella obscura	Testudinella	Rotifera
Anuraeopsis fissa	Anuraeopsis	Rotifera	Trichocerca pusilla	Trichocerca	Rotifera
Ascomorpha ovalis	Ascomorpha	Rotifera	Trichocerca rattus carinata	Trichocerca	Rotifera
Ascomorpha sp.	Ascomorpha	Rotifera	Trichocerca ruttneri	Trichocerca	Rotifera
Asplanchna brightwellii	Asplanchna	Rotifera	Trichocerca similis	Trichocerca	Rotifera
Asplanchna priodonta	Asplanchna	Rotifera	Trichocerca similis grandis	Trichocerca	Rotifera
Asplanchna sieboldii	Asplanchna	Rotifera	Trichocerca sp.	Trichocerca	Rotifera
			Trichotria tetractis similis	Trichotria	Rotifera

Appendix E Coorong sampling sites

E.1 Sampling sites in the Coorong along with their sequence order from north to south and their site code.

Sequence of sites North to South	Site Name	Site Code
1	Coorong: Monument Road	MRd
2	Coorong: Hunter's Creek	HCk
3	Coorong: Mundoo Channel	MCh
4	Coorong: Half Way	Hlf
5	Coorong: Sugar's Beach	Sug
6	Coorong: Boundary Creek	BCk
7	Coorong: Murray Mouth	MRM
8	Coorong: Southern Ocean	Ocn
9	Coorong: Ewe Island Barrage	EIs
10	Coorong: Tauwitchere	Tau
11	Coorong: Mark Point	MPt
12	Coorong: Long Point	LPt
13	Coorong: Noonameena	Nnm
14	Coorong: Bonneys	Bon
15	Coorong: McGrath Flat North	MGF
17	Coorong: Parnka-Villa	P-V
19	Coorong: Hamilla Downs	Ham
20	Coorong: Stony Well	Sto
21	Coorong: North Jack Point	JPt
22	Coorong: Sth of Policeman Point	Pol
23	Coorong: South Salt Creek	Sal

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