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Report on the Coorong, Lower Lakes and Murray Mouth 2012-13 Microalgae and Water Quality Monitoring Data:

A Multivariate Analysis in the Context of the Millennium Drought

Rod Oliver, Zygmunt Lorenz, Daryl Nielsen, Russel Shiel and Kane Aldridge

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Executive summary

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region, which encompasses Lake Alexandrina and Lake Albert, forms a region of considerable value to South Australia. Positioned at the end of the Murray-Darling Basin the CLLMM region is impacted by changes in river flows and water quality as a result of upstream and regional activities. Information on ecological responses to changes in these environmental conditions is required to inform management.

The importance of nutrients and microalgae to aquatic ecosystems has been well documented in the literature and consequently they have been monitored across the region since the 1970's, although irregularly and inconsistently. Also important are the zooplankton, but monitoring of these communities commenced only in 2010.

Monitoring in both the Coorong and Lower Lakes has produced extensive data sets but these have not been collated and analysed together to describe long-term changes in microalgae or zooplankton community composition or to identify the principal drivers of those changes. Previous studies have generally focussed on covering one hydrological condition or analysing annual data in isolation of the extended data sets.

The major purpose of this study was to undertake preliminary, multivariate analyses of the long term monitoring data on water quality, microalgae communities, and zooplankton communities in the CLLMM. A particular focus was to report on the findings of the 2012-13 monitoring program but to set this information within a broader context of system level characteristics derived from previous monitoring. The aim was to demonstrate that despite the intermittent and inconsistent nature of these monitoring programs they provide useful information describing the changing characteristics of these systems, enabling an assessment of their status for management purposes.

A significant amount of time was taken checking and organising the monitoring data that was provided for analysis. The task of trying to collate a consistent dataset was difficult because of the changes in terminology and site depictions that had occurred over the extended period of data collection and it is recommended that an effort be made to create a functional CLLMM monitoring data set for use in future projects.

All analyses were undertaken using the methods within the statistical program Primer 6 and PERMANOVA+ (Anderson, Gorley & Clarke 2008). These multivariate statistical analyses explore the similarity of community composition (microalgae and zooplankton), or sets of water quality parameters across locations and time. Plots of the data are readily interpreted in that points closer together are more similar to each other while points increasingly further apart are more dissimilar.

Monitoring data on water quality and microalgae in the CLLMM region were available for periods prior to the drought that commenced in 2003 and during the return of high flows from 2010-2013. However, the data was not continuous and the monitoring covered different locations for different periods of time determined by management requirements. Few measurements of microalgae were made during the drought but water quality measurements were continued at some sites. Zooplankton data was only available for a 2.5 year period (2010-2013) and was not always coordinated with other data collections.

Multivariate analyses of selected water quality parameters in the Lower Lakes and the Coorong (conductivity, the nutrients N and P, reactive silica, turbidity, flow and chlorophyll a) showed that there were major shifts in water quality between the pre-drought period of 1997-98 and the final drought affected years of 2008-09. With the return of flows in late 2010 the system changed again and during the high flow period of 2010-12 water quality conditions differed from those observed either prior to or during the drought. However, with a reduction in flows in 2013 water quality conditions changed to become more similar to those that were present prior to the drought indicating a degree of recovery to these preceding conditions which were associated with more typical pre-drought river flow conditions.

Prior to the drought Lakes Alexandrina and Albert were freshwater systems, but during the drought salinity increased to almost half that of seawater. Salinity dropped quickly when river flow returned in 2010 with Lake Alexandrina becoming fresh again, but even by 2013 Lake Albert had not returned to pre-drought levels. Total nitrogen concentrations in the lakes showed similar patterns in concentration change as

salinity, increasing during the drought and then decreasing with the return of flows. Total phosphorus concentrations did not show consistent changes that could be associated with the reduced flows of the drought or the following return of flows. Total phosphorus and turbidity were closely associated and less influenced by flow than nitrogen. Multivariate analysis indicated that conductivity, TN, TKN, and TP were largely associated with the within year variations in water quality, while reactive silica and flow were more associated with between year differences in water quality, especially from 2010 to 2013.

In the period immediately prior to the drought conductivity in the Coorong was similar to sea water at Tauwitchere but increased along the north-south axis of the system to twice seawater at Salt Creek. During the drought conductivities increased consistently at all sites with concentrations at Salt Creek reaching four times seawater. All salinities declined during the high river flows of 2010 and 2012 with Tauwitcherie becoming almost fresh while Salt Creek had concentrations similar to seawater. In early 2013 when river flow reduced salinity increased back to sea water levels at Tauwitcherie and higher levels at Salt Creek. Total nitrogen and Total phosphorus concentrations showed similar patterns as salinity, generally decreasing as flow increased at the end of the drought but then increasing again as flow declined in 2013, although phosphorus changes in the southern part of Coorong were smaller and not as noticeably related to flow. Changes in turbidity and total phosphorus were closely aligned as they were in the lakes.

Characterisation of Coorong water quality is complicated by the longitudinal gradient that occurs due to its geomorphology and the supply of freshwater and sea water at the northern end. Even when the water quality attributes of each station were aggregated over 10 years of sampling, a sequential, longitudinal change in water quality was still evident between stations, demonstrating the constancy of a gradient under most conditions.

The microalgae were analysed at several scales as different sets of data were more relevant to different locations and time periods. A multivariate analysis encompassing all sites and all times for which there was microalgae data demonstrated three broad groups of communities across the system. The microalgae communities of the Lakes prior to the drought were substantially different from those following the drought and formed two distinct sets suggesting little recovery in the microalgae. A third set consisted of Coorong sites that were distinctly different from the lake sites indicating development of separate microalgae communities. However, there was also significant overlap of some Coorong sites with the post-drought lake sites suggesting the transport of communities from the lakes by connecting flows during this period.

An analysis focussed on just the lake sites, including the long historical series for Milang in Lake Alexandrina, showed that during the pre-drought period microalgae communities in the lakes varied widely in composition between years. These differences are the result of inter-annual changes in environmental conditions and because of the many possible environmental influences (eg. river flow, meteorological conditions, nutrient supplies) inter-annual variability in microalgae composition is expected. It was suggested that this data set might depict a multivariate operating space that defined lake conditions during a period in which the annual hydrological cycles were relatively typical of managed, pre-drought river flows. This ecosystem operating space might then provide a basis for assessing the condition of the system over time and directing management actions. The drought responses provided an opportunity to investigate this suggestion because despite the large variation in microalgae communities observed prior to the drought the communities present immediately following the drought were substantially different.

A further analysis of the lake microalgae was undertaken using a selection of the sites that included more detailed monitoring before and after the drought. This data was separated into three time periods, pre-drought, end of drought (2008-2011) and the recent 2012-2013 sampling. The results indicated that the recent (2012-2013) microalgae communities were still very similar to those occurring at the end of the drought with only a slight indication that community composition might be reverting back to pre-drought conditions.

Microalgae community composition in the Coorong was only measured from 2010 onwards but the annual patterns of change reflected those observed in the lakes. In 2010 and 2011 the Coorong microalgae communities were similar to each other, but they changed during 2012 and by 2013 were largely different from those present in the earlier periods. There is no pre-drought data to indicate whether the community composition is returning to a prior state. Environmental parameters correlated with the community shift indicated that the 2013 change was associated with reduced turbidity and phosphorus concentrations and increased conductivities and these all related to the reduced river flows at that time.

Analysis of the zooplankton data demonstrated that even with a short-term data set major changes in community composition could be recognised and associated with environmental conditions. Zooplankton communities in Lake Alexandrina were sometimes similar to communities at sites in the Coorong suggesting connection by flow. At other times Coorong samples were quite dissimilar to those in the lake suggesting independent development of these communities. Similar connections and disconnections were observed with the microalgae demonstrating the role of connectivity within the system.

Flow was found to be correlated with the distribution of the zooplankton communities but the relationship was weak, presumably because this preliminary analysis includes a mixture of sites that are differently influenced by flow. Re-analysis with a focus on particular times and sites should improve the interpretation of the role of flow in connecting the lakes and the Coorong.

When the zooplankton communities within the Coorong were compared between sites along the north-south axis, using data aggregated over the total sampling period, a longitudinal gradient was evident as was found for water quality and microalgae. The data on gradients of water quality, microalgae and zooplankton provide an opportunity for further exploration of the interactions of these components within the Coorong.

This report has highlighted the benefits of using multivariate techniques to explore long term trends in community patterns in relation to environmental variables. As predicted the data shows differences in community patterns between drought and non-drought periods. Interestingly the water quality post-drought in 2013 appeared to be more similar to pre-drought conditions in both the Lakes and the Coorong, while the microalgae appeared still to be more similar to the drought conditions. This might indicate that water quality recovery is required to support the recovery of microalgae communities.

The analyses have demonstrated major trends in water quality, microalgae and zooplankton in response to the Millenium drought and to returning flows but much more could be drawn from the data. It is hoped that the fascinating and insightful results that have come from this project will encourage further analyses of the CLLMM monitoring data. It is a valuable resource providing our only overview of the biogeochemical characteristics of the CLLMM region and as such should be more extensively used to advise on management strategies.

A list of recommendations was made including:

1. Extracting a consistent, functional CLLMM monitoring data set from the main data store for use in future projects. This would make the data more accessible to researchers and managers and avoid the need for repeatedly compiling a set from the central database.
2. Developing a stable, long term monitoring program to underpin the required event response monitoring. There should be regular statistical analysis of the monitoring data and the results should be incorporated into developing conceptual models and process based models to provide better mechanistic descriptions of key relationships necessary for improved management.
3. Analyses of the microalgae communities were focused on describing large scale changes in community composition across the CLLMM region. Consequently, seasonal and yearly measurements were used to compare inter-annual changes rather than investigate smaller scale changes such as seasonal influences. More detailed analyses could be undertaken to assist in better identifying the characteristics of the CLLMM region that would be useful for short-term management interventions.
4. Water quality parameters used in the analyses were limited for the purposes of this study to those considered most relevant to the microalgae. There would be value in further analyses of water quality across a range of parameters and time scales to improve understanding of the shifts that are occurring.
5. Combined microalgae and water quality data sets were extracted for the different regions and different sampling sites by using the presence of microalgae counts as a template and extracting water quality parameters that matched the microalgae sampling dates. However there are many within and

6. On occasions the microalgae and zooplankton communities at sites in the Coorong were similar to those at sites in the lakes. This might be expected if flow from the lakes carries these communities into the Coorong. Further analysis of the data to assess the system connectivity would be insightful and important to its management.
7. The zooplankton data was not fully incorporated into the analyses of the microalgae and the water quality. Consequently zooplankton fluctuations could not be closely matched with the microalgae or with water quality. The data is now in a suitable format for a complete analysis to be undertaken and it is recommended that this be done.
8. Similar longitudinal gradients in water quality attributes, microalgae, and zooplankton were observed along the Coorong providing the opportunity to investigate interactions between them. There is also the opportunity to assess these interactions in context of the hydrological model developed for the Coorong by DEWNR and CSIRO. It is recommended that these analyses be further advanced in order to explore the benefits of combining the statistical and process models to improve the understanding required for management of this complex system.

1 Introduction

The Coorong, Lower Lakes and Murray Mouth (CLLMM) region, which encompasses Lake Alexandrina and Lake Albert, forms a region of considerable value to South Australia as a result of its ecological status as a Ramsar *Wetland of International Importance*, and because of its recreational, cultural and aesthetic attributes. Positioned at the end of the Murray-Darling Basin, the condition of these ecosystems is largely determined by changes in river flow. To effectively manage the system, information on the ecological responses to riverine inputs is required. The importance of nutrients and microalgae to aquatic ecosystems has been well documented and as such they have been monitored across the region for some time. However, to date there has not been an integrated assessment of the long term changes across the region (Grigg and Oliver 2012).

Analysis of a long-term water quality data set for the Lower Lakes provided some important insights into the biogeochemistry of the region (Cook *et al*. 2010). This work demonstrated that dissolved nutrients are readily retained within the Lower Lakes, but that the lakes are likely to be an important source of particulate organic nutrients to the Coorong. This monitoring program ceased in 1998, but various sampling programs have been conducted in the Lower Lakes between 2007 and now by the University of Adelaide (UoA) and South Australian Environment Protection Authority (SA EPA) and the Department of Environment, Water and Natural Resources (DEWNR). This monitoring program documented the water quality response to the recent extreme low flow period (Aldridge and Brookes 2011; Mosley *et al*. 2012; Mosley *et al.* 2013) and whilst data has been collected for the subsequent high flow period, changes during this time have not been analysed. Similarly, changes in the microalgae community during these periods have not been investigated in detail even though data exists. Analyses of the water quality data has revealed that the water quality conditions with the Lower Lakes are primarily determined by the balance of inputs and exports of water, as well as the resulting salinity and water levels, both of which can influence the biogeochemistry in complex ways (Aldridge and Brookes 2011; Mosley *et al.* 2013).

Similar complexities have been observed for the Coorong, with concentrations dependent upon external inputs, as well as internal processes (Ford 2007). Monitoring of physico-chemical properties and nutrients in the Coorong by DEWNR, UoA, and the SA EPA took place between 1997 and 2013. Between 1997 and 2003, it was apparent that whilst dissolved nutrient concentrations were low, particulate concentrations were high, suggesting dissolved nutrients were readily incorporated into aquatic biomass or inorganic material (Ford 2007). This data was later incorporated into a nutrient budget and biogeochemical model for the Coorong (Grigg *et al*. 2009). This study found that in years with inputs from the barrages, these inputs are the dominant source of material, including nutrients and microalgae. However during years of no inputs from the barrage, there was an exchange of material from the Southern Ocean to the Southern Lagoon. Post-flood nutrient and microalgae measurements documented by Aldridge and Brookes (2011) and Aldridge and Payne (2012) have supported the findings of Cook *et al*. (2010) and Grigg *et al*. (2009). During periods of inputs from the Lower Lakes, the microalgae community and nutrient concentrations within the Northern Coorong are largely determined by those inputs from the Lower Lakes.

The monitoring in both the Coorong and Lower Lakes form quite extensive data sets and have yielded important information, but they have major problems for assessing long-term and regional response to river flow. In particular the measurements have not been made regularly over the monitoring period, have often been separated by long time intervals, and in some periods have stopped completely. In addition the sampling locations have changed and the range of parameters measured at any location has altered. Added to this is the hydrological and hydrodynamic complexity of the connected water ways. Due to these conditions a coherent analysis of all the data is difficult, especially if it is not set within a connecting hydrological/hydrodynamic framework. As a result, the analyses of annual data have often been made in isolation of the extended data sets.

A recent review of the analyses of the CLLMM monitoring data strongly argued the case for integrating annual measurements into the larger data sets available for the region through the application of both process and statistical system-scale modelling (Grigg and Oliver 2012). Although this is the preferred option, it is not possible within the resources available for this current analysis. The major purpose of this study was to undertake a preliminary, multivariate analysis of the long term monitoring data on water quality, microalgae communities, and zooplankton communities in the Coorong and Lakes Alexandrina and Albert. A particular focus was to report on the findings of the 2012-13 monitoring program but to set this information within a broader context of system level characteristics derived from previous monitoring. The aims are set out in Table 1. The purpose was to demonstrate that despite the intermittent and inconsistent nature of the monitoring programs they provide useful information describing the changing characteristics of these systems, enabling an assessment of their current status for management purposes.

#	Monitoring Objective	Key Questions	Hypotheses	Rationale
5	To assess the response of microalgae, nutrients and zooplankton to: The increased water flows following the recent drought.	1. How do nutrients and other materials respond to the different flow conditions including non-flow periods? 2. Concentrations and distributions How do microalgal communities respond to different flow conditions including non-flow periods? - Cell concentrations and distributions - Shifts in community composition 3. Do the water quality data demonstrate interactions between components e.g salinity and turbidity, turbidity and nutrients, etc. 4. Are there interactions between flow, microalgae, nutrients and zooplankton that are described by the data? 5. Are the interactions between microalgae, nutrients and zooplankton expected to influence other trophic levels?	It is hypothesised that: 1. In the Lower Lakes In response to changing flow conditions (river inflow and barrage releases) and water depth, and 2. In the Coorong In response to changing flow conditions (barrage releases and ocean exchange) there will be consistent seasonal, annual or long term patterns in: • the concentrations and distributions of water quality attributes • the concentrations and community composition micro-algae • the concentrations and community composition of zooplankton.	In order to manage ecosystems it is necessary to identify patterns of responses to environmental changes that provide a basis for the setting of management targets and that identify means by which these targets can be achieved. In this project a statistical approach will be used to try and identify patterns of responses in nutrients, microalgae and zooplankton to flow changes.

Table 1 The 2012-2013 short-term monitoring objectives, hypotheses and key questions: Coorong and Lower Lakes nutrients, microalgae and zooplankton

2 Methods

2.1 Data sets

2.1.1 GENERAL DESCRIPTION

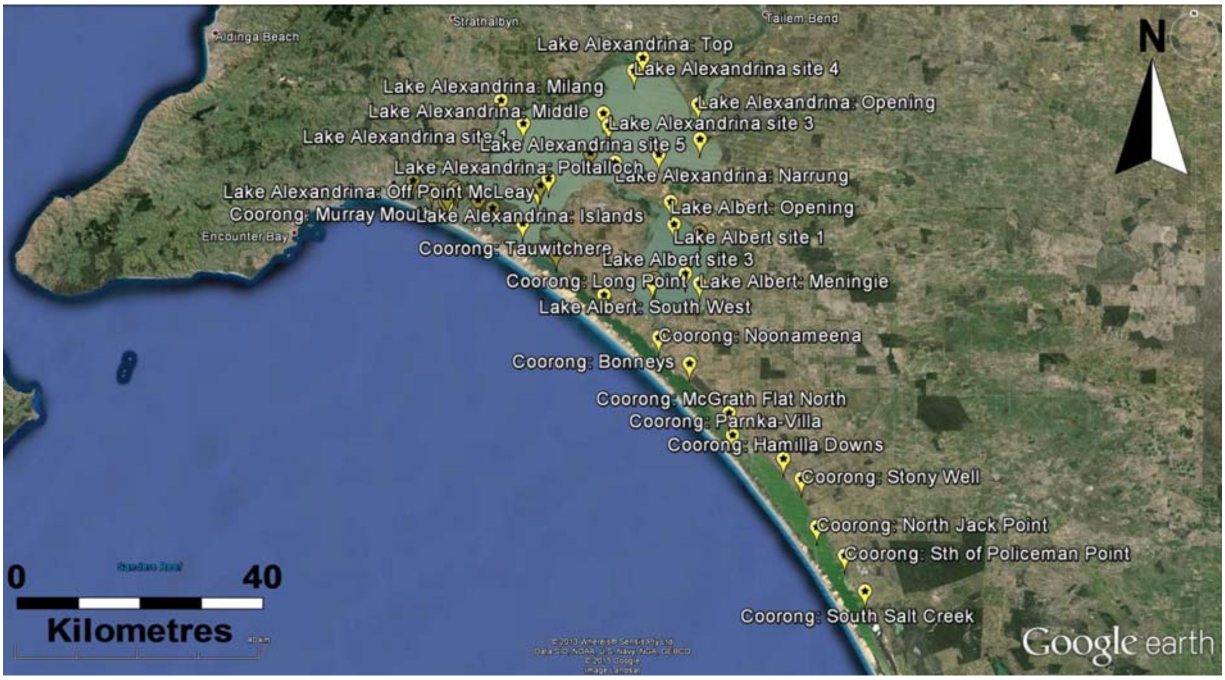
Monitoring data for the Coorong, Lower Lakes and Murray Mouth was provided by the SA EPA from their database. Before the data could be used in analyses a number of inconsistencies typical of large and long lived databases had to be addressed. These included changes in names and acronyms for water quality and environmental parameters, changes in the level of identification for organisms and alterations in their taxonomy, mixed sampling regimes across dates including surface measurements mixed with multiple readings from depth profiles, changes in the names or acronyms of sampling sites, and changes in the location of sites. These types of problems require significant effort to correct due to the volume of data that needs to be assessed. In this project several weeks were spent writing software code in “R” to handle the problematic characteristics inherent in the data sets.

2.1.2 STANDARDISING SAMPLING SITES AND MICROALGAE

Sampling Site standardisation

The different sampling programs across the Lakes and the Coorong often used different sets of sampling sites. Sometimes different selections of established sites were used, at other times the names of existing sites were slightly altered by the sampling teams, and in some cases new sampling sites were established. Occasionally these new sites are nearby to previously established locations but were given a separate name. These practises fragment the data collected from particular locations reducing its usefulness for analyses of changes through time. To maximise the data available for locations the original database sampling names were standardised and in some cases data collected at nearby neighbouring sites was consolidate into one site. The consolidation exercise was done by visual interpretation of site positions on a map as time constraints did not allow for statistical checking of the validity of the amalgamations. The list of consolidated names for the sites used in this report and the respective original site names are shown in Appendix A1 while the locations of these sites are shown in Figures 1 A-D.

The focus of this study was to look at changes in the main water bodies pre- and post-drought. For that reason sampling stations in the Goolwa Channel were not included in order to avoid the specific and complicating influences of acid sulfate soils on water quality. Also this region was essentially cut off from the main part of Lake Alexandrina for an extended period during the drought. However, the changing characteristics of the Goolwa Channel could be investigated using the statistical approaches described here.



1A

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1B

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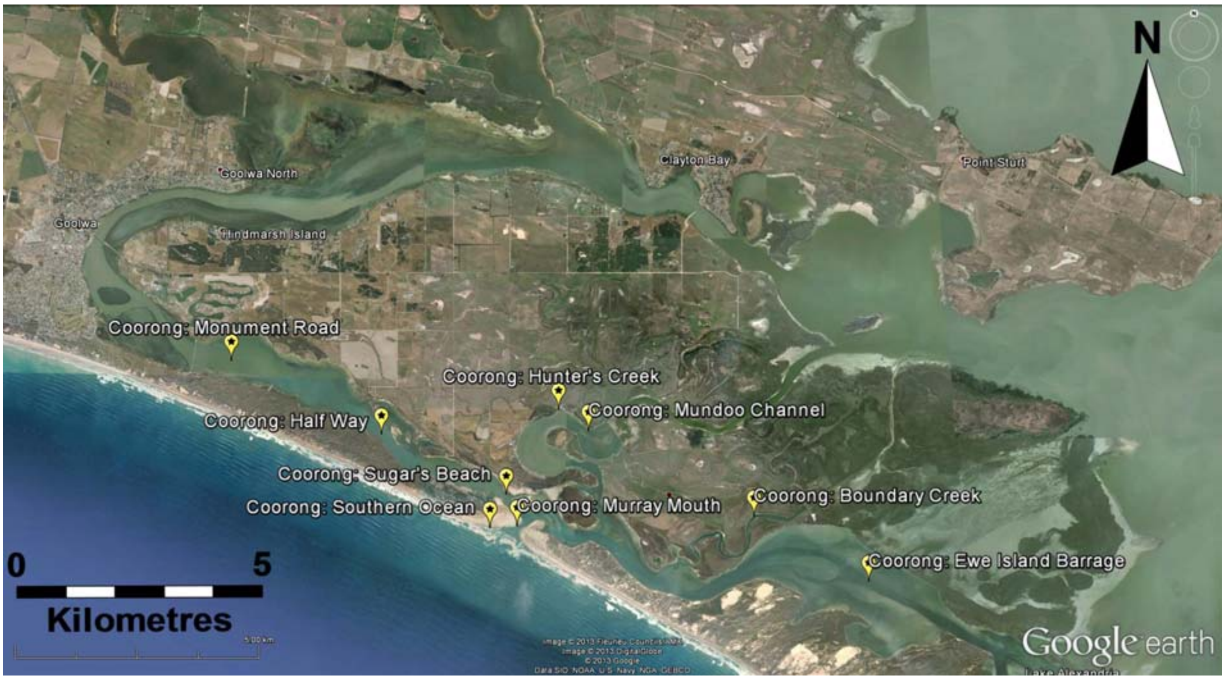

1C

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Figure 1 (A) all sampling sites in Lake Alexandrina, Lake Albert and the Coorong (B) sampling sites in Lake Alexandrina (C) sampling sites in the Northern Coorong including the Murray Mouth (D) sampling sites in Lake Albert and sections of Lake Alexandrina and the mid-Coorong.

Microalgae nomenclature and enumeration

A large number of microalgae have been identified and enumerated at sampling sites in the CLLMM region through a 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 is largely dependent on the taxonomy and microscopy skills of the analyst, with little opportunity for independent verification of 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 variability, different methods of enumeration may be used in different monitoring projects depending on their objectives. For example, cells of microalgae may be enumerated until a defined total cell number is achieved, or until a certain total volume of sample has been viewed, or for a fixed period of time. In some cases cells were not counted at all, but a rapid visual estimate was made of their concentration on a logarithmic scale. For organisms in high abundance these techniques might produce similar results, but for moderate and less common species the different counting techniques can produce quite different outcomes, with some species occurring or not occurring depending on the method used. This can be a vexing problem when basing comparisons on statistical analyses of community composition. Consequently, although the preliminary statistical analyses often included total cell counts for all of the microalgae identified, these results are not generally reported here because of concerns about consistency of the data. An exception is the Coorong where counting of microalgae only commenced in November 2010 and was assumed to be consistently done until 2013.

Several approaches were used to reduce the effects of unknown changes in the reliability of the microalgae data. In general, cell count data was converted to presence and absence data as this increases the number of sites for analysis and reduces the reliance on consistent cell enumeration over time. Microalgae identifications were standardised to genera in most cases, as cell attributes at this taxonomic level are often more reliably recognized than for species. Samples have been collected In Lakes Alexandrina and Albert over a prolonged period with substantial breaks in sampling during this time. These characteristics lead to increased chances of inconsistencies in microalgae identifications, especially of uncommon species. To try and minimise problems of misidentification, the occurrences of microalgae were compared and a set of organisms that appeared at all sites was extracted and used in analyses. This reduces the inclusion of uncommon and rare microalgae and focuses on species that have been regularly identified. This selection process reduces the number of microalgae considered and so reduces the analytical sensitivity, but the set of common microalgae consisted of 51 different genera which are considered sufficiently extensive to provide meaningful descriptions of microalgae community composition. The effects of these efforts to improve the reliability of the microalgae data can be appraised by carrying out multiple analyses using the various data set selections and comparing the outcomes. Only a few such detailed comparisons could be made within the time constraints of the project.

2.1.3 SELECTING SAMPLING DATES FOR ANALYSES

The CLLMM region has not had a continuous, consistent monitoring program like that on the Murray River (MDBC 2005). Monitoring of the region increased from the beginning of the Millennium Drought in 2003, but with individual sampling programs often driven by particular water quality issues. This makes it difficult to construct a continuous, reliable data set that describes spatial changes in characteristics of the system over time and is suitable for statistical analysis. To assess large scale changes pre- and post-drought this project required extended and extensive sets of data on microalgae, water quality, zooplankton and other pertinent environmental parameters including flow. In some cases monitoring programs contained only one, or a few of these data types, while at other times all of the data types were represented. Fortunately each of the individual sampling programs had its own repeated pattern of measurements so providing at least short periods of consistent measurements. The outcome of this irregular monitoring program is highlighted in the following discussions on selecting sites and dates for inclusion in the statistical analyses.

Selecting microalgae sampling dates

Microalgae have been analysed at a number of sites at various times as depicted in Figure 2, resulting in 10 sites in Lake Alexandrina, 5 sites in Lake Albert, and 12 sites in the Coorong. Note the absence of microalgae analyses during most of the drought period. In some cases, including Lake Alexandrina Sites 1-5 and Lake Albert Sites 1-3, microalgae were not always counted, but their presence was noted and their number approximated.

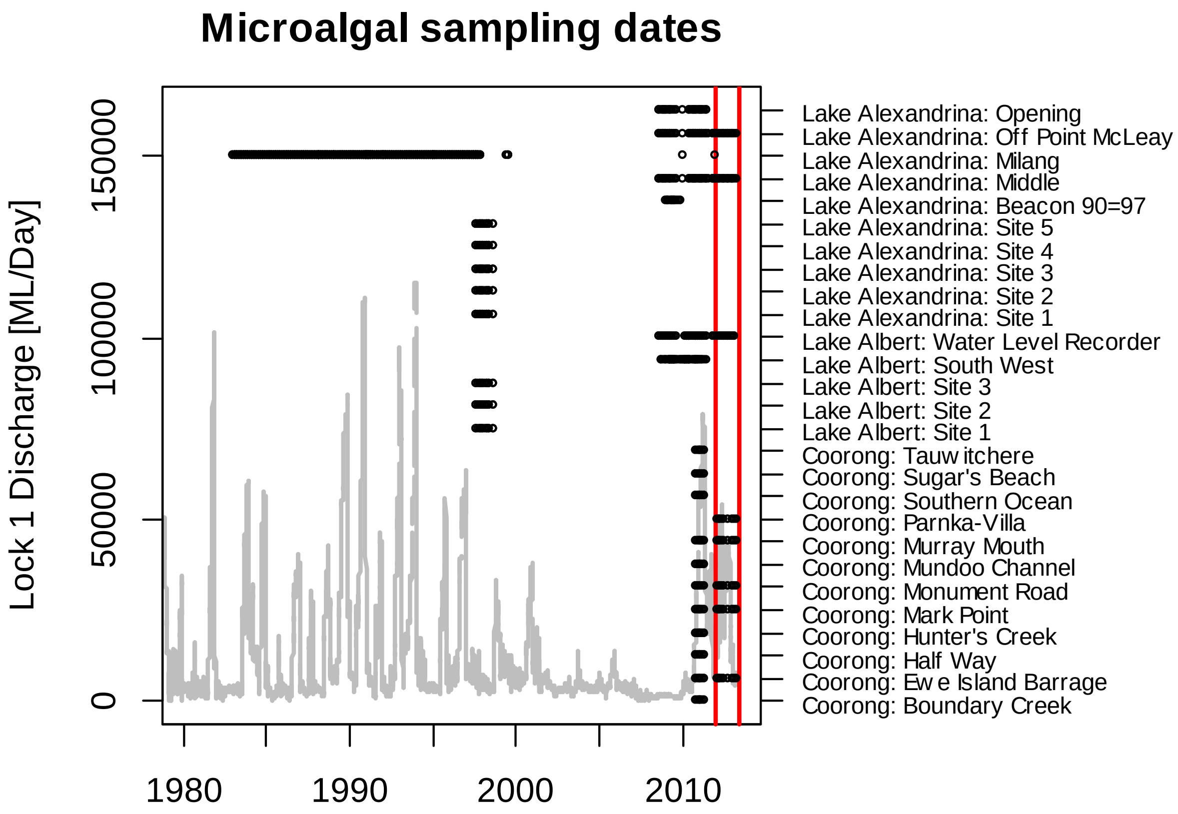


Figure 2 Microalgae sampling dates for sites listed on the right hand axis, with 2012-13 indicated by vertical red lines. Daily Murray River discharge at Lock 1 is shown as a continuous line (data sourced from SA Water).

Dealing with this large variation in sampling effort required a phased approach in order to maximise the use of the available data. In Lakes Alexandrina and Albert microalgae were analysed in a series of steps. The extensive Milang data set collected largely prior to the drought (Figure 2) provided a historical perspective on microalgae community composition in Lake Alexandrina under a hydrological regime typical of the pre-drought period. The Milang data was then contrasted with Lake Alexandrina Sites 1-5 and Lake Albert Sites 1-3 which broadened the spatial distribution of the descriptions of pre-drought microalgae community patterns in the lakes (Figure 2; Figure 1B, D). The pre-drought patterns were then contrasted with the post-drought community patterns measured at other sites across the lakes. In contrast, all sampling information was considered in analysing changes in microalgae communities the Coorong because of the limited amount of data.

Selecting water quality sampling dates

The distribution of water quality measurements across sites also varied substantially. The longest comprehensive data collection for a selected set of indicative water quality parameters was from Milang in Lake Alexandrina (Figure 3). Relatively long series were also available from other sites including Meningie in Lake Albert and Tauwitcherie in the Coorong (Figure 3). In contrast sites such as Middle Station and Beacon Station in Lake Alexandrina and the Murray Mouth station in the Coorong provided much less data (Figure 3).

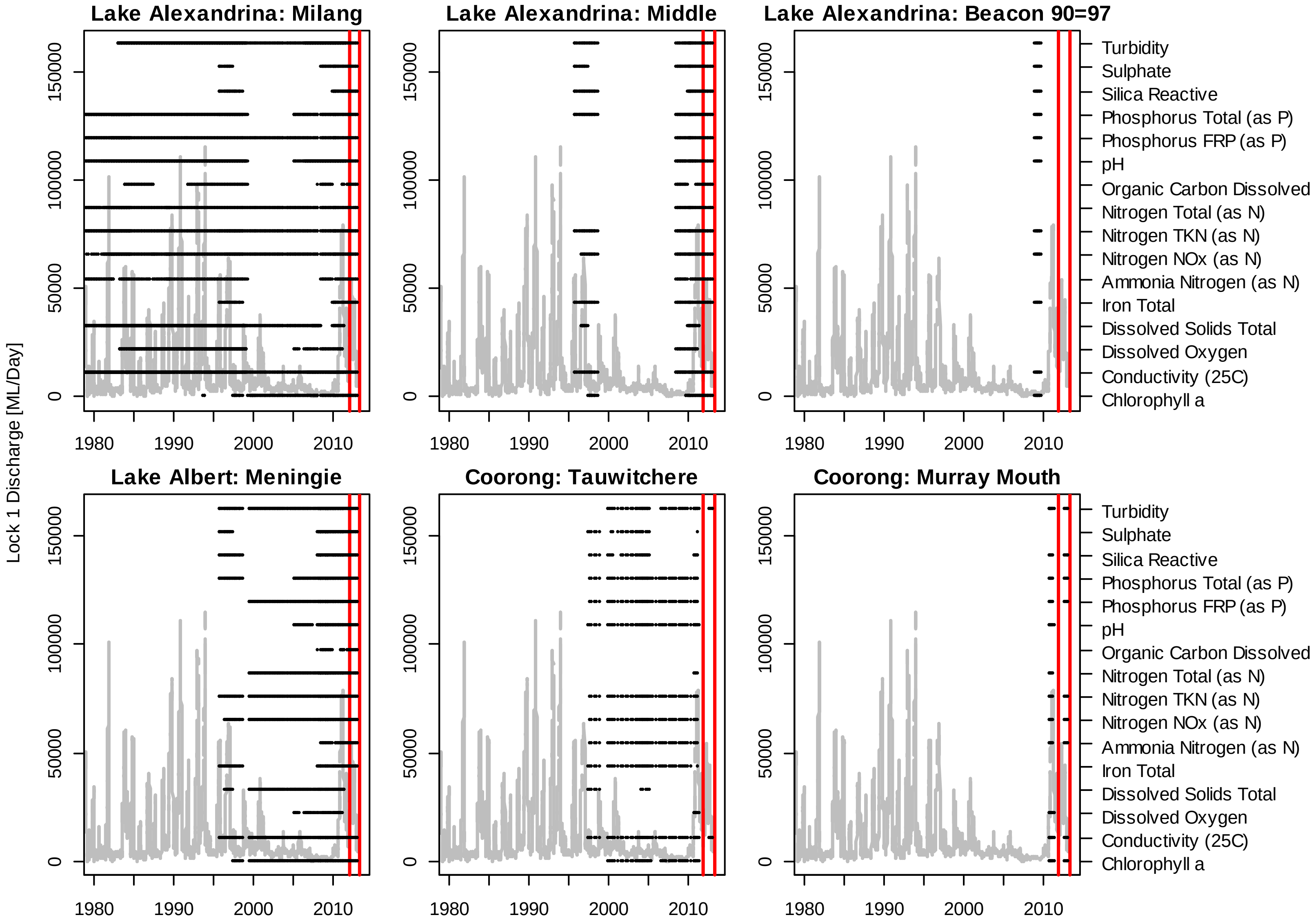


Figure 3 Water quality sampling dates for parameters listed on the right hand axis, with 2012-13 indicated by vertical red lines. Daily Murray River discharge at Lock 1 is shown as a continuous line (data sourced from SA Water). Site names are above the graphs.

The water quality parameters for analysis were limited to those listed on Figure 3 as these were considered most likely to be relevant to the microalgae. However, not all of these parameters were measured as part of each sampling regime and so for the different regions (Lake Alexandrina, Lake Albert, and the Coorong) different sets of parameters were chosen for intra- and inter-region analyses. But even within a region, different time periods could be chosen that would increase or decrease the availability of parameters for analysis. Most of these permutations could not be investigated in this project but would be worthwhile testing in future studies along with additional water quality attributes that were measured. The focus here was on balancing the desire for extra water quality attributes against the need to compare across the pre- and post-drought periods using the same set of consistent parameters.

Selecting sampling dates with co-occurring data

In order to statistically analyse the effects that environmental conditions might be having on patterns of microalgae community composition it is necessary to have co-occurring environmental and biological measurements. Matched sets were extracted for the different regions and sampling sites using the presence of microalgae counts as a template and extracting as many of the water quality parameters that matched all of the microalgae sampling dates. This exercise substantially reduced the spatial and temporal extent of the data available for analysis and in some situations, sites and regions were discarded. There are many permutations available and by reducing the number of water quality parameters more sampling sites become available for analysis. Most of these alternatives could not be tested here but should be investigated in future studies. The focus here was to try and maximise the number of sampling sites and times that had adequate matching water quality data and this was done visually from Figures 2 and 3.

Selecting zooplankton sampling dates

Zooplankton data was restricted to the period 2010-2013 and covered sites in Lake Alexandrina, Lake Albert and the Coorong. A number of the zooplankton sites did not correspond to microalgae and water quality sampling sites making it too difficult to include them in this project. Those sites that remained for analysis were treated independently of the microalgae and the water quality data as again it was too difficult within the constraints of this project to fully incorporate them within the joint analyses. This would be worthwhile doing in the future.

2.1.4 STATISTICAL ANALYSES

All analyses were undertaken using the methods within the statistical program Primer 6 and PERMANOVA+ (Anderson, Gorley & Clarke 2008). Patterns in microalgae community composition and zooplankton community composition were displayed using non-metric multi-dimensional scaling (nMDS). All nMDS were derived from a Bray-Curtis similarity matrix. Unless otherwise stated all data was transformed to presence and absence data prior to analysis.

Environmental and water quality parameters were treated in an analogous way to the microalgae except that the measurements were 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) were used to examine 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.

These types of 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 easily interpreted. Points that are close together are more similar to each other while points increasingly further apart are more dissimilar.

3 Results

3.1 Water Quality Patterns

3.1.1 TIME SERIES OF WATER QUALITY PARAMETERS

Scatter plots of major water quality parameters (electrical conductivity, 4 forms of Nitrogen, 2 forms of Phosphorus and turbidity) demonstrate the differences in water quality at selected locations in the Coorong, Lake Alexandrina and Lake Albert and there changes over time (Appendix B). These figures also demonstrate the intermittent nature and the variability of the sampling regimes, a characteristic that makes analyses difficult by normal statistical methods. Even visual analyses across the multiple, complex data sets is difficult to interpret and multivariate analysis is required to understand the aggregated influences when many parameters are changing together. However, general characteristics of the data series are worth describing and especially the changes in 2012-13 which is the focus year for this report and marked by red vertical lines on the time series figures (Appendix B). The descriptions are restricted to total nutrient concentrations so as to avoid over complicating the general patterns. Detailed discussion of water quality fluctuations throughout these periods are provided in Cook *et al*. (2010), Grigg *et al*. (2009), Aldridge and Brookes (2011), Mosley *et al*. (2012), and Mosley *et al.* (2013).

The Coorong time series (Appendix B, Figure B1) show data for seven sites spread along the length of the Coorong in order from north to south (Monument Road, Murray Mouth, Ewe Island Barrage, Tauwitchere, Mark Point, a combined site Parnka-Villa, and South Salt Creek). The data series commenced in 1997 and some sites contain 2012-13 measurements. The most complete time series are from Tauwitchere, Parnka-Villa (which combines the data of Parnka Point and Villa de Yumpa-Appendix 1), and South Salt Creek, but even at these sites not all parameters were measured regularly. However, the data provides an overview of the changes in water quality along the Coorong during the drought and pre- and post-drought periods (Figure 4). Prior to the drought, conductivity (an indicator of salinity) at Tauwitchere was similar to sea water levels or less, presumably diluted at times by high river flows (Appendix B, Figure B1). During the drought, conductivities increased consistently at this site but then dropped to very low levels comparable to freshwater during the high flows of 2010 and 2011. These low values continued through 2012 consistent with higher river flows, but then increased back to sea water concentrations again in early 2013 as river flows fell back to very low levels. Similar patterns were observed at Parnka-Villa and Salt Creek except that the conductivities at these sites were substantially higher due to evaporation of water from the closed system (Grigg *et al*. 2009). At Parnka-Villa conductivities commenced at sea water levels or slightly higher and during the drought increased up to approximately four times seawater levels. No data was collected from this site during the return of flows, but late in 2012 and into 2013 as flows declined, conductivities increased from approximately seawater up to several times seawater concentrations. At Salt Creek the conductivities commenced at ca. twice sea water levels, increased to about four times sea water during the drought but then decreased back to sea water levels before increasing again as flows reduced in 2013.

Nitrogen and Phosphorus data were not collected at Tauwitchere or Salt Creek during or following the return of flows (Appendix B, Figure B1). However by comparing sites along the system it is estimated that total nitrogen concentrations at the end of the drought were similar at Monument Road and Mark Point with typical values of 1.5 mgN/L but varied widely. Concentrations increased between Mark Point and Parnka-Villa with typical values of 4 mgN/L. Total nitrogen concentrations between Monument Road and Mark Point were reduced by the increased flows of 2010-12 and remained low through to 2013. Also at Parnka-Villa the period of increased river flows was associated with a reduction in TN but in 2013 concentrations began increasing again as flows subsided.

In the northern sections of the Coorong the increases in flow were associated initially with an increase in total phosphorus concentrations and then a reduction as flows continued. South of Tauwitchere this pattern was less clear and showed no close relationship with flow. Turbidity at these sites showed a pattern similar to that of total phosphorus.

In Lake Albert two sites, Meningie and the Water Level Recorder had monitoring data covering the selected set of water quality parameters (Appendix B, Figure B2). The results for both sites were very similar. Conductivity was initially that of a freshwater system but during the drought it increased markedly to peak at a level almost half that of sea water. When flows returned conductivity dropped quickly, but even by 2013 it had not returned to the pre-drought levels. A similar pattern was seen for Total Nitrogen, but not for Total Phosphorus and turbidity. Total Phosphorus and turbidity showed similar patterns to each other but these were not consistently related to flow changes although concentrations did increase during the drought.

Three sites in Lake Alexandrina, Middle, Milang and Off Point McLeay (Appendix B, Figure B3), were examined and found to have very similar responses to each other for the selected water quality parameters. The patterns were similar to those found in Lake Albert except that conductivity and total nitrogen were higher in Lake Albert than in Lake Alexandrina. In the case of phosphorus and turbidity both the patterns and the concentrations were similar between Lakes. A notable difference between the two regions was that conductivity and total nitrogen in Lake Alexandrina had returned to pre-drought levels following the increased flows whereas those in Lake Albert had not.

It is clear that changes in flows during the drought have changed water quality attributed both within the Lakes and the Coorong. As the Lakes are relatively well mixed the changes are quite uniform across sites, unlike in the Coorong where gradients are formed due to its geomorphology and the delivery of both fresh and sea water to the northern end. However, even from this detailed look at the time series of water quality parameters it is not apparent how closely the various sites have returned to their pre-drought condition.

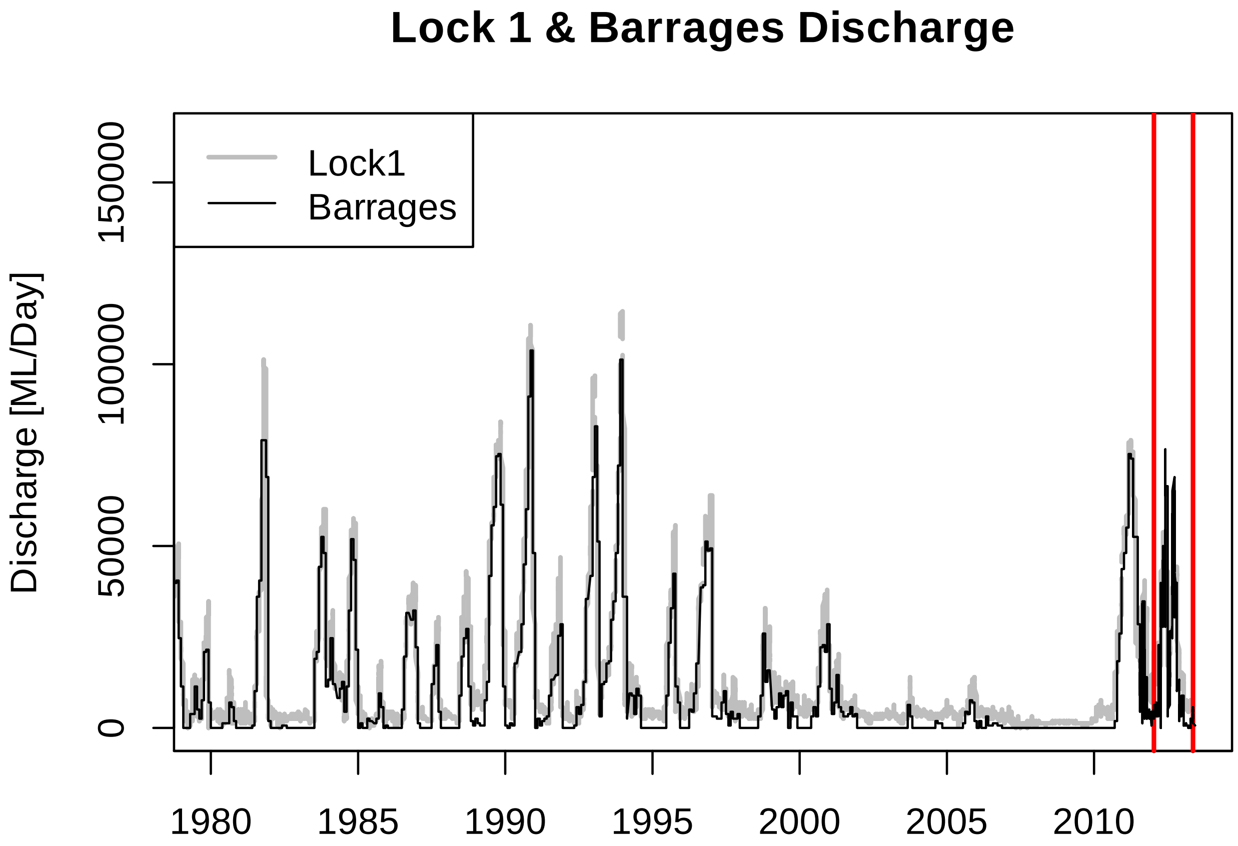


Figure 4 Discharge at Lock 1 (data SA Water) and flow over the barrages in Lake Alexandrina (data DEWNR).

3.1.2 LAKES ALEXANDRINA AND ALBERT WATER QUALITY PATTERNS

As described in the methods, parameters were selected that would provide a reasonable overview of water quality while at the same time ensuring a representative selection of sampling sites and a suitable length of record. The selected water quality parameters used in these analyses were conductivity, three forms of nitrogen (NO_X, TKN and TN), Total phosphorus, Reactive silica, turbidity, chlorophyll a, and the flow on the day of sampling or the integral flow over the previous 5 days for the Murray River (Disch or Disch5) and the barrages (Barrage or Barrage5). On the basis of these parameters a PCA showed little separation between Lakes Alexandrina and Albert in water quality composition (Figure 5).

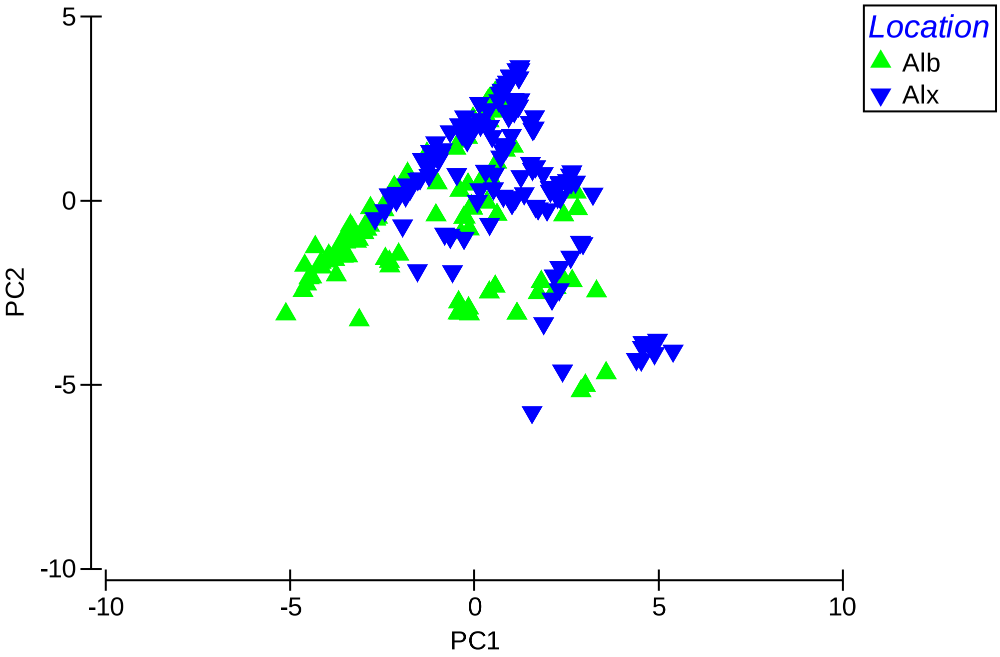


Figure 5 Water quality characteristics in Lakes Alexandrina and Albert compared through a PCA.

For this same result the data points were re-defined to show the distribution of data between seasons (Figure 6) and years (Figure 7). Even though there were differences in the number of replicate samples taken in seasons, and differences in the number of seasons sampled in any year, there is no strong seasonal pattern to the spread of the data across the years being compared (Figure 6). There will be seasonal changes within and between years but these have not been investigated here as the focus is on larger scale changes across time. PERMANOVA showed that all years were significantly different from each other except 2008 and 2010, 2010 and 2013, 2011 and 2012. As most years were significantly different from each other the water quality parameters accounting for these changing patterns could be identified. The parameters with Pearson correlations>0.3 were conductivity, TN, TKN, and TP, which were largely associated with the within-year variation, while reactive silica and the two measure of flow were more associated with between-year differences, especially 2010 to 2013. To more clearly represent the annual shifts the data was re-analysed at the annual level, plotted using a PCA, and then a trajectory line added (Figure 8). Years that were not significantly different from each other are circled. This analysis suggests a significant change in conditions between 1997-98 which was prior to the drought, and 2009 which was towards the end of the drought. Following the increase in flows in late 2010 and during 2011 and 2012 the water quality patterns changed significantly from the previous periods, but in 2013 moved back towards earlier patterns and perhaps more towards the pre-drought conditions as river flows declined. More detailed analyses of the data will be required to confirm these findings.

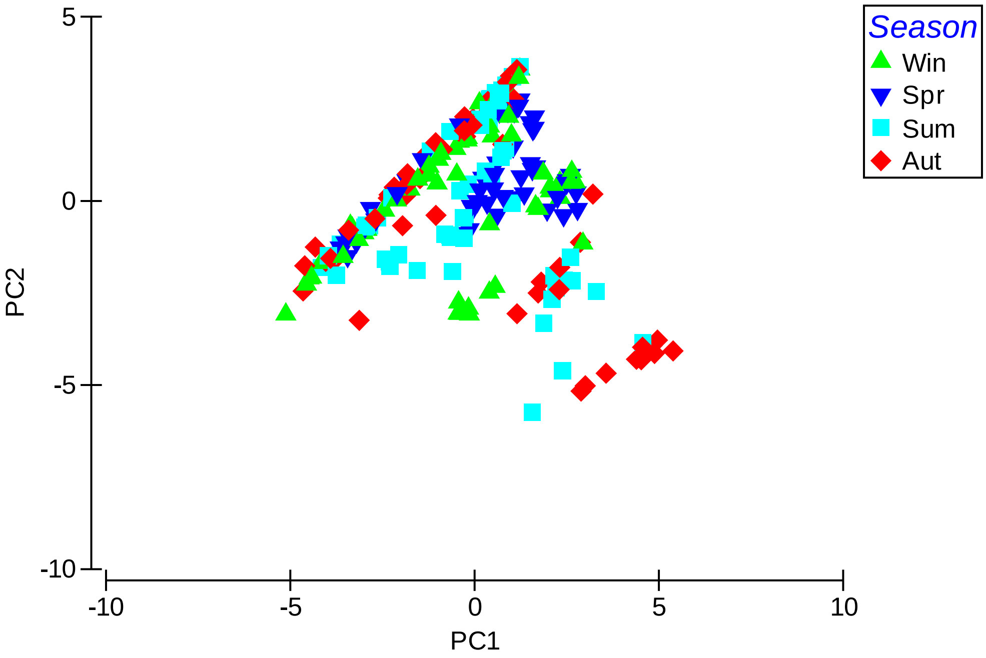


Figure 6 Seasonal water quality characteristics in Lakes Alexandrina and Albert compared through a PCA

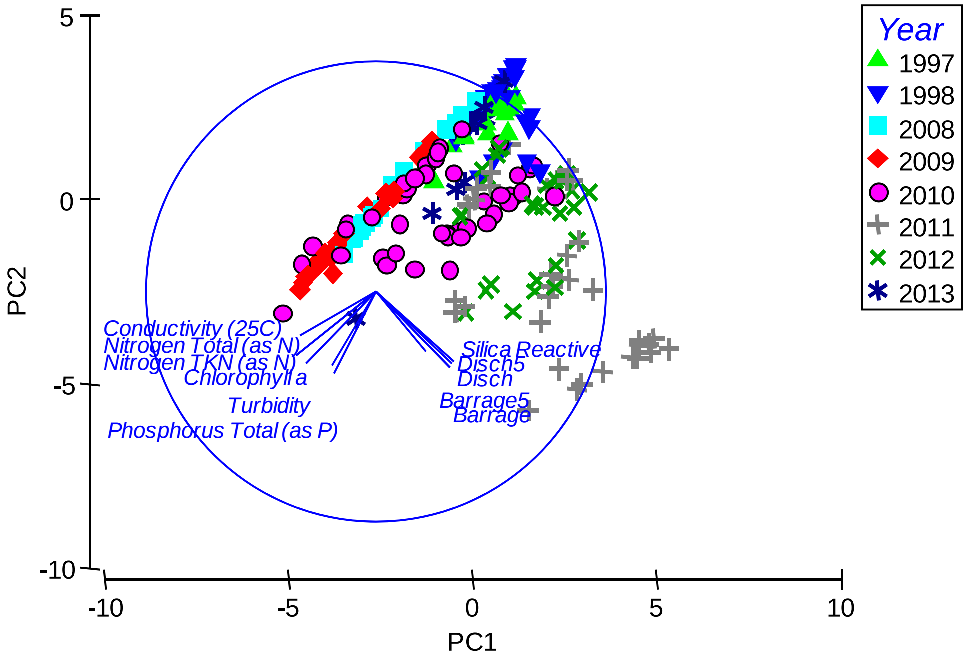


Figure 7 Annual water quality characteristics in Lakes Alexandrina and Albert compared through a PCA and correlated with major influences on water quality.

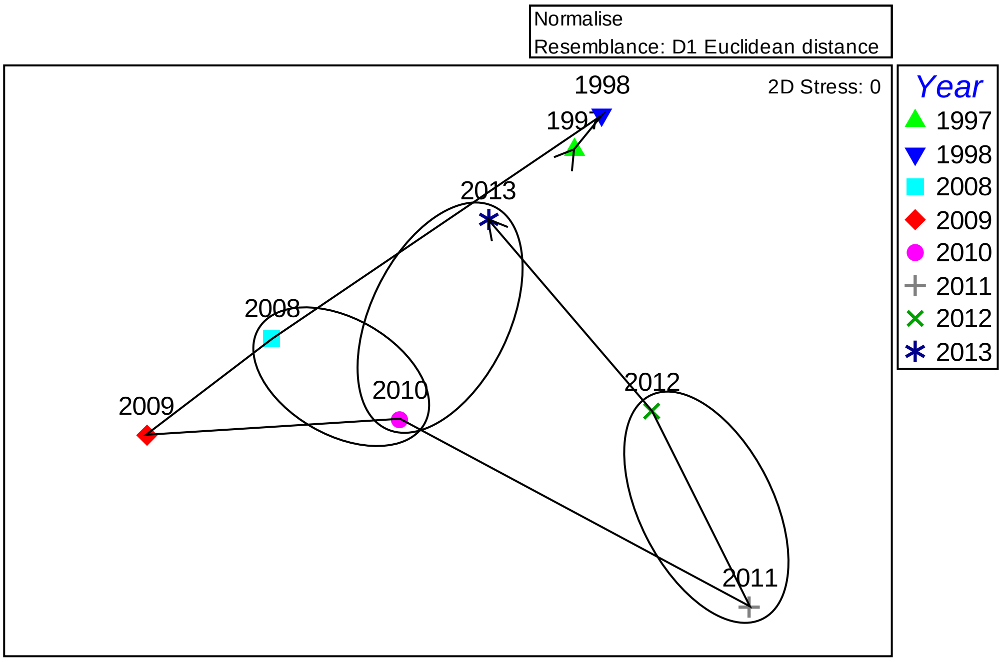


Figure 8 Annual shifts in water quality characteristics in Lakes Alexandrina and Albert compared through nMDS and connected with a time trajectory line. Ellipses enclose years where water quality is not significantly different.

3.1.3 COORONG WATER QUALITY PATTERNS

The parameters selected to provide an overview of water quality in the Coorong were conductivity, four forms of N (NO_X, NH_4, TKN and TN), two forms of P (TP and FRP), reactive silica, turbidity, chlorophyll-a and the integral flow over the previous five days for the river or the barrages. The PCA distribution of seasonal

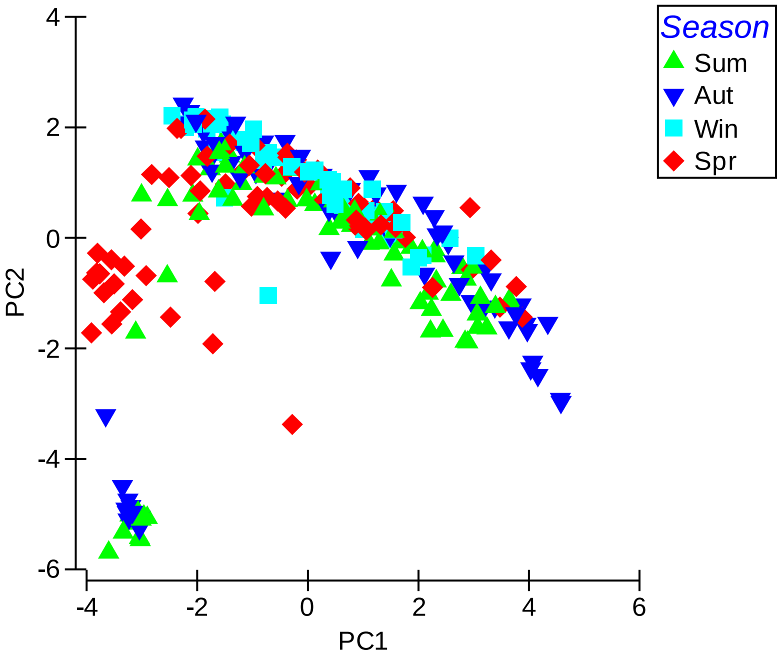


Figure 9 Seasonal water quality characteristics in the Coorong compared through a PCA

measurements (Figure 9) compared with annual measurements (Figure 10) suggests there may be some bias in seasonal sampling evident in the 2010-2012 periods due to monitoring programs focusing on particular times of the year. For example, data from 2010 was restricted to spring sampling, but in most other years at least two seasons were represented.

When the data points are recoded to show the distribution of years it is evident that the outlying points are associated with particular years, noticeably 2010, 2011, 2012 (Figure 10). Despite the variations in seasonal sampling these years appear different and PERMANOVA showed that in fact most years were significantly different from each other. The exceptions were that 1999 was not different from the years 2000 to 2005 while 2001, 2004 and 2005 were not significantly different from 2013. The differences between 2010, 2011, 2012 and 2013 were significant and they show a progression of increasing and then decreasing differences from the drought and pre-drought periods, with 2011 the most dissimilar and 2013 similar to the earlier conditions. The data for each year was collated and an nMDS based on year shows the inter-annual pattern more clearly (Figure 11).

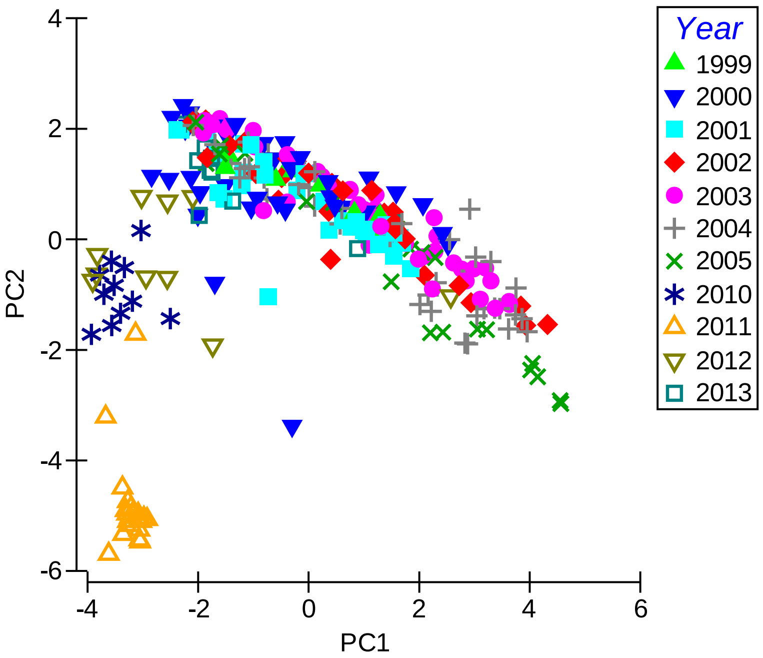


Figure 10 Annual water quality characteristics in the Coorong compared through a PCA

As most years were significantly different from each other the water quality parameters accounting for the changing patterns could be identified. The parameters with Pearson correlations>0.4 were added as vectors showing the direction of influence on the PCA in Figure 12. Conductivity, Total Nitrogen, TKN, Total Phosphorus, and reactive silica were largely aligned to the variations occurring within years, especially during the earlier years. Turbidity and the two measures of discharge largely aligned with the inter-annual changes especially between 2010 and 2013. Chlorophyll a which is a measure of the biomass of microalgae increased as expected as nutrient conditions increased. These results match the interpretations of the time series data (Section 3.1.1) and indicate a freshening of the system with reduced conductivity and nutrient concentrations due to the high flows commencing in 2010. The changes in water quality patterns peak in 2011 and then through 2012 and 2013 return towards patterns similar to the original water quality conditions. Unlike the time series data where the cumulative effects of the many individual changes were difficult to assess, the multivariate approach describes the time series of changing water quality conditions and provides managers with an assessment of the overall system condition.

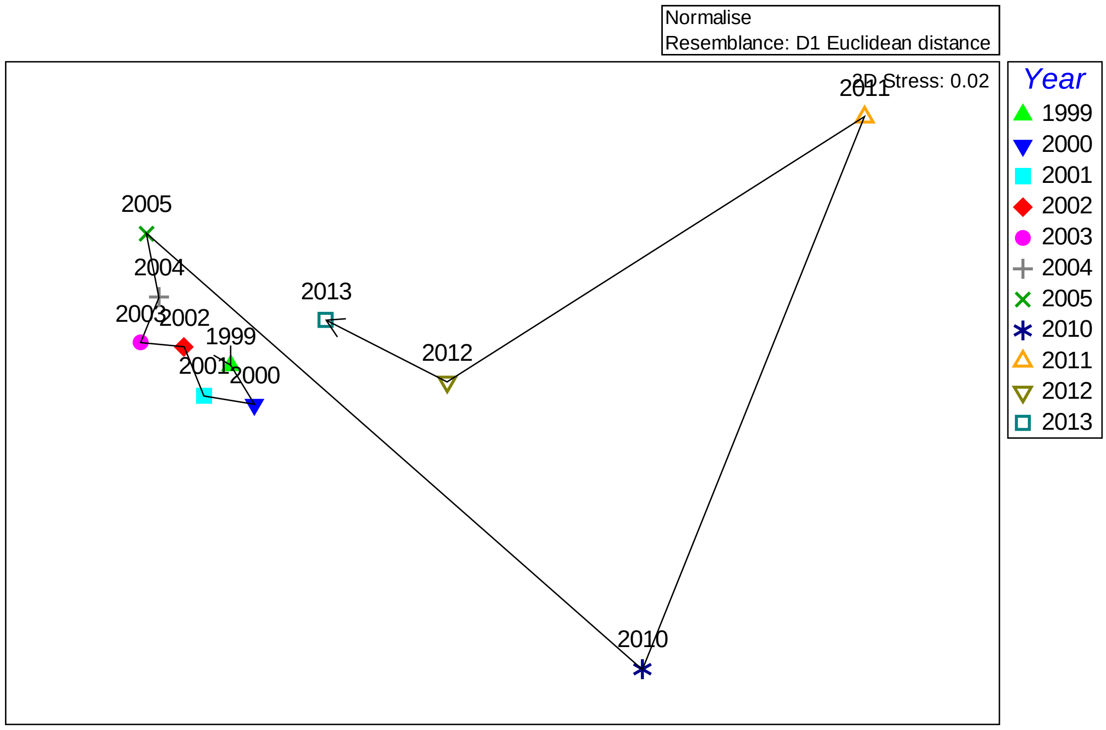


Figure 11 Annual sequence of water quality characteristics in the Coorong compared through nMDS

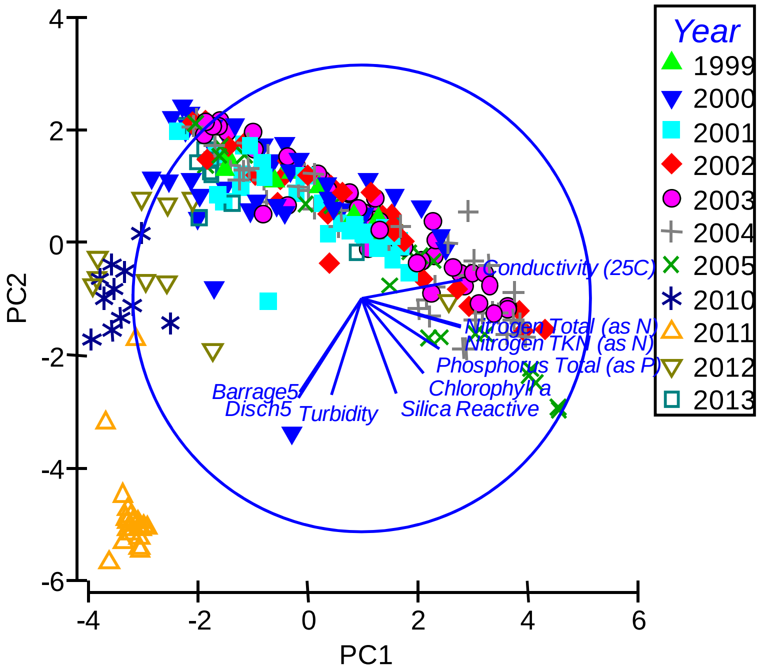


Figure 12 Annual water quality characteristics in the Coorong compared through a PCA and correlated with major influences on water quality.

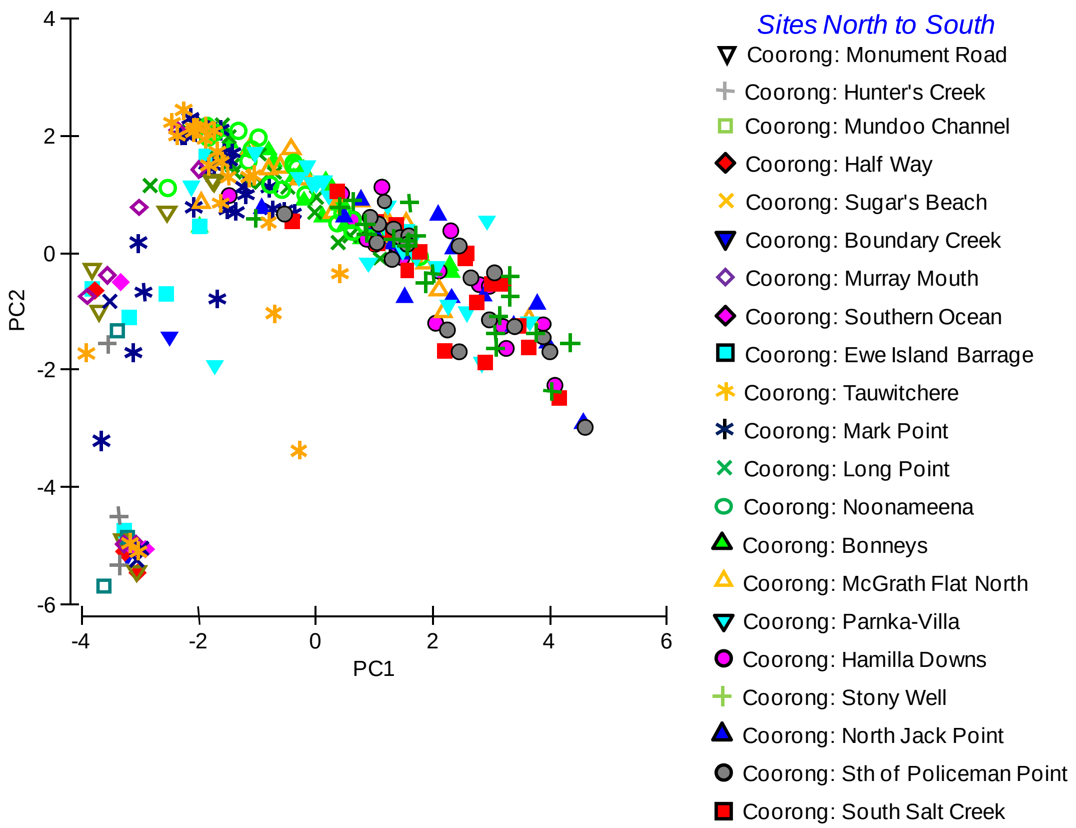


Figure 13 Individual site water quality characteristics in the Coorong compared through a PCA

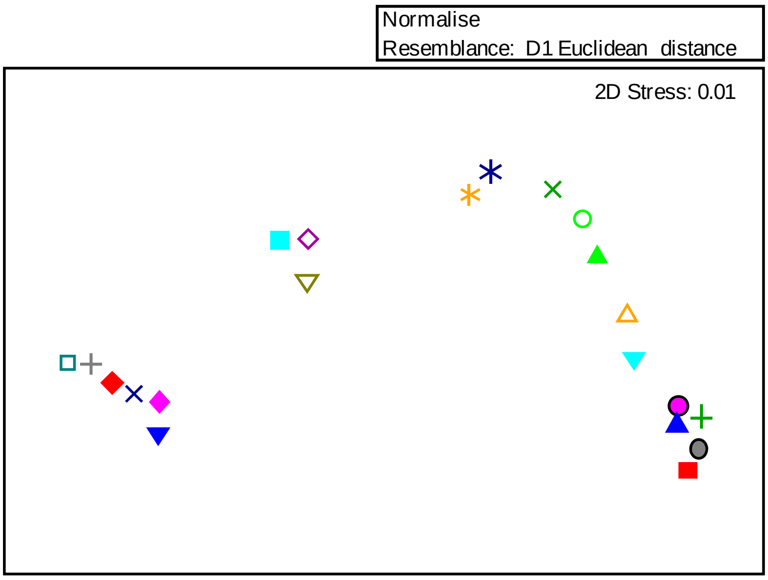


Figure 14 Aggregate water quality characteristics for each site in the Coorong compared through nMDS. Symbols defined in Figure 13.

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

Table 2 Sampling sites in the Coorong along with their sequence order from north to south and their site code.

The geomorphology combined with the hydrology of the Coorong results in longitudinal gradients in water quality. Recoding of the data points of previous figures indicates that differences between seasons and years, especially during the period of increased flows, was not due to sampling of selective sites (Figure 13). Most of the monitoring programs included measurements along the length of the Coorong, although often using different sites (Figure 13). The sequential order of sites along the Coorong from North to South is listed in Table 2. It is difficult to see any longitudinal patterns in water quality from Figure 13, so the data was re-analysed for individual sites across all seasons and years to show that despite seasonal and annual differences there was a persistent longitudinal gradient in water quality (Figure 14). This sequence analysis is for demonstration purposes and provides an overview of the large scale conditions within the system. More sophisticated analyses could be done to look at the gradient and its changes over time.

3.2 Microalgae community composition patterns

3.2.1 SYSTEM SCALE COMPARISONS OF LAKE MICROALGAE COMMUNITIES

The Lower Lakes and Coorong form a variably interconnected system with the degree of interaction determined by river inflows. Data on the composition of microalgae communities collected across all sites and years from 1983 until 2013 was analysed collectively at the generic level but with counts converted to presence/absence data. This overarching analysis needs to be interpreted carefully as it is likely to include problems arising from factors such as changes in the reliability of microalgae identification. However, the results provide an overview for the more detailed analyses that follow in later sections and that generally support these large scale findings.

An nMDS of the total microalgae data shows three distinct groupings (Figure 15). Group A contains all samples taken prior to 2000 and is indicative of the pre-drought period. It includes the historical Milang data plus samplings from sites across Lakes Alexandrina and Albert (Figure 2). Group B is dominated by samples taken post-drought and includes sites from both lakes, although these are different sites to those sampled pre-drought (Figure 2). Group C contains sites mainly from the Coorong, but a number of Coorong sites also overlap significantly with Group B. Only a short time sequence of data was available for the Coorong with microalgae samples not collected until post-drought, commencing in 2010. The cross-system results indicate that the post-drought microalgae communities are different from those observed prior to the drought despite the increased flows of 2010-2011.

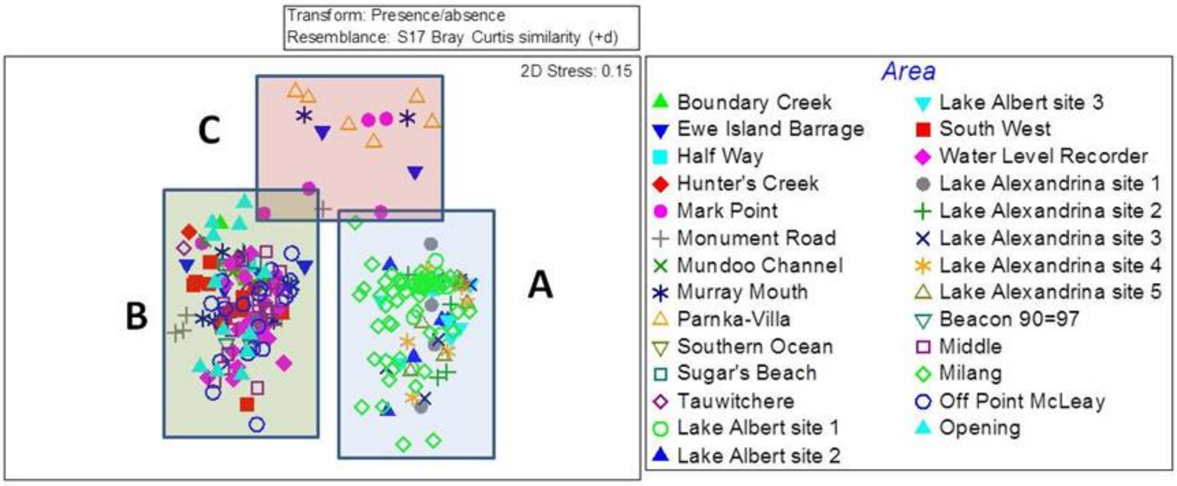


Figure 15 Microalgae community data from sites sampled in Lake Alexandrina, Lake Albert and the Coorong compared though nMDS. In the key the first 12 sites are from the Coorong, the next five from Lake Albert and the remainder from Lake Alexandrina. Rectangle A encloses pre-drought lake samples, Rectangle B encloses post-drought lake samples and Rectangle C largely encloses Coorong sites, although these overlap into Rectangle B.

3.2.2 MILANG AND HISTORICAL MICROALGAE RESPONSES WITHIN LAKE ALEXANDRINA

Microalgae data was collected at Milang from 1983-1997 providing the longest continuous record and a historical perspective on community composition. This data was analysed across years based on presence and absence using the original microalgae identifications. An nMDS of all sampling occasions showed a spread of data (Figure 16) and PERMANOVA indicated that microalgae communities differed significantly between years and seasons (Table 3). A pair wise comparison of years showed that most were significantly different from each other. The data was re-analysed using cell count data and multiple samples within seasons as replicates in order to compare similarities between years in an nMDS (Figure 17). A trajectory line connecting the annual points shows no clear directional progressions between years, although the early 1990's may prove to be a distinct cluster following more detailed analyses. These results suggest that the microalgae community is being influenced by a number of different factors that are changing from year to year and that consistent sequences, as often seen in lakes that regularly temperature stratify in summer, are not present in these shallow well mixed lakes. It was not surprising then that when this extensive Milang data set was compared with environmental measurements there were no major correlations with any of the environmental parameters measured (data not shown). A detailed analysis of the 15 year data sets including statistical clustering of distinct periods is likely to be more informative but was not part of this study.

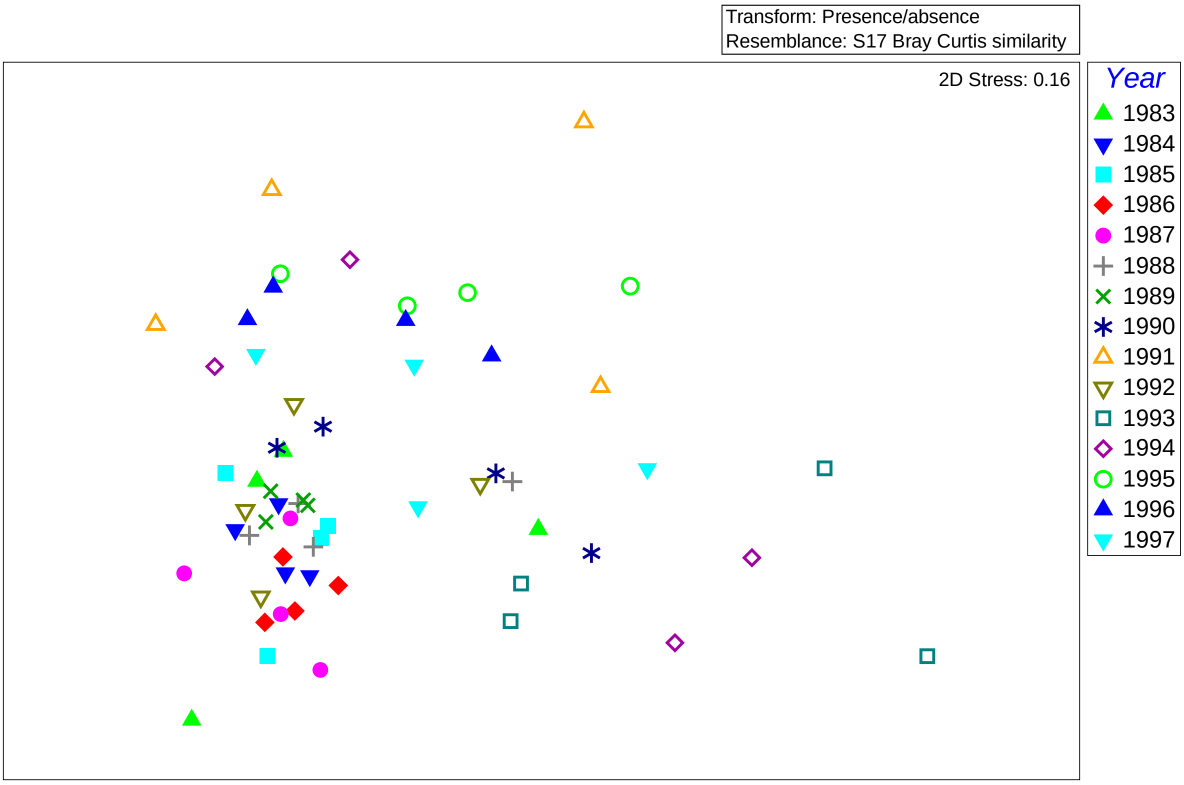


Figure 16 Microalgae communities at Milang compared for sampling times within years through nMDS.

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Year	15	1.0609E5	7072.4	5.2199	0.001	998
Season	3	25269	8423.2	6.2168	0.001	998
YearxSeason	42	85673	2039.8	1.5055	0.001	995
Res	113	1.531E5	1354.9			
Total	173	3.7717E5				

Table 3 PERMANOVA of Milang microalgae communities

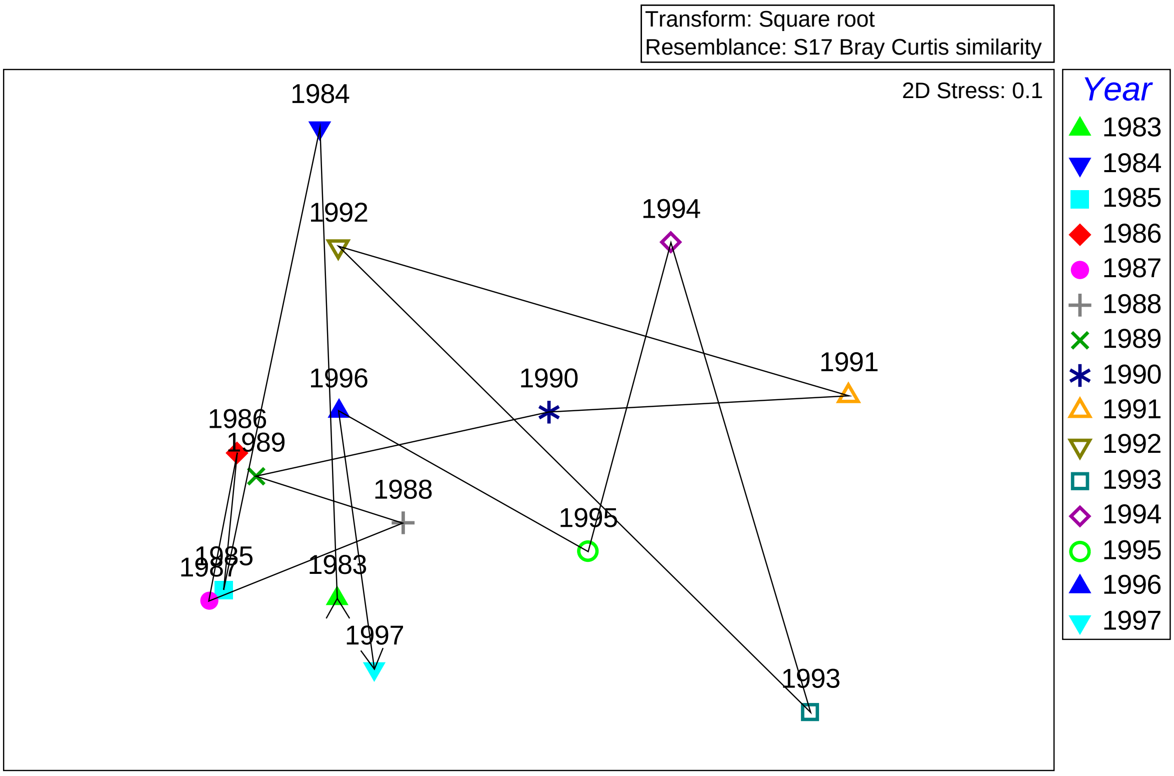


Figure 17 Annual sequence of microalgae community composition at Milang in Lake Alexandrina compared through nMDS

3.2.3 LAKE ALEXANDRINA MICROALGAE PRE- AND POST- DROUGHT

When analysing the Milang site it was assumed that the identification and enumeration of microalgae remained relatively consistent over time. This is less likely to be the situation when comparing Milang with other sites in Lake Alexandrina, especially those that were sampled after the end of the drought in 2008 following a considerable break in monitoring (Figure 2). To try and minimise the effects from possible changes in methods a common set of microalgae comprised of 51 genera was extracted from across all of the sites analysed (Table 4). Data were transformed to presence absence as samples collected during 1997-98 from Lake Alexandrina did not always have cell counts but used order of magnitude indicator levels.

Despite the reduction in the number of microalgae genera available for analyses there is a clear separation between sites prior to and after the drought. Sites coded “Nor” are samples from the period of more typical river hydrology prior to 1998, while those coded “Dro” are samples from 2008-2013. The Milang site dominates the data set prior to the drought but samples collected from Lake Alexandrina Sites 1-5 (Alx1 to Alx5) during 1997-98 and distributed across the lake overlap with part of the Milang data (Figure 18). This suggests that the range of variation in the micro-algal community composition of Lake Alexandrina has been captured over the pre-drought period. Data collected after the drought came from different sampling sites than those prior to the drought (Figure 2) but these sites were also widely distributed across the lake (Figure 1B) and together are expected to provide a representative estimate of the microalgae community composition. The nMDS indicates that the post-drought microalgae communities are different from those measured prior to the drought. Also data from prior to the drought is more widely dispersed suggesting the microalgae communities were more heterogeneous then.

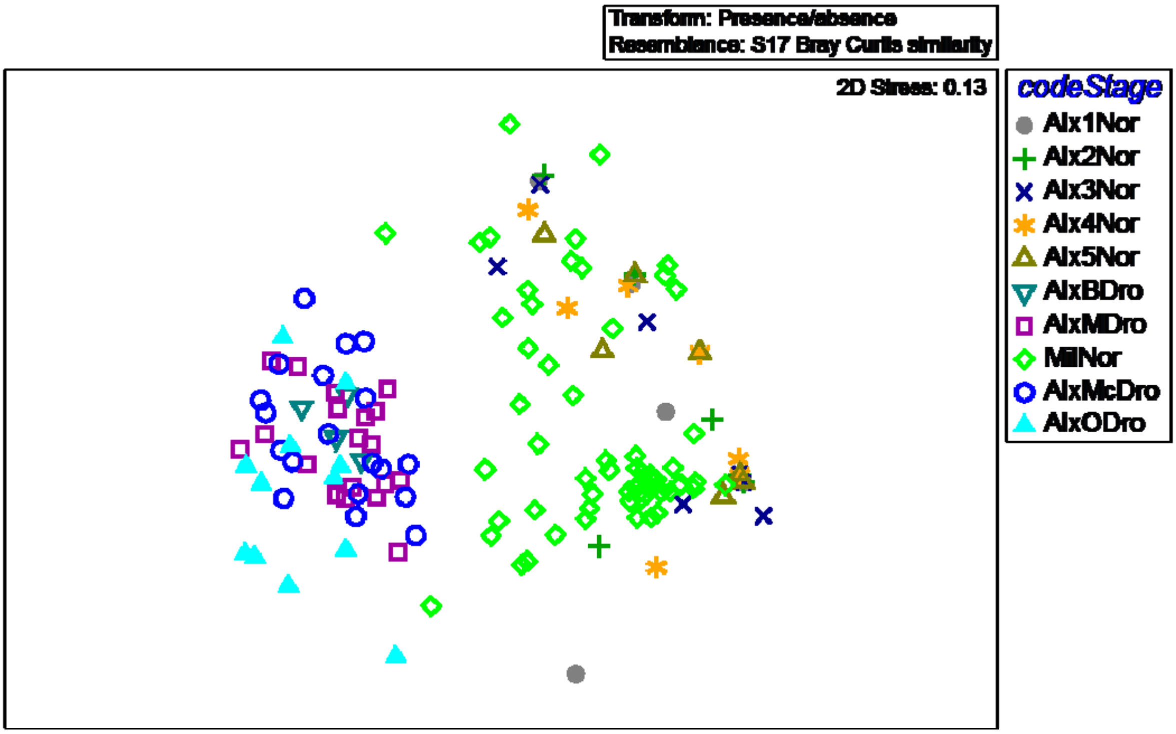


Figure 18 Pre-drought (Nor) and Post drought (Dro) measurements of microalgae composition made in Lake Alexandrina (Alx) compared through nMDS. The site codes refer to: Alx 1-Alx 5 = the 1997-98 sites distributed across the lake; AlxB = Beacon 90=97; AlxM = Middle; AlxMc = Point McLeay; AlxO= Opening

Common genera analysed across sites in Lake Alexandrina between 1983 and 2013			
Cyanophyta	Anabaena	Chlorophyta	Actinastrum
	Anabaenopsis		Ankistrodesmus
	Aphanizomenon		Botryococcus
	Aphanocapsa		Chlorella
	Cylindrospermopsis		Crucigenia
	Microcystis		Dictyosphaerium
	Nodularia		Micractinium
	Phormidium		Nephrocytium
	Planktolyngbya		Oocystis
	Planktothrix		Pediastrum
	Pseudanabaena		Planctonema
Bacillariophyceae	Amphiprora		Scenedesmus
	Asterionella		Schroederia
	Attheya		Sphaerellopsis
	Cyclotella		Sphaerocystis
	Gyrosigma		Tetraedron
	Melosira		Tetrastrum
	Navicula	Charophyta	Closterium
	Nitzschia		Cosmarium
	Staurosira		Elakatothrix
	Synedra		Mougeotia
	Tabellaria		Spirogyra
Dinophyta	Glenodinium		Staurastrum
Euglenophyta	Euglena	Cryptophyta	Chroomonas
	Phacus		Cryptomonas
	Trachelomonas		

Table 4 Microalgae genera common to sampling sites across Lakes Alexandrina and Albert during the pre- and post-drought periods and used in analyses of community composition changes.

3.2.4 LAKE ALEXANDRINA AND LAKE ALBERT SITES PRE-DROUGHT

The pre-drought comparison between algal community composition at Milang and at other sites in Lake Alexandrina was expanded to include measurements from Sites 1-3 in Lake Albert (Alb1 to Alb3) that were sampled at the same times during 1997-1998 as Sites 1-5 in Lake Alexandrina (Alx1 to Alx5) (Figure 2). An nMDS showed that at this time the microalgae communities from the Lake sites were similar (Figure 19), and showed some overlap with the Milang site.

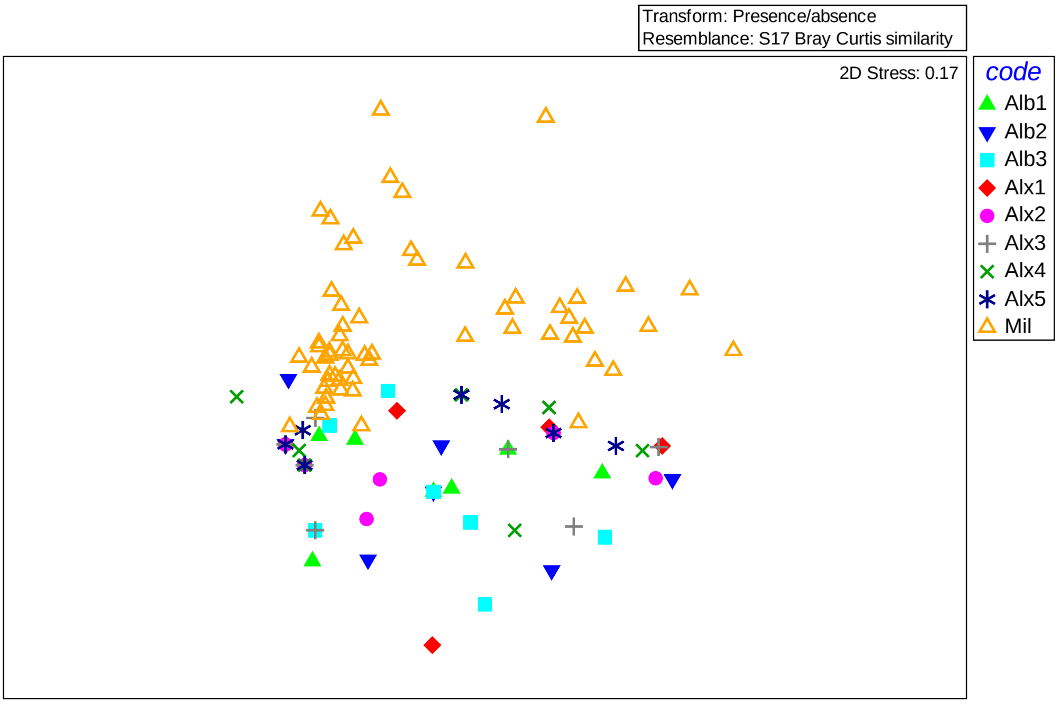


Figure 19 Lake Alexandrina and Lake Albert microalgae community composition pre-drought compared through nMDS.

PERMANOVA of sites across years using all samples within a season as replicates indicated that there were differences between the sites and between years but no interaction between sites and years. Pair wise comparison between sites (data not shown) indicated that the Milang algal communities were generally different from the other Lake Alexandrina sites and from the Lake Albert communities but there were no differences between communities of Lakes Alexandrina and Albert.

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Site	8	44479	5559.9	3.1815	0.001	998
Year	15	5.843E5	38953	22.29	0.001	999
SitexYear	7	10025	1432.1	0.81949	0.741	999
Res	902	1.5763E6	1747.6			
Total	932	2.2457E6				

Table 5 PERMANOVA of Lakes Alexandrina and Albert microalgae communities pre-drought.

Pearson correlation of the genera of microalgae associated with the changes in community composition indicated that 7 genera had a Pearson correlation >0.3 (Table 6) and that these had higher abundances associated with particular sites and times as shown by the genera vectors on the nMDS (Figure 20). This analysis suggests that the Milang data has two clusters, one with a community associated with the green algae *Oocystis*, *Dictyosphaerium* and *Scendesmus* along with the diatom *Cyclotella*, and a second cluster associated with the cyanobacteria *Anabaena*, *Nodularia* and *Anabaenopsis*. The other sites sampled in both lakes during 1997-1998 were more strongly associated with the cyanobacteria *Aphanizomenon*, *Cylindrospermopsis* and *Planktolyngbya*. Pearson correlation of the measured environmental parameters associated with the community changes indicated that differences between sites were weakly related to discharge with correlations of approximately 0.35 (Figure 21).

	Anabaena	Anabaenopsis	Aphanizomenon	Cyclotella	Dictyosphaerium	Nodularia	Oocystis	Planktolyngbya	Scenedesmus	Staurastrum
MDS1	0.7	0.5	0.7	-0.2	0.0	0.7	-0.2	0.5	0.1	0.0
MDS2	0.3	0.1	-0.1	0.5	0.7	0.2	0.7	-0.4	0.5	0.5

Table 6 Pearson correlations of microalgae general contributing to the distribution of micr-oalgae communities across sites in Lakes Alexandrina and Albert pre-drought.

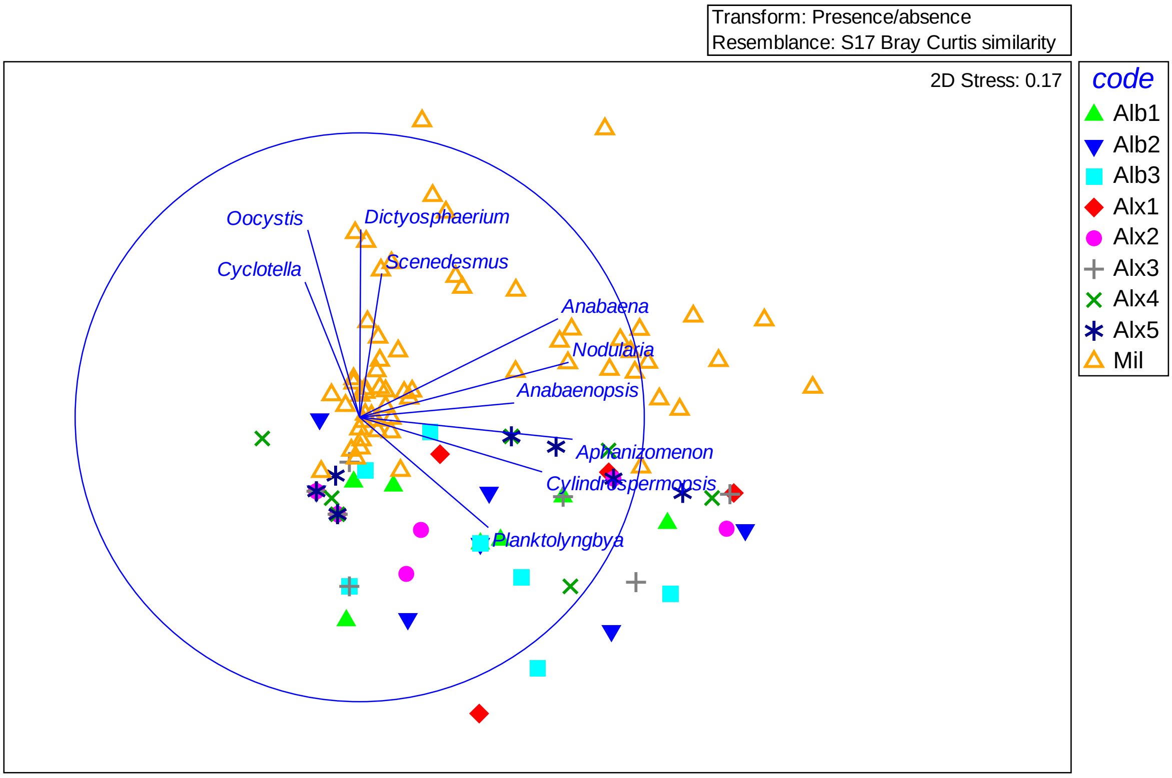


Figure 20 Lake Alexandrina and Lake Albert microalgae community composition pre-drought compared through nMDS and correlated with major microalgae genera influencing the distribution.

In general there were periods of higher flows during the extended sampling at the Milang site while during the one year sampling period for the Lakes Alexandrina and Albert sites (July 1997- September 1998) samples were collected during a prolonged low flow period (Figure 4). Correlations with the two flow measures, five day integral flow at either Lock 1 or the barrages, are almost identical reflecting the flow through conditions at the time where inflow changes were largely matched by changes in outflows (Figure 4).

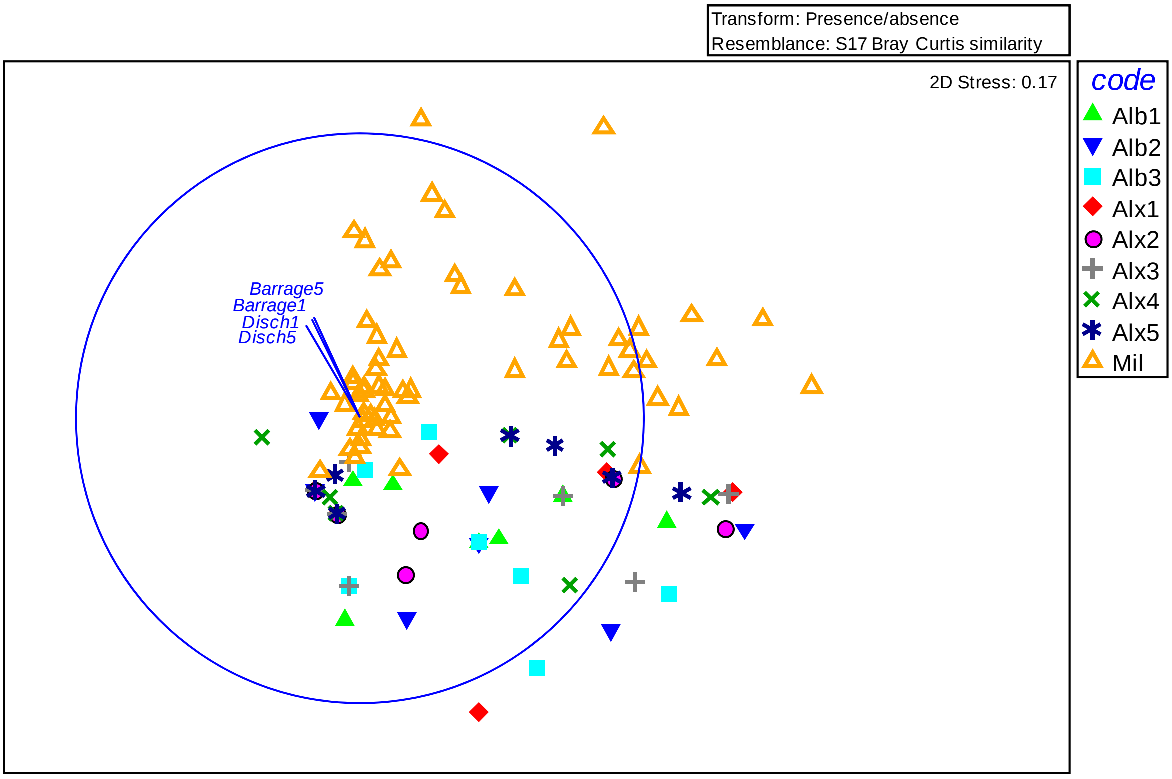


Figure 21 Lake Alexandrina and Lake Albert microalgae community composition pre-drought compared through nMDS and correlated with major water quality parameters influencing the distribution.

Comparison of Figures 20 and 21 suggest that there is a progression of species through the three microalgae groupings and these are associated with changing flow. The analysis suggests that the microalgae communities at the Milang site contain increased occurrences of diatoms and green algae during periods of higher flow and increasing occurrences of filamentous cyanobacteria during periods of reduced flow. In contrast the sites on Lake Alexandrina and Lake Albert sampled during 1997-98 (a low flow period) have increased occurrences of small, narrow filamentous cyanobacteria. Experience in other systems would suggest that flow and turbulence might have a role in this type of sequence. Communities of green algae and diatoms are considered more palatable to grazers and so are more important food resources for planktonic foodwebs than are the cyanobacteria (Oliver and Ganf 2000).

3.2.5 LAKES ALEXANDRINA AND ALBERT MICROALGAE PRE- AND POST-DROUGHT

The presence of the large Milang data set strongly influenced the dimensional depiction of the other lake sampling sites and generally had a different microalgae community composition from the sites collected more broadly across the Lakes pre-drought (Figure 19). Samples collected from the Lakes post-drought were also spread across the Lakes and so to improve the comparability of the pre- and post-drought data, the Milang site was removed from the analyses. The sites from Lakes Alexandrina and Albert were divided into three time periods, the pre-drought sampling period of 1997-98, an end of drought period including

2008-2011, and the most recent sampling in 2012-2013. In the nMDS data was converted to presence/absence data as full microalgae counts were not performed in 1997-98.

One purpose of this analysis was to describe the 2012-13 microalgae communities in the context of historical community compositions to try and assess the current status of the lake system. The results indicate that the 2012-13 microalgae community compositions were more similar to those from the immediate post-drought period than the pre-drought period. However, they show a tendency to be closer to the pre-drought data suggesting that the microalgae community composition may be slowly moving back towards what it was before the drought. Continued monitoring will be required to determine whether this shift is continuing.

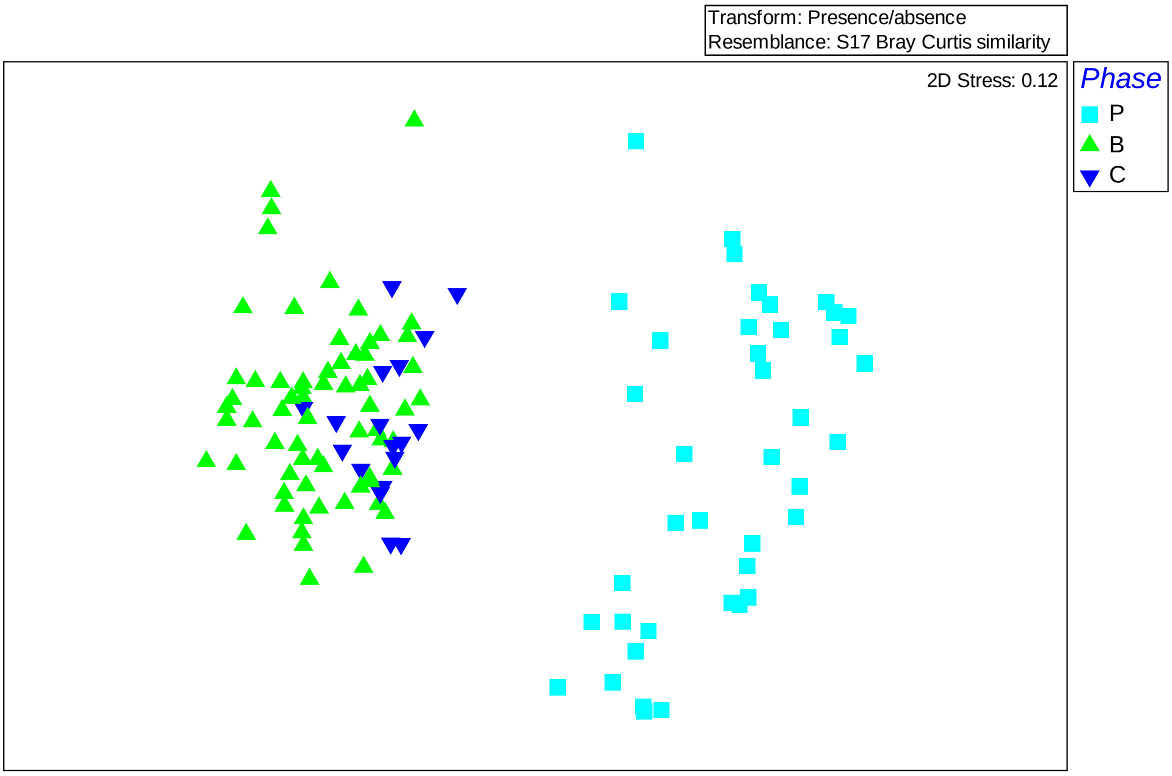


Figure 22 Microalgae community composition at sites from Lake Alexandrina and Lake Albert pre-drought (P), at the end of the drought in 2008-11 (B), and during the most recent sampling in 2012-13 (C), compared through nMDS.

3.2.6 COORONG MICROALGAE POST-DROUGHT

Data on the microalgae communities in the Coorong was available only from November 2010 until March 2013 with the first sampling period closely associated with the large increases in flow at the end of the drought (Figure 4). Only two sampling trips were carried out in 2010 (1st and 27th November) at 11 sites along the Coorong when barrage flows were at 26,000 ML/day having increased from very low values a month before (Figure 4). In 2011 samples were taken in January, February and April, while in 2012 samples were taken in February, March, May, June, September and December, followed by samplings in February and March 2013. This is an example of the complexity created by non-standard monitoring protocols where samples are collected at irregular intervals, with different numbers of samples in years capturing different seasons and different sites (Figure 2). As the Coorong data set is from a relatively short time period the microalgae identifications were considered reliable and no attempt was made to reduce to common genera. Analyses have been based on presence/absence data and also on actual counts because of the expected consistency of enumeration methods. Comparison of these two approaches gave consistent results (Figures 23 and 24) with both indicating that 2010 and 2011 were closely associated, while 2013 was substantially different and 2012 appeared to span between these two groupings. In future analyses some of these assumptions might need to be re-visited.

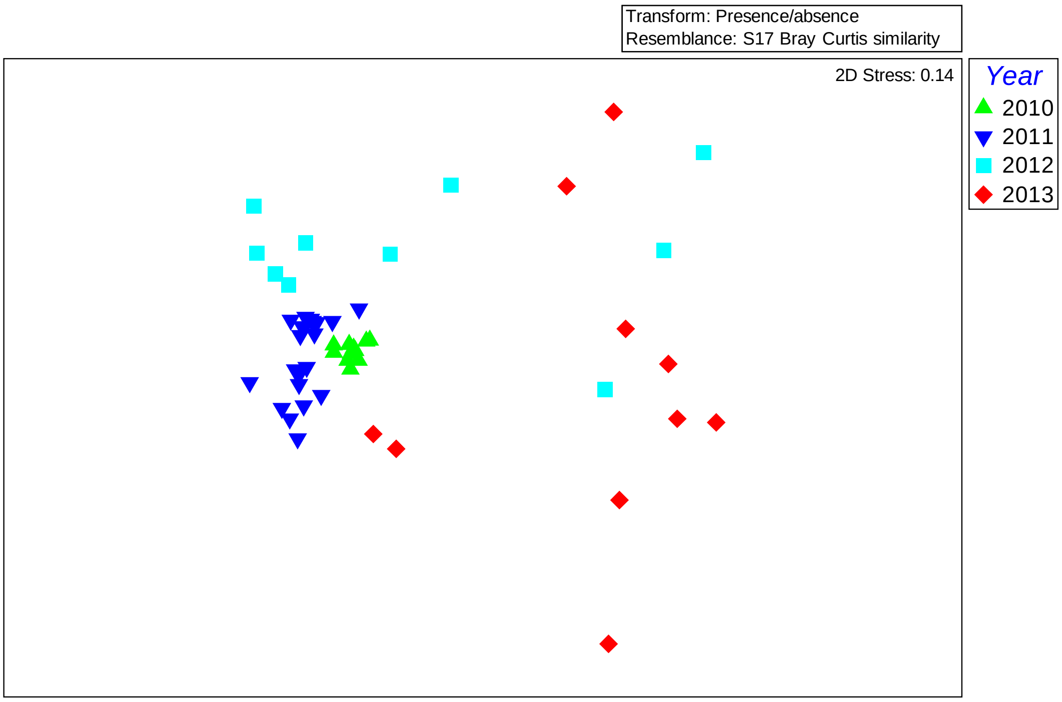


Figure 23 Coorong microalgae community composition post-drought across years compared through nMDS based on presence/absence data.

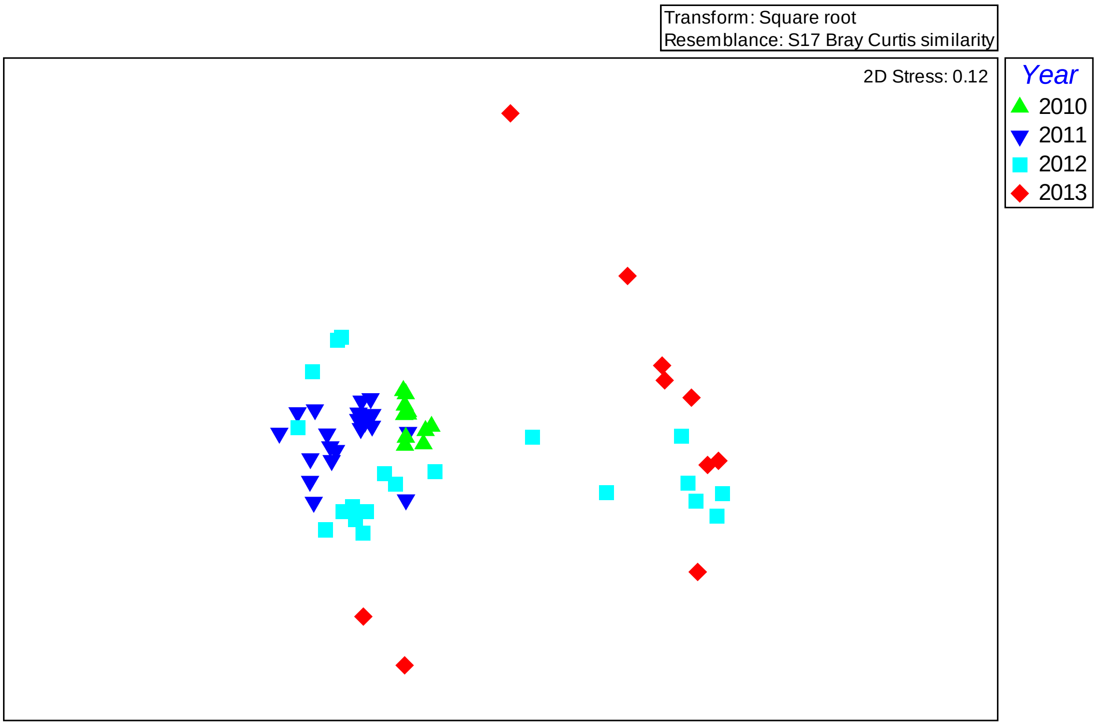


Figure 24 Coorong microalgae community composition post-drought across years compared through nMDS based on abundance data.

Pair wise comparison of the longitudinal series of Coorong sites that could be tested (Table 7, note cP-V could not be tested against cBck, cHlf, cHck, cMCh, cOcn, cSug or cTau because of lack of data) showed that most are similar to each other but with Ewe Island significantly different from Mark Point and Parnka-Villa, Mark Point significantly different from Monument Road and Parnka-Villa, and Murray Mouth significantly different from Parnka-Villa. These differences are in accord with the sequence of sites along the Coorong (Table 7) and suggest a longitudinal change in community composition. Based on presence/absence data PERMANOVA indicated that there were significant differences in microalgae community composition between sites and years (Table 8). Re-coding of the nMDS plotted data points to sampling sites does not give a strong sense of a longitudinal gradient when all sites for all seasons and years are included individually, although it is present (Figure 25). The data was re-analysed for sites across all years and seasons and an nMDS of the data overlain with a trajectory line showing the sequence of sites along the Coorong (Figure 26). It is evident that a longitudinal gradient exists in the microalgae community of the Coorong and that this is apparent even when the data is aggregated across seasons and years.

To identify major environmental influences on changes in microalgae community composition in the Coorong a data set was extracted where environmental variables that extended throughout the total monitoring period could be matched with the microalgae. This reduced the number of sites for analyses, but what remained still represented the spread of communities observed in the full microalgae data set (Figures 24 and 27). The environmental parameters included were conductivity, four forms of N (NO_X, NH_4, TKN and TN), two forms of P (TP and FRP), reactive silica, turbidity, chlorophyll-a and the five day integrated flow measures for the river and the barrages. Parameters with Pearson correlations >0.4 (Turbidity, Disch5, Barrage5, filterable reactive phosphorus and conductivity) are shown as vectors on Figure 27. These indicate that changes between 2010 and 2013 are largely due to reduced flows in 2013 resulting in increased conductivity and lower turbidity and filterable reactive phosphorus. More detailed analyses would further improve these interpretations.

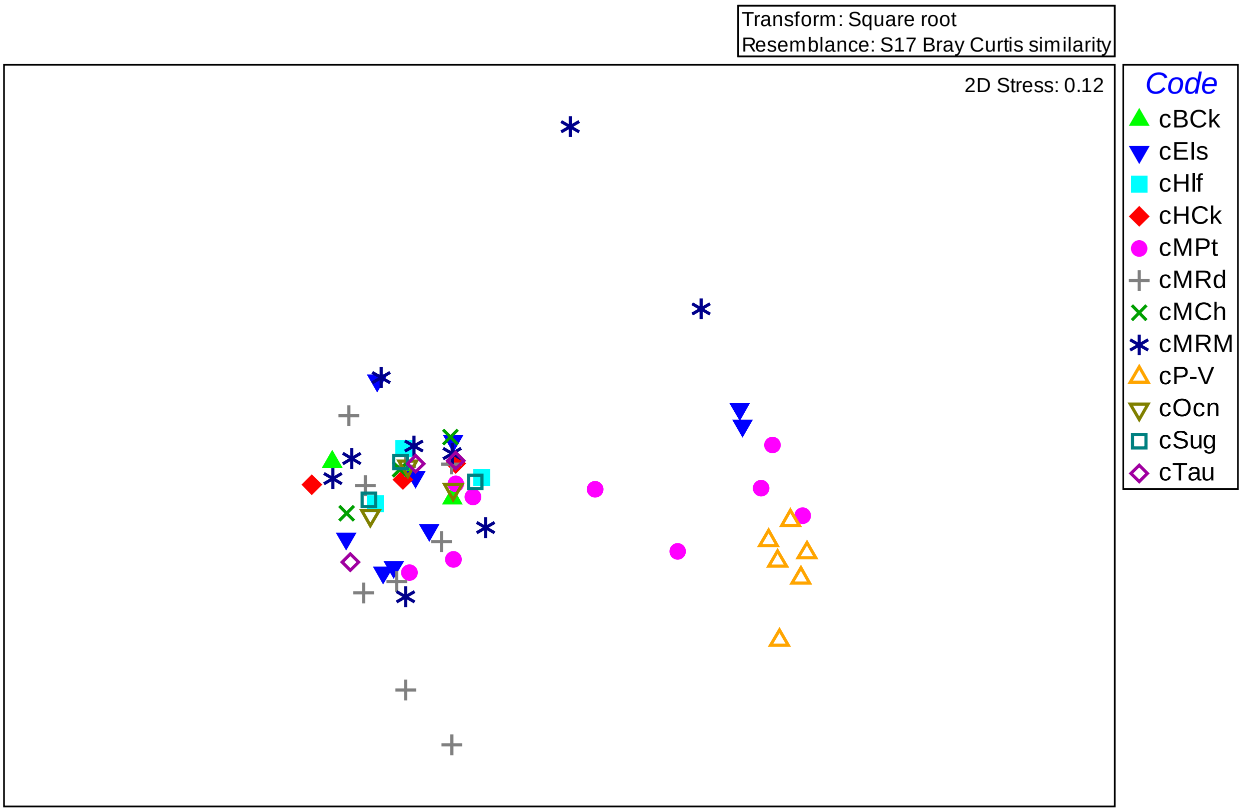


Figure 25 Coorong microalgae community composition post-drought across sites compared through nMDS based on abundance data. Codes are described in Table 7.

Site	Code	Sequence
Monument Road	cMRd	1
Hunter's Creek	cHck	2
Mundoo Channel	cMCh	3
Half Way	cHlf	4
Sugar's Beach	cSug	5
Boundary Creek	cBck	6
Murray Mouth	cMRM	7
Southern Ocean	cOcn	8
Ewe Island Barrage	cEIs	9
Tauwitchere	cTau	10
Mark Point	cMPt	11
Parnka-Villa	cP-V	17

Table 7 Selected sampling sites in the Coorong along with their sequence order from north to south and their site codes (compare with Table 2).

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	perms
Site	11	16067	1460.6	1.6558	0.003	996
Year	3	34367	11456	12.986	0.001	999
SitexYear	17	19439	1143.4	1.2962	0.049	998
Res	54	47637	882.16			
Total	85	1.3059E5				

Table 8 PERMANOVA of Coorong microalgae communities post-drought.

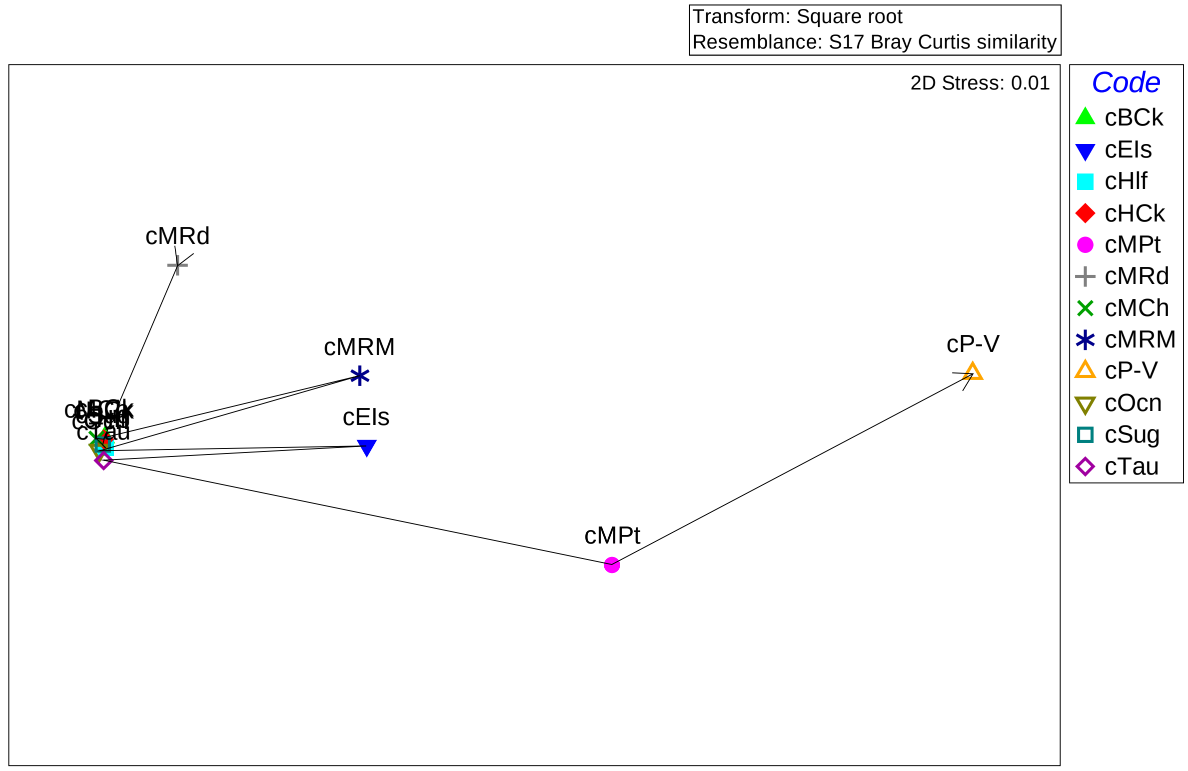


Figure 26 Coorong microalgae composition for sites aggregated across seasons and years compared through nMDS. Codes are described in Table 7.

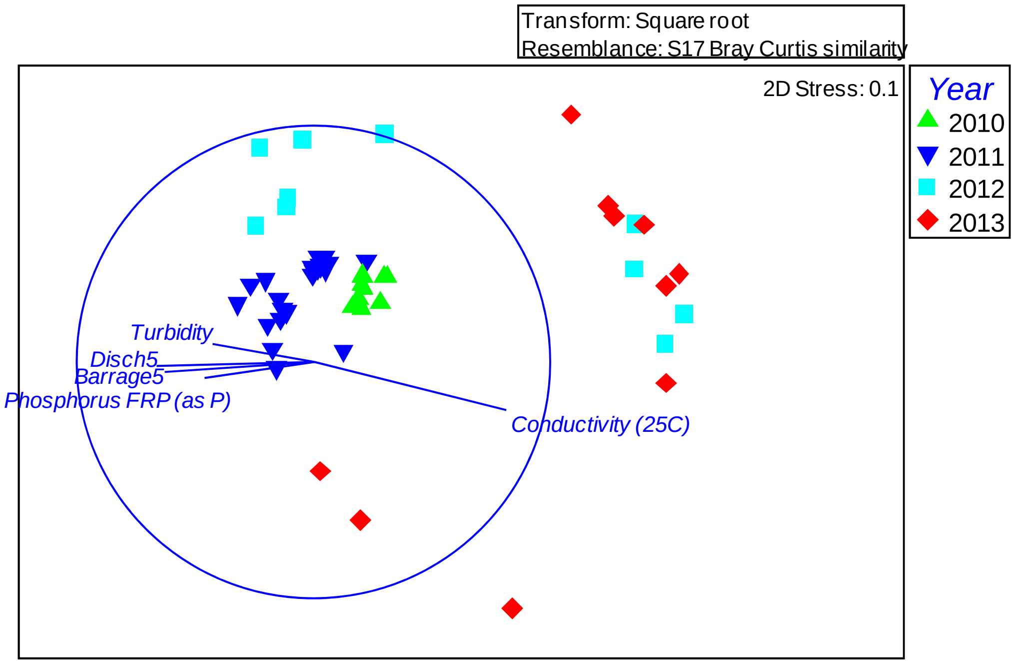


Figure 27 Coorong microalgae community composition for selected sites compared through nMDS and correlated with major water quality parameters influencing the distribution.

3.3 Zooplankton community composition patterns

Due to the time constraints of the project the full zooplankton data sets could not be incorporated into the analyses and only those zooplankton sampling sites which matched the Lake Alexandrina and Coorong water quality and microalgae sites were included. The zooplankton data consists of sets of seasonal measurements which were taken between November 2010 and March 2013. This provided 20 samples from Lake Alexandrina and 102 from the Coorong. This is not a large number of samplings, even for the Coorong where the number includes multiple sites measured on single sampling occasions. The number of samples within a season varied markedly from two to six, but for the purposes of the analyses all samples within a season at each site were treated as replicates for seasonal comparisons, and all samples within a year treated as replicates for yearly comparisons. Further testing of the validity of these approaches is required. The analyses were based on presence/absence of genera to provide a general overview, but the data is of high quality and could be analysed using species counts which would provide more detailed insight into community changes.

When the selected zooplankton data was analysed there was a substantial overlap of community composition between Lake Alexandrina and some of the Coorong sites (Figure 28). The influence of the five day integrated river flow (Disch5) and Barrage flow (Barrage5) was quite strongly correlated with the observed pattern (the x-axis has a -0.59 correlation with Disch5 and -0.57 with Barrage 5) suggesting that the spread of the zooplankton community composition was strongly influenced by flow. Genera having a >0.6 Pearson correlation with the composition pattern changes are shown in Figure 29 and increasing contributions of *Filinia*, *Keratella* and *Difflugia* aligned closely with increasing flows. Geographically, *Synchaeta* was more strongly associated with sites in Lake Alexandrina than the Coorong. More detailed analyses will be required to reliably describe these interactions.

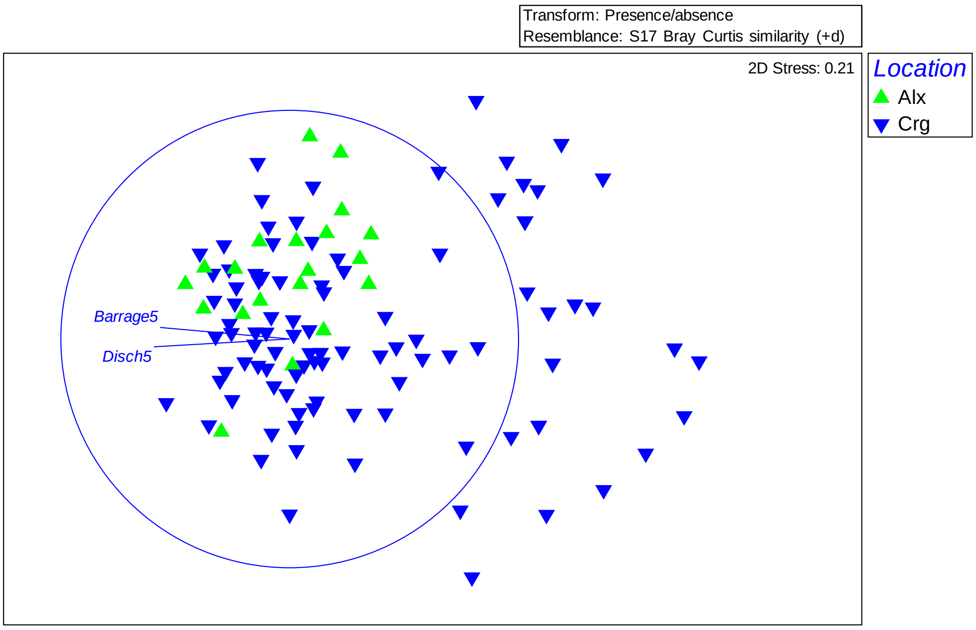


Figure 28 Lake Alexandrina and Coorong zooplankton community composition compared through an nMDS and correlated with major water quality parameters influencing the distribution.

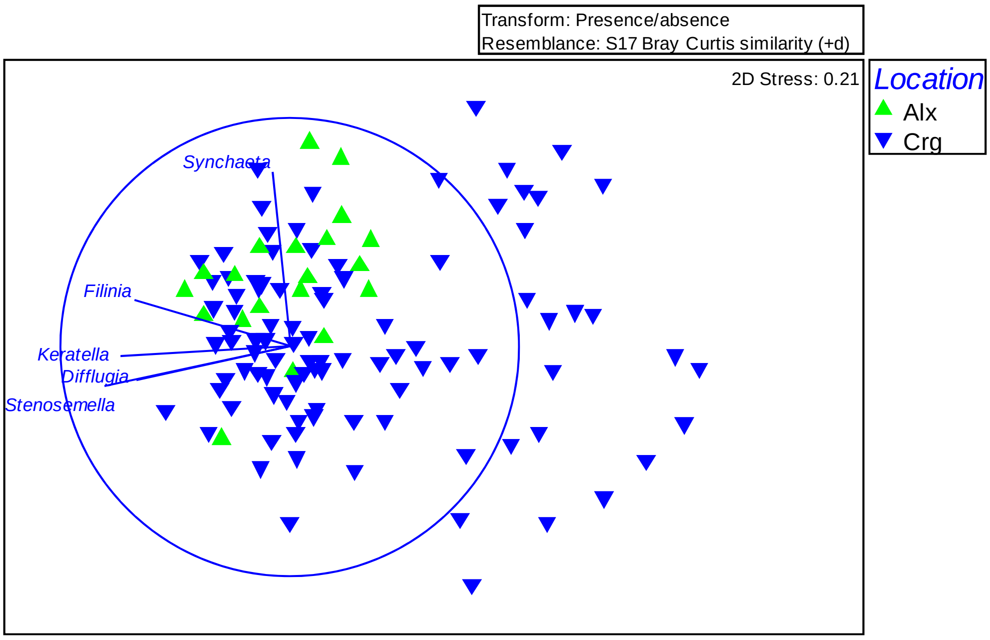


Figure 29 Lake Alexandrina and Coorong zooplankton community composition compared through an nMDS and correlated with major zooplankton genera influencing the distribution.

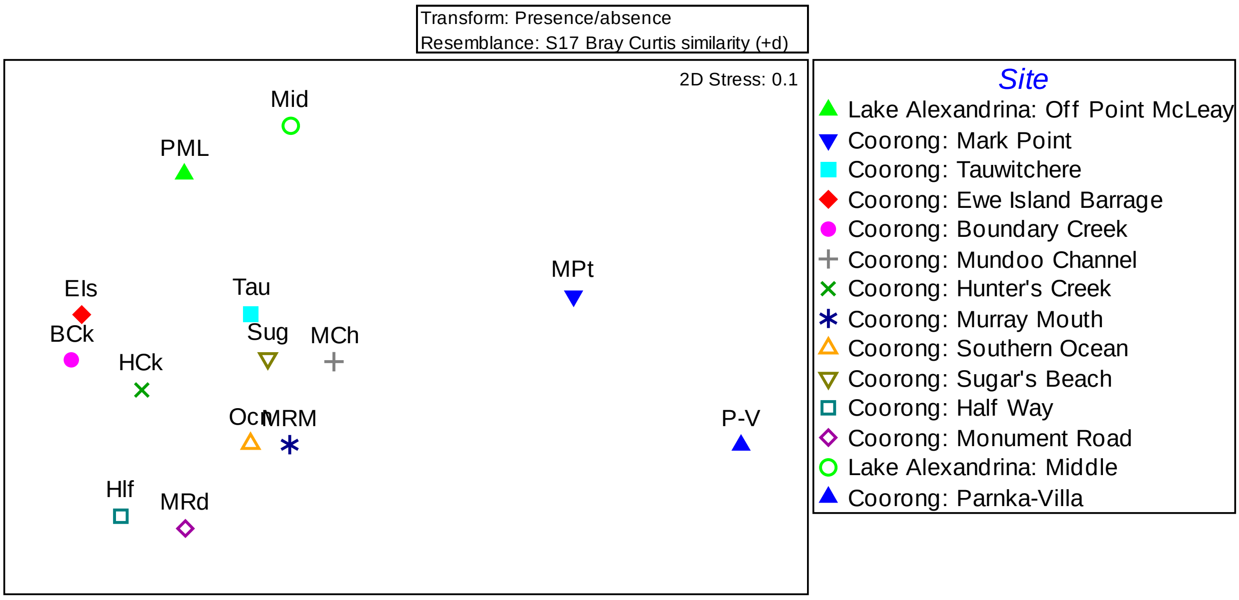


Figure 30 Lake Alexandrina and Coorong zooplankton community composition for sites compared through an nMDS.

The zooplankton community data was re-analysed after aggregating at individual sites for the whole monitoring period. The two sites in Lake Alexandrina separated away from those in the Coorong, while the sites along the Coorong formed a distinct pattern associated with their longitudinal position (Figure 30). The Coorong data was re-analysed and the sites connected in sequence according to their position along the length of the Coorong (Table 7). The trajectory follows the order of the longitudinal sequence of sites indicating gradients in zooplankton communities along the Coorong (Figure 31). The longitudinal pattern is similar to that observed for water quality attributes (Figure 14) and for microalgae communities (Figure 26). In future studies it would be valuable to analyse a single collated set of all data to investigate the direct interactions between zooplankton, water quality and microalgae.

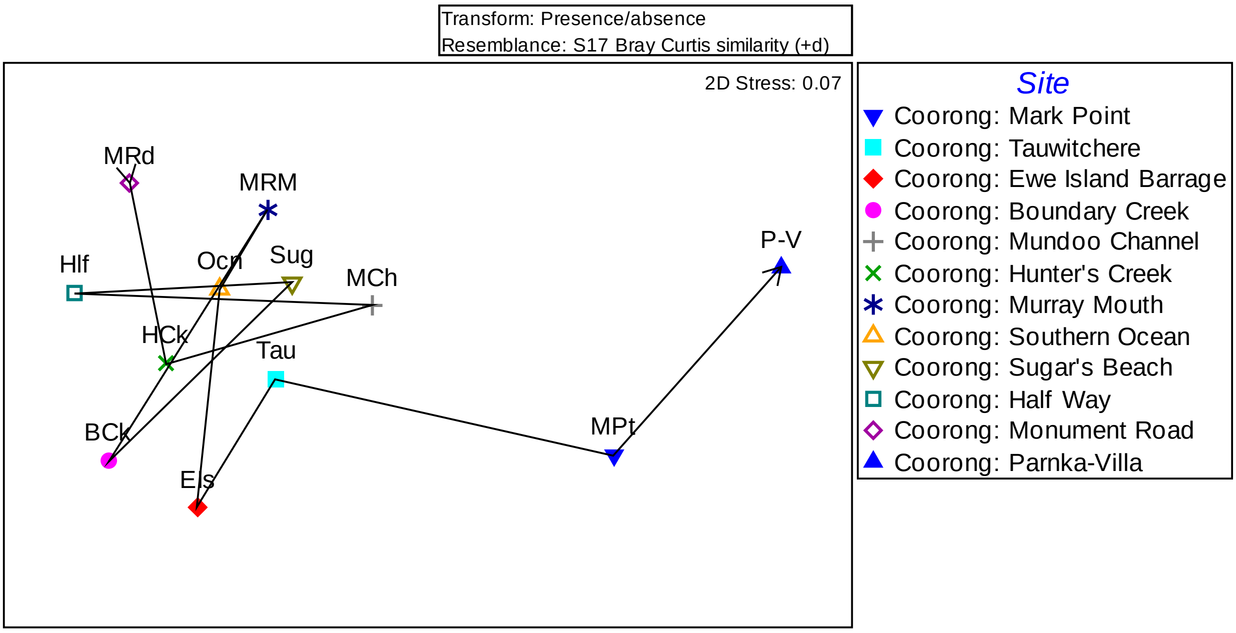


Figure 31 Longitudinal sequence of zooplankton community composition with sites in the Coorong compared through an nMDS.

4 Conclusions

The major purpose of this study was to undertake a preliminary multivariate analysis of the long term monitoring data on water quality, microalgae and zooplankton communities in the Coorong and Lakes Alexandrina and Albert. A particular focus was to report on the findings of the 2012-13 monitoring program, but to set this information within a broader context of system level characteristics derived from previous monitoring programs. The aim was to demonstrate that despite the intermittent and inconsistent nature of these monitoring programs they provide useful information describing the changing characteristics of these systems, enabling an assessment of their status for management purposes.

A significant amount of time was taken checking and organising the monitoring data that was provided for analyses. Typical of many large collections of long term monitoring data, it contained a significant number of inconsistencies, mainly due to changes in terminology and site depictions over the period of data collection. The approaches used to correct or minimise these problems are outlined in the text, although not all potential problems were addressed. One that was not directly dealt with was changes in sampling protocols, especially where samples were sometimes taken from the shoreline and at other times off-shore. It would be possible to test the influence of these different sampling techniques provided information was available on how each sample was collected. There may well be other problems in the data set that were not identified during the course of this project.

Water quality time series for the Coorong, Lake Alexandrina and Lake Albert showed that conditions changed significantly as a result of the drought and also in response to the period of high flows that followed the drought in 2010-12 (Appendix B). In general, these increased flows reduced conductivity and the concentrations of nutrients from the higher levels associated with the drought, although in the Coorong concentrations started increasing again as a result of the reduced flows in 2013. The difficulty with these individual parameter descriptions is trying to assess whether on aggregate the water quality conditions, and the microalgae and zooplankton communities, are recovering in response to the improved flow conditions following the drought. To make such an assessment requires identification of a target condition that can be used to determine when recovery has occurred.

Setting such targets is difficult, especially when many variables are changing simultaneously. These difficulties are compounded by the significant variability found in microbial communities even when growing under apparently stable conditions. Consequently there is not a single target condition, but rather a range of conditions that are sufficiently similar, or occur sufficiently often, to create a multivariate operating space that sustains the characteristics of an ecosystem. With adequate data it is possible to use multivariate analyses to define such operating spaces and then over time to develop an understanding of how the system responds to perturbations. However, this analysis assumes periods of environmental stationarity and these can be difficult to find in regions like the CLLMM where for many years there has been a continual change in environmental conditions. Nevertheless, this concept was applied to the CLLMM data with analyses undertaken to determine whether pre-drought data defined a multivariate operating space. The long-term monitoring data from Milang on Lake Alexandrina was particularly important for this analysis as it was collected during a period in which annual hydrological cycles were relatively typical of managed, pre-drought river flows. However, in such large and complex systems it is preferable to have patterns from a broad range of sites to define a multivariate operating space that management strategies might target. Trying to achieve this required a difficult collating of data across sites and times to provide improved representation of the regions.

Using general water quality parameters (conductivity, the nutrients N and P, reactive silica, turbidity, flow and chlorophyll a) multivariate analyses of water quality in the Lakes (Figure 8) showed that there were major shifts between the pre-drought period of 1997-98 and the final drought affected years of 2008-09. With the return of flows in 2010 the system changed again and during 2011-12 water quality conditions were different from those observed either prior to or during the drought. However, with the reduction of flows in 2013 there was an increased similarity in water quality to conditions that were present prior to the drought (Figure 8). This might be interpreted as a move towards recovery, or at least to conditions present before the drought, but further monitoring will be required to assess if this shift continues. Analysis of environmental influences indicated that the within-year shifts in water quality were largely associated with changes in nutrient concentrations and conductivity, while the between-year shifts following the drought were associated with the increased flows and increases in reactive silica concentrations (Figure 7).

A comparable analysis of system wide annual water quality changes in the Coorong showed a similar pattern of responses (Figure 11). During the drought there was a continual shift in water quality away from the pre-drought conditions. On the return of flows in late 2010-11 the water quality conditions were different from those observed prior to or during the drought, but in 2012 and 2013 they changed to become more similar to pre-drought conditions. As with the Lakes, the within-year shifts in water quality of the Coorong were largely associated with changing nutrient concentrations and conductivity, while between-year shifts during and following the increase in flows were associated with flows and increases in turbidity (Figure 12).

Characterisation of water quality conditions within the Coorong is complicated by the longitudinal changes that occur due to its geomorphology and the supply of freshwater and sea water at one end. Most of the measurements in the Coorong were taken during the drought period when there was reduced longitudinal mixing. Perhaps that is why the water quality attributes of each station along the Coorong, when aggregated over the 10 or more years of sampling, still demonstrated sequential, longitudinal changes in water quality characteristics (Figure 14).

The microalgae were analysed across different sets of data depending on their relevance to different locations and time periods. This provided contrasting views of the CLLMM system and improved the usefulness of the intermittent sampling regimes (Figure2 and Figure 3). A nMDS analysis encompassing all sites and all microalgae genera based on presence and absence data demonstrated three broad groups of communities across the system (Figure 15). The microalgae communities of Lakes Alexandrina and Albert prior to the drought were substantially different from those following the drought and formed two distinct sets. The communities in the Coorong were either separate from those of the lakes, or on occasions overlapped with the post-drought communities from the Lakes. This might be expected if flow from the Lakes carried microalgae communities into areas of the Coorong. The distinct differences between microalgae communities in the Lakes pre- and post-drought suggested that recovery had not occurred with return of flows in late 2010. However, the reliability of the microalgae data sets was uncertain as methods could have changed over the extended period of monitoring. Consequently more detailed analyses were performed to try and improve the reliability of comparisons between data sets from different sites.

The monitoring at Milang from 1983-1997 provided a historical perspective on microalgae community composition at this site. The analyses indicated that communities were significantly different between years and showed no directional change but rather a random pattern of occurrences (Figure 17). Over this period flows were typical of the pre-drought managed river system, and the results were interpreted to show a multivariate operating space that characterised these communities during a period of typical, pre-drought flow conditions. The Milang sampling did not continue through the drought and so pre-drought data from other sites across the lakes were compared with the Milang data to determine how representative it was of the lakes. Because of concerns about whether microalgae analyses were consistent across sites over extended periods of time a group of 51 common genera that had occurred intermittently at all lake sites was used in the analyses to reduce problems associated with the identification of uncommon genera. Based on this constrained community set, the analyses showed that the pre-drought microalgae communities from Milang and from the dispersed lake sites often differed widely in composition, throwing some doubt on whether the Milang data depicted a representative multivariate operating space for the lake. Despite the larger variation introduced by combining the Milang data with other lakes sites, the pre-drought microalgae communities were subsequently found to be substantially different from the post-drought communities (Figure 18). Perhaps the combined site data provided a better representation of a multivariate operating space containing the pre-drought lake communities.

The Milang microalgae communities were at times similar to those in the dispersed lake sites, but often they were substantially different (Figures 18 and 19). An analysis of the environmental factors influencing these differences gave a correlation with flow, and indeed many of the Milang sampling periods aligned with periods of higher flow in comparison with the lake sites which were sampled when flow was generally lower. The genera of microalgae associated with the differences in community composition were identified and three groups were recognised which were likely to be strongly influenced by flow. The green algae genera *Oocystis*, *Dictyosphaerium* and *Scendesmus* along with the diatom *Cyclotella*, were more associated with the Milang site under conditions of higher flows. The cyanobacteria *Anabaena*, *Nodularia* and *Anabaenopsis* were also associated with the Milang site but under conditions of reduced flow. The smaller cyanobacteria *Aphanizomenon*, *Cylindrospermopsis* and *Planktolyngbya* were more strongly associated with the lake sites which were sampled under conditions of low flows. This indicates that more detailed analyses of the occurrence of specific microalgae genera are warranted as these may help identify an advantageous multivariate operating space for management to target. For example, the community associated with green algae and diatoms is considered more palatable to grazers and so a more important food resource for planktonic foodwebs than the communities associated with cyanobacteria.

A further analysis of the lake microalgae discarded the Milang data and used only the data from the dispersed lake sites so that similar types of sites providing more detailed information either side of the drought were used for comparison. This data was separated into three time periods, pre-drought, end of drought (2008-11) and the recent 2012-13 sampling. The results suggest that the recent microalgae communities are similar to those occurring at the end of the drought but may be changing their composition slightly towards communities that occurred before the drought (Figure 22). Continued monitoring will be required to determine if this reflects a recovery of the community structure.

Microalgae community composition in the Coorong was only measured from 2010 onwards but the annual patterns of change reflected those observed in the lakes. In 2010 and 2011 the Coorong microalgae communities were similar to each other. The communities changed during 2012 and by 2013 were largely different from those during the previous high flow years. Unfortunately there is no pre-drought data to provide any idea of the typical multivariate operating space of these communities prior to the drought and so there is no indication of the direction that community composition is moving. Environmental parameters that correlated with the community shifts indicated that the 2013 change was associated with reduced turbidity and phosphorus concentrations and increased conductivities and these related to the reduced flows (Figure 27). As found in the water quality analyses, generalisation of the microalgae community across the entire Coorong is complicated by the presence of a gradient in composition along its length, which is sustained even when data for sites is aggregated over the measurement period (Figure 26). More detailed analyses of the water quality gradients and the microalgae gradients are warranted.

The analysis of the zooplankton data demonstrated that even with a short-term data set major changes in community composition could be recognised and associated with environmental conditions. Zooplankton communities in Lake Alexandrina were similar to some of the communities in the Coorong, while many of the Coorong samples were quite dissimilar to those in the lake (Figure 28). Time did not allow for analyses of particular sites or particular periods in order to focus on these differences and assess their causes. This would be interesting to investigate as it is presumably linked to the transport of communities from the lake to the Coorong. A similar connection was observed with the microalgae and it would improve understanding of the system to see if these links occurred at the same times and across the same sites, and if they are associated with flow conditions. Flow was found to play a role in the distribution of the zooplankton communities but the relationship was quite weak (Figure 28). This might be because the analysis includes a mixture of sites that are differently influenced by flow. Clustering and focusing on particular data sets should improve the interpretation.

Differences in community composition between sites in the Coorong were strongly associated with four zooplankton genera (Figure 29) and further exploration of the significance of these interactions is warranted. The zooplankton data was also analysed with a view to determining whether longitudinal gradients were evident in the zooplankton communities as had been observed in the water quality parameters and microalgae communities. When the zooplankton communities were compared between sites with data aggregated over the total sampling period a longitudinal gradient was evident. The data on gradients of water quality, microalgae and zooplankton provide an opportunity for further exploration of these interactions. Zooplankton analyses were restricted to presence and absence data because of time limitations but the zooplankton abundance data is of high quality and its analysis should provide greater insight into the changes in community composition.

The findings of this report highlight the benefits of using multivariate techniques to explore long term trends in community patterns in relation to environmental variables. The multivariate approach describes the time series of changes but also provide managers with an assessment of the overall system condition. As predicted the data demonstrated differences in community patterns between drought and non drought periods. While communities were different between the drought and non drought periods, the analysis indicated that post drought communities were beginning to become more similar to those in the pre drought periods. Interestingly the water quality in 2013 appeared to be more similar to pre-drought conditions while the microalgae still appeared more similar to the drought conditions in the lakes and Coorong. This might indicate that water quality recovery is required to support the recovery of microalgae communities.

The analyses also demonstrated the longitudinal trends in changing microalgae and zooplankton communities along the Coorong. The results suggest that these trends may be predictable and further analyses should provide valuable information for managing the system. There is an opportunity to link these statistical analyses with the hydrological process model developed by DEWNR in conjunction with CSIRO which describes salinity changes along the Coorong in response to changing flows. This provides an exciting opportunity to explore the benefits of combining statistical and process models to improve the conceptual understanding required for management of this complex system.

The results provided in this project are necessarily preliminary in nature. There was not time to delve into the detail of many of the patterns and interactions that were exposed by these first analyses. Environmental parameters likely to be important in explaining patterns including hydrological conditions such as lake depth and meteorological conditions such as wind characteristics, have not been included. In many of the analyses presence and absence data were used although abundance data was available. Analyses of abundance data could provide more detail of changes in community components and link organisms more closely with environmental conditions. It is hoped that the fascinating and insightful results that have come from this project will encourage further analyses of the CLLMM monitoring data. It is a valuable resource providing our only overview of the biogeochemical characteristics of the CLLMM region and as such should be more extensively used to advise on management strategies.

5 Recommendations

1. Large monitoring databases invariably develop inconsistencies over time as different agencies, different teams, and different individuals upload data in a manner suitable for their individual project needs. These inconsistencies reduce the functionality of the database and make data collation difficult. In this project a significant amount of time was spent extracting, re-organising and validating data sets and apparently this has occurred before (Hipsey and Busch 2012). It is recommended that an effort be made to extract a consistent, functional CLLMM monitoring data set from the main data store for use in future projects. This would make the data more accessible to researchers and managers and avoid the need for repeatedly compiling a set from the central database. Projects such as this one can help achieve the objective.
2. Analyses and interpretations were made difficult by the intermittent and inconsistent nature of the monitoring programs. More reliable and useful information would be provided if the event response monitoring, which is necessary, was underpinned by a stable, long term monitoring program. For long term monitoring programs to be valuable they need to have consistency in collection times and collection methods, continuity in identification of community components, and careful documentation of changes in monitoring activities. They require a core set of parameters that are consistently collected because they are considered to be major drivers of system condition. There should be regular statistical analysis of the monitoring data and the results should be incorporated into developing conceptual models and process based models to provide better mechanistic descriptions of key relationships necessary for improved management. This fusion of statistical, conceptual and process modelling is one of the most powerful ways to understand the complexities of natural systems and provide guidance for their management.
3. Analyses of the microalgae communities were focused on describing large scale changes in community composition across the CLLMM region. Consequently, seasonal and yearly measurements were collated to compare inter-annual changes rather than investigate smaller scale changes such as seasonal differences. Detailed analyses would provide finer scale measures of community responses to environmental conditions and identify important influences on microalgae composition. These smaller scale changes were lost in the noise of the large scale changes being investigated here. Conversely, the annual microalgae compositions were sometimes more similar than at other times and careful clustering of such periods could enable more specific drivers of community change to be identified. In addition, selecting different sets of algae and making more use of abundance rather than presence/absence data would enable more specific questions of community change to be addressed. It is recommended that more detailed analyses be undertaken to assist in better identifying the characteristics of the CLLMM region that could be useful for short-term management interventions.
4. Water quality parameters used in the analyses were limited to those considered most likely to be relevant to the microalgae but not all of these parameters were used on all occasions as different sets of parameters were chosen for different analyses. Quite a number of parameters were not included in the analyses at all. As noted in the previous point in relation to the microalgae, finer scale analyses of the water quality data would provide information on more subtle variations in conditions so that seasonal variations could be investigated along with year to year shifts. Clustering of similar periods would also provide more reliable insight to multi-year changes. As with the algae, there would be value in further analyses of water quality across a range of time scales to improve understanding of the shifts that are occurring.
5. Combined microalgae and water quality data sets were extracted for the different regions and different sampling sites by using the presence of microalgae counts as a template and extracting water quality parameters that matched the microalgae sampling dates. However there are many

within and between group combinations of microalgae and water quality parameters possible with selection dependent on the questions to be answered. Comparisons of microalgae and water quality across smaller scales than the decadal influences focused on in this study will provide greater understanding of the ecology of the CLLMM region. It is recommended that these analyses be undertaken.

6. On occasions the microalgae and zooplankton communities at sites in the Coorong were similar to those at sites in the lakes. This might be expected if flow from the lakes carries these communities into the Coorong. Further analysis of the data to address this suggestion would be insightful and important to its management.
7. The zooplankton data was not fully incorporated into the analyses of the microalgae and the water quality and consequently zooplankton fluctuations could not be closely matched with the microalgae or with water quality. The data is now in a suitable format for a complete analysis to be undertaken in 2013-14.
8. Similar longitudinal gradients in water quality attributes, microalgae, and zooplankton were observed along the length of the Coorong providing the opportunity to investigate interactions between them. There is also the opportunity to assess these interactions in context of the hydrological model developed for the Coorong by DEWNR and CSIRO. It is recommended that these analyses be further advanced in order to explore the benefits of combining statistical and process models to improve conceptual understanding required for system management.

Appendix A

A.1 Sampling site names consolidated and standardised for this report and matching sampling site names in the SA EPA database exactly as recorded

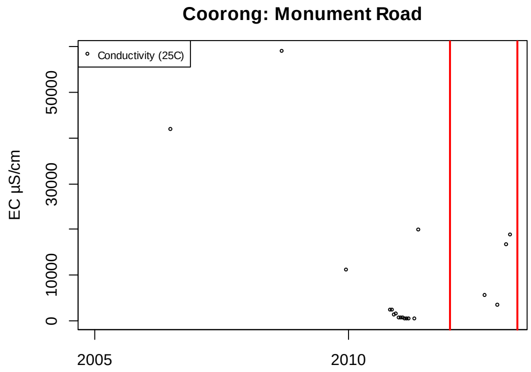
Standardised Name	Database Name
Lake Alexandrina: Opening	Lake Alexandrina: Opening
Lake Alexandrina: Opening	EPA - Lake Alexandrina Opening
Lake Alexandrina: Top	Lake Alexandrina: Top
Lake Alexandrina: Top	EPA - Lake Alexandrina Top
Lake Alexandrina: Middle	Lake Alexandrina: Middle
Lake Alexandrina: Middle	EPA - Lake Alexandrina Middle
Lake Alexandrina: Milang	Lake Alexandrina: Milang
Lake Alexandrina: Milang	Lake Alexandrina Milang
Lake Alexandrina: Milang	EPA - Lake Alexandrina Milang
Lake Alexandrina: Milang	milang
Lake Alexandrina: Milang	L Alex/Milang
Lake Alexandrina: Poltalloch	poltalloch
Lake Alexandrina: Poltalloch	Lake Alexandrina: Poltalloch plains
Lake Alexandrina: Poltalloch	EPA - Lake Alexandrina Poltalloch
Lake Alexandrina: Poltalloch	Lake Alexandrina: Poltalloch
Lake Alexandrina: Narrung	Lake Alexandrina: Narrung
Lake Alexandrina: Narrung	Lake Albert - Narrung
Lake Alexandrina: Beacon 90=97	Lake Alexandrina: Beacon 97
Lake Alexandrina: Beacon 90=97	Lake Alexandrina at Beacon 90
Lake Alexandrina: Off Point McLeay	Lake Alexandrina: Off Point McLeay
Lake Alexandrina: Off Point McLeay	EPA - Lake Alexandrina: Off Point McLeay
Lake Alexandrina: Off Point McLeay	EPA - Lake Alexandrina Point
Lake Alexandrina: Islands	Lake Alexandrina: Islands
Lake Alexandrina: Islands	EPA - Lake Alexandrina Islands
Lake Albert: Opening	Lake Albert - Opening
Lake Albert: Water Level Recorder	Lake Albert - Middle
Lake Albert: Water Level Recorder	Lake Albert: Water Level Recorder
Lake Albert: Water Level Recorder	Lake Albert - Water Level Recorder
Lake Albert: Meningie	albert
Lake Albert: Meningie	Lake Albert: Meningie
Lake Albert: Meningie	Lake Albert - Meningie
Lake Albert: South West	Lake Albert: South West
Lake Albert: South West	Lake Albert - South West
Coorong: Monument Road	EPA - Coorong Monument Road
Coorong: Monument Road	Goolwa Barrage Downstream
Coorong: Monument Road	Lake Alexandrina: Goolwa Barrage (Downstream)
Coorong: Half Way	Half Way
Coorong: Sugar's Beach	Sugar's Beach
Coorong: Murray Mouth	EPA - Murray Mouth

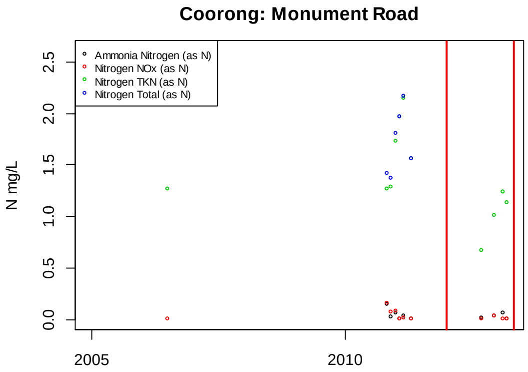
Coorong: Murray Mouth	Murray Mouth
Coorong: Southern Ocean	Southern Ocean
Coorong: Mundoo Channel	Mundoo Channel
Coorong: Hunter's Creek	Hunter's Creek
Coorong: Boundary Creek	Boundary Creek
Coorong: Ewe Island Barrage	EPA - Ewe Island Barrage
Coorong: Ewe Island Barrage	Ewe Island
Coorong: Tauwitchere	EPA - Tauwitcherie
Coorong: Tauwitchere	Tauwitchere
Coorong: Tauwitchere	Coorong sub-lagoon 1(Tauwitchere)
Coorong: Mark Point	Coorong sub-lagoon 2 (Mark Point)
Coorong: Mark Point	EPA - Mark Point
Coorong: Mark Point	Mark Point
Coorong: Long Point	Coorong sub-lagoon 3 (Long Point)
Coorong: Long Point	EPA - Long Point
Coorong: Noonameena	Coorong sub-lagoon 4 (Noonameena)
Coorong: Bonneys	Coorong sub-lagoon 5 (Bonney's)
Coorong: Bonneys	EPA - Bonneys
Coorong: McGrath Flat North	Coorong sub-lagoon 6 (McGrath Flat North)
Coorong: Parnka-Villa	Coorong sub-lagoon 7 (Parnka Point)
Coorong: Parnka-Villa	Parnka Point
Coorong: Parnka-Villa	EPA - Villa de Yumpa
Coorong: Hamilla Downs	Coorong sub-lagoon 8 (Hamilla Downs)
Coorong: Stony Well	Coorong sub-lagoon 9 (Stony Well)
Coorong: North Jack Point	Coorong sub-lagoon 10 (Jack Point)
Coorong: North Jack Point	EPA - Nth Jack Point
Coorong: Sth of Policeman Point	Coorong sub-lagoon 11 (South of Policeman Point)
Coorong: South Salt Creek	Coorong sub-lagoon 12 (Sth of Salt Creek)
Coorong: South Salt Creek	EPA - Sth Salt Creek

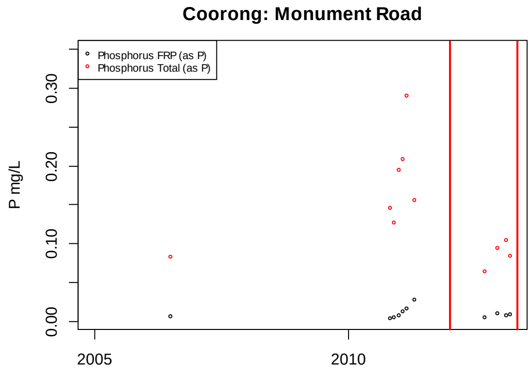
Sampling site names consolidated and standardised for this report and matching sampling site names in the SA EPA database.

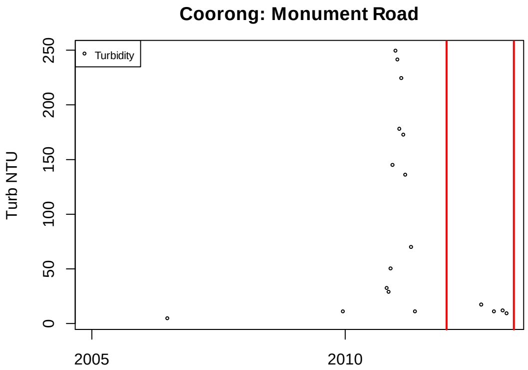
Appendix B

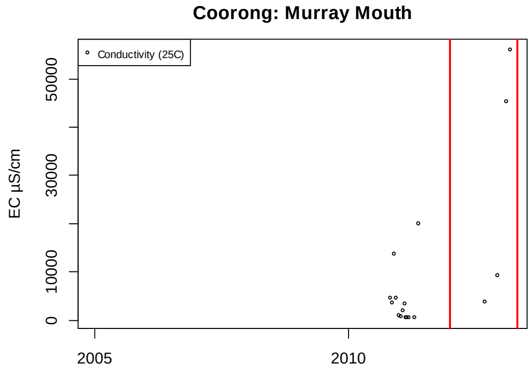
B.1 Time series of selected water quality data at sites in the Coorong

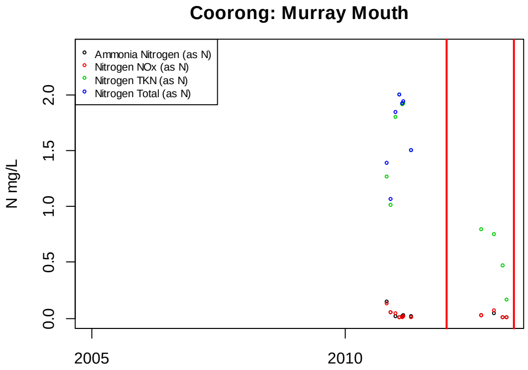


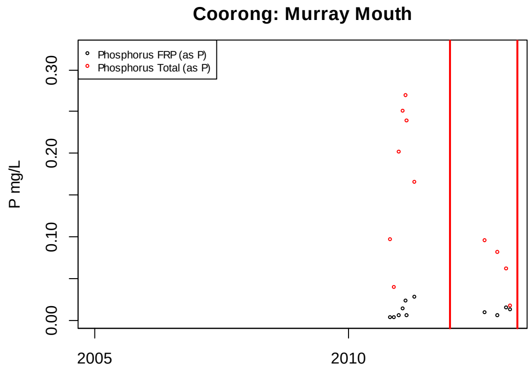


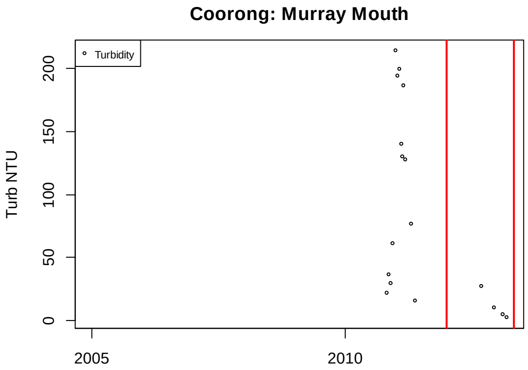


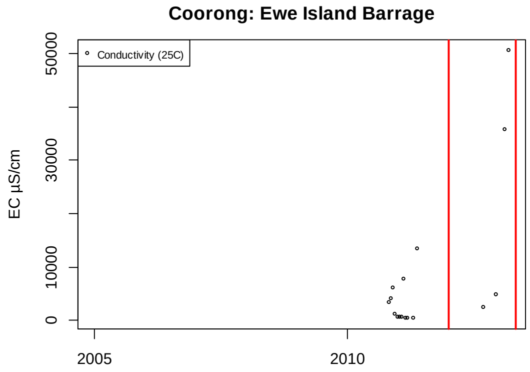


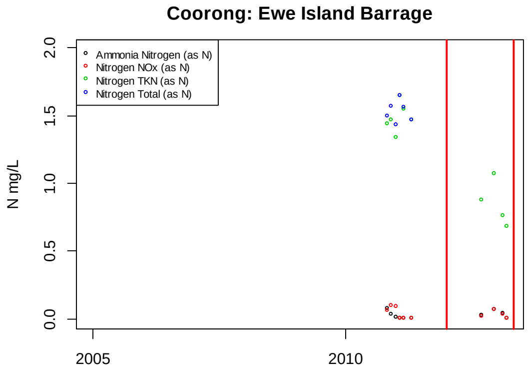


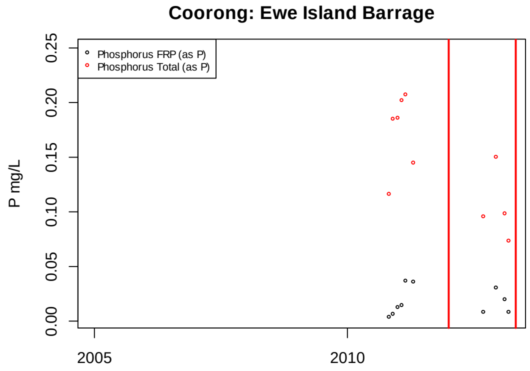







Coorong: Ewe Island Barrage


Coorong: Ewe Island Barrage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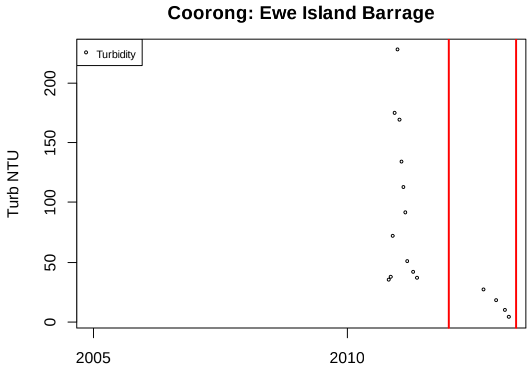
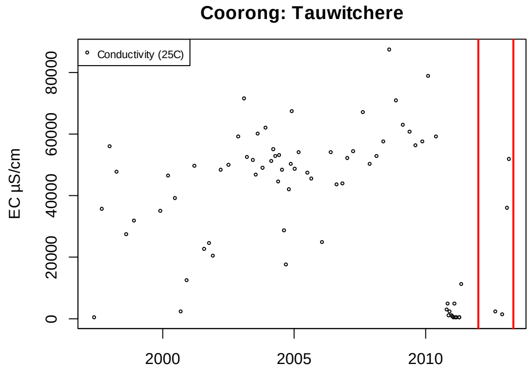
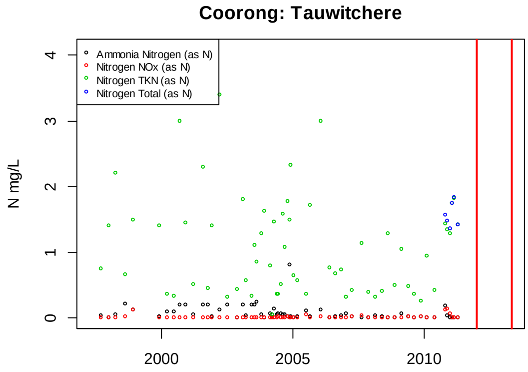

Coorong: Ewe Island Barrage


Coorong: Tauwitchere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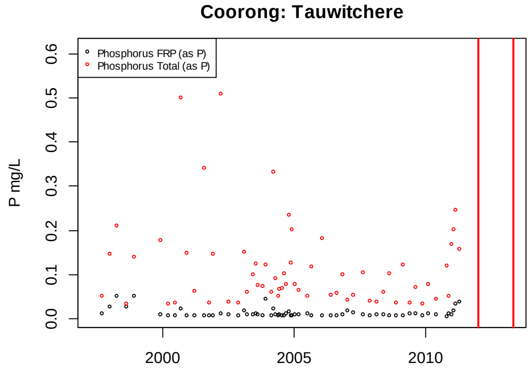
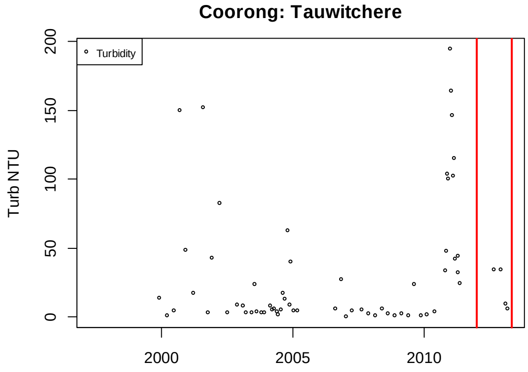
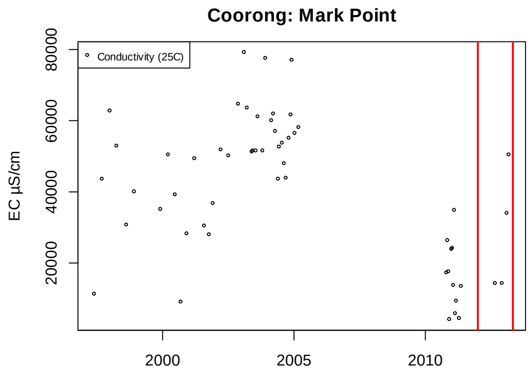
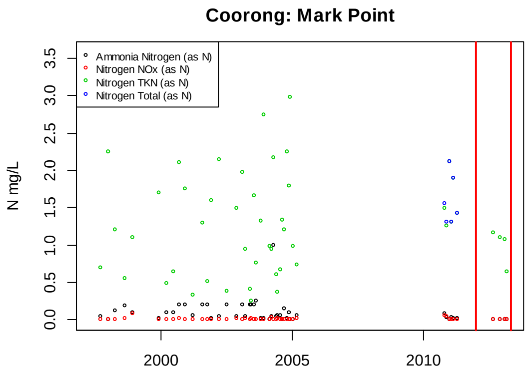
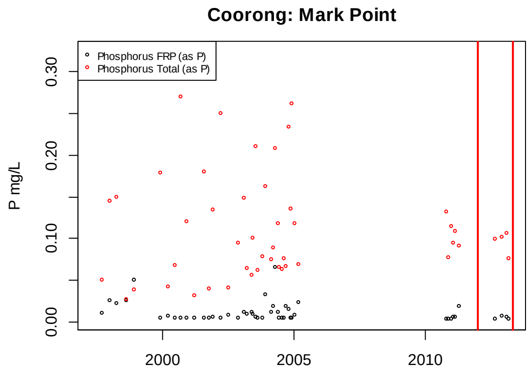
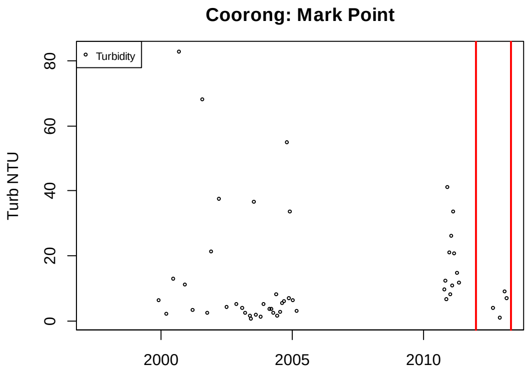

Coorong: Tauwitchere

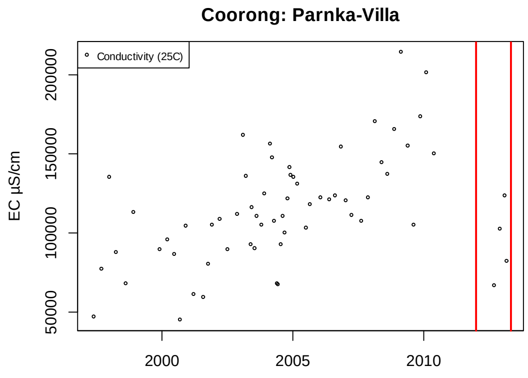

Coorong: Tauwitchere

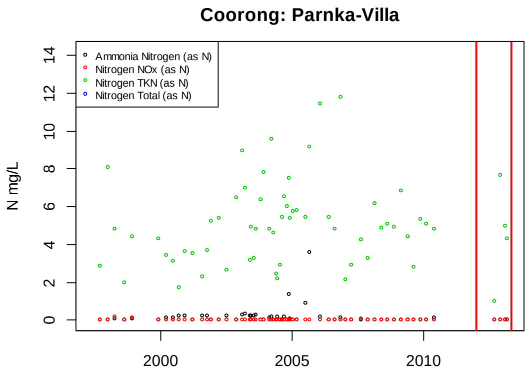

Coorong: Mark Point
EC µS/cm
20000
40000
60000
80000
Conductivity (25C)
2000
2005
2010

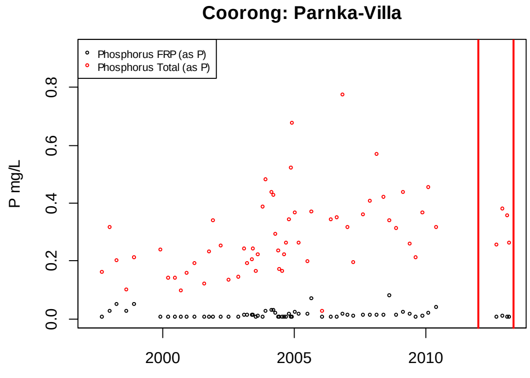

Coorong: Mark Point
N mg/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Ammonia Nitrogen (as N)
Nitrogen NOx (as N)
Nitrogen TKN (as N)
Nitrogen Total (as N)
2000
2005
2010

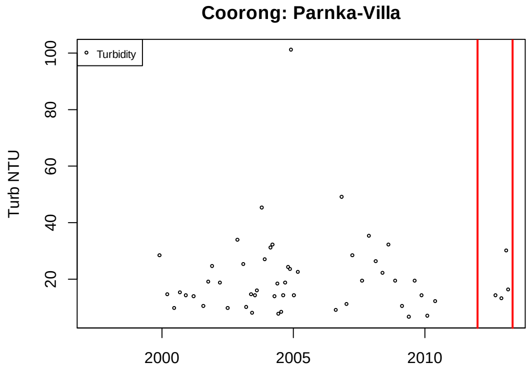

Coorong: Mark Point
P mg/L
0.00
0.10
0.20
0.30
Phosphorus FRP (as P)
Phosphorus Total (as P)
2000
2005
2010

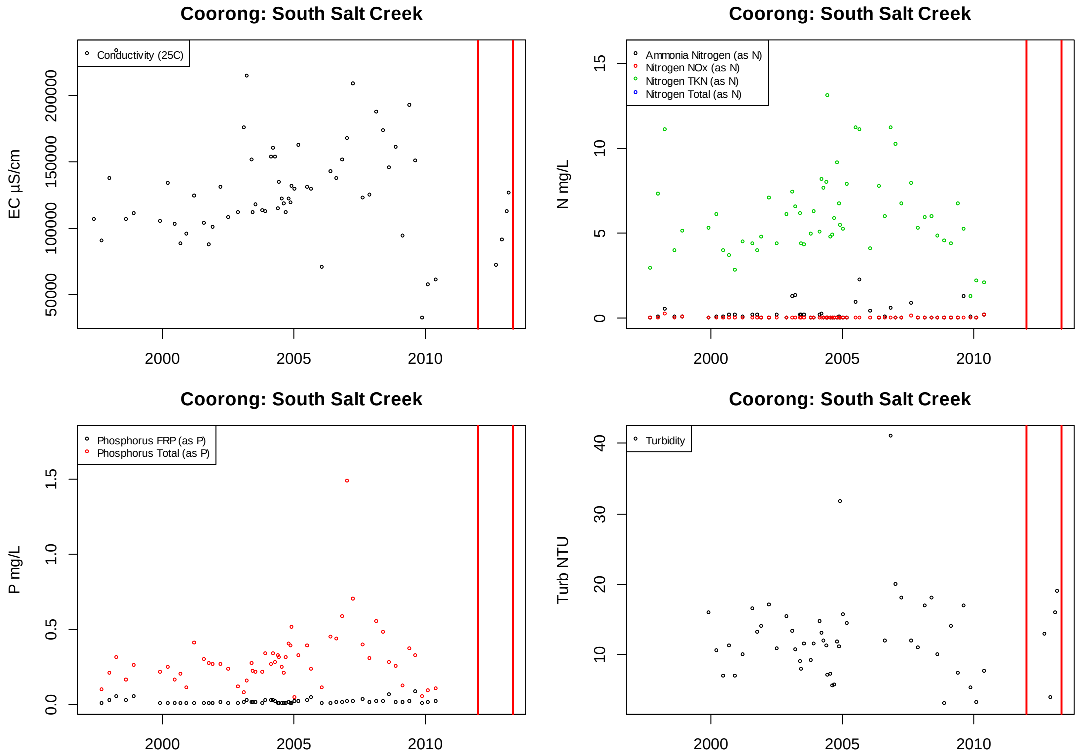

Coorong: Mark Point
Turb NTU
0
20
40
60
80
Turbidity
2000
2005
2010


Coorong: Parnka-Villa
EC µS/cm
50000
100000
150000
200000
Conductivity (25C)
2000
2005
2010


Coorong: Parnka-Villa
N mg/L
0
2
4
6
8
10
12
14
Ammonia Nitrogen (as N)
Nitrogen NOx (as N)
Nitrogen TKN (as N)
Nitrogen Total (as N)
2000
2005
2010

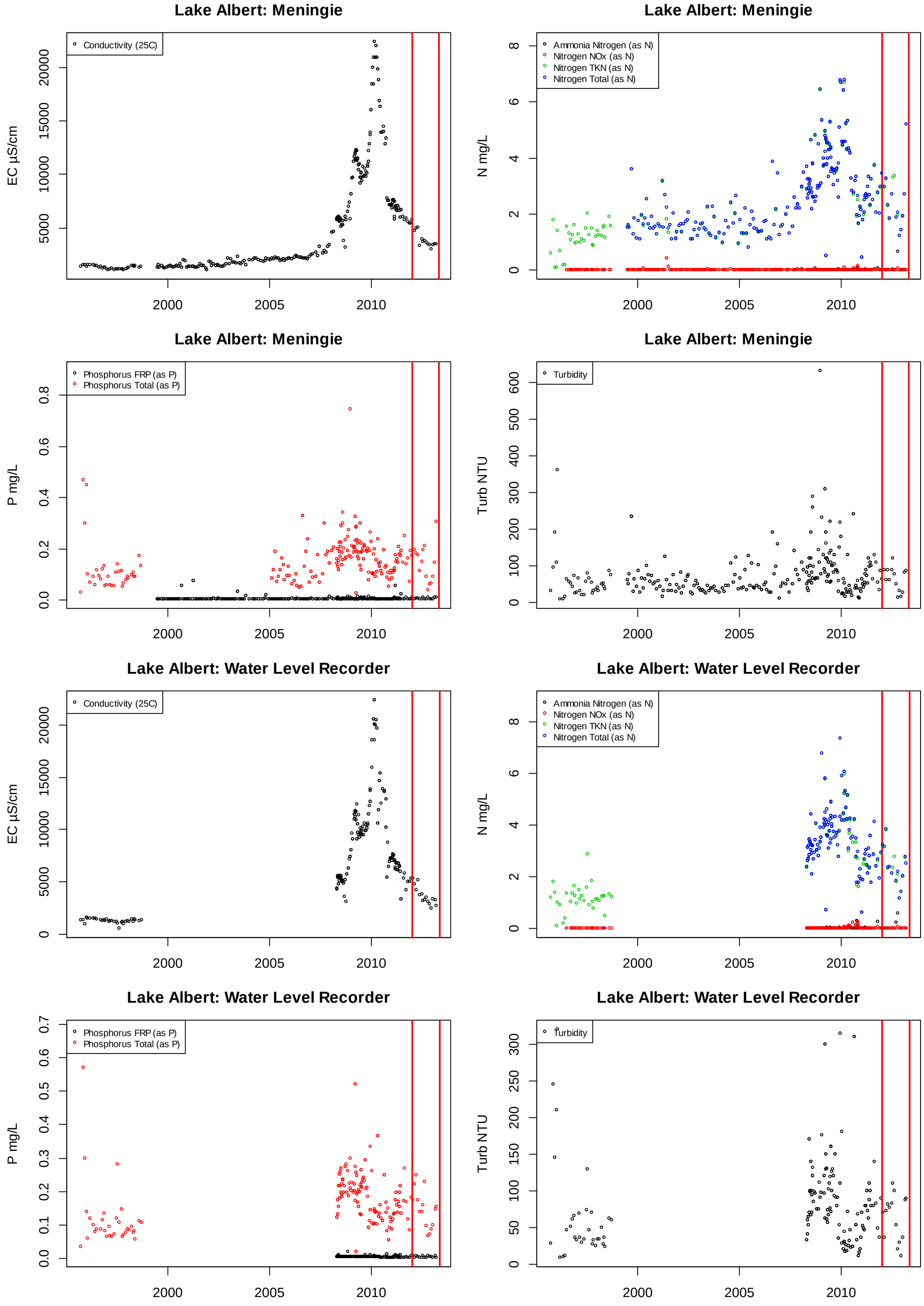

Coorong: Parnka-Villa
P mg/L
0.0
0.2
0.4
0.6
0.8
Phosphorus FRP (as P)
Phosphorus Total (as P)
2000
2005
2010


Coorong: Parnka-Villa
Turb NTU
20
40
60
80
100
Turbidity
2000
2005
2010



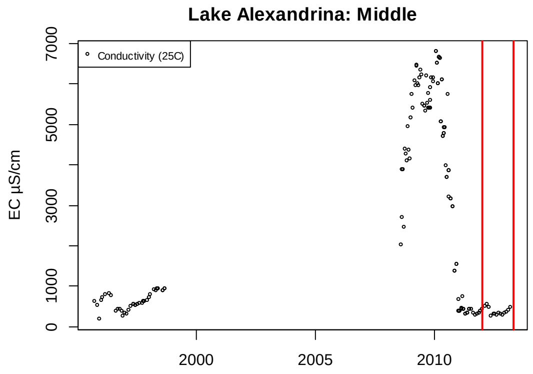
Time series of selected environmental parameters at sites in the Coorong

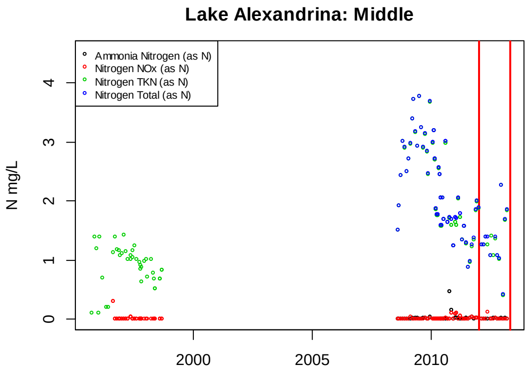
B.2 Time series of selected water quality data at sites in Lake Albert

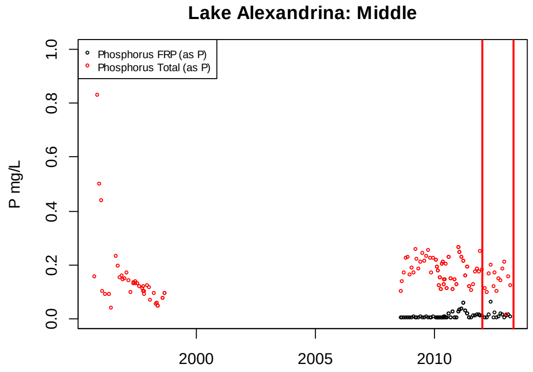


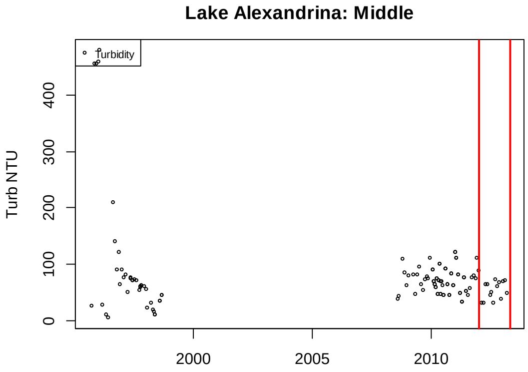
Time series of selected environmental parameters at sites in Lake Albert

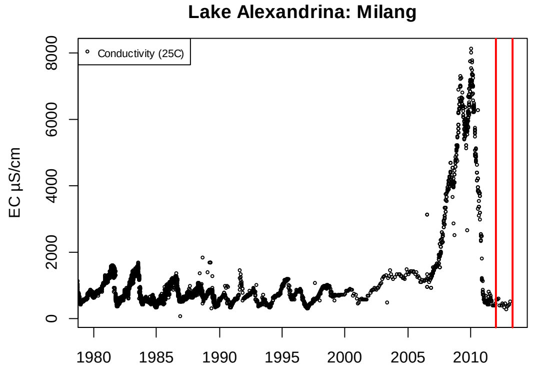
B.3 Time series of selected water quality data at sites in Lake Alexandrina

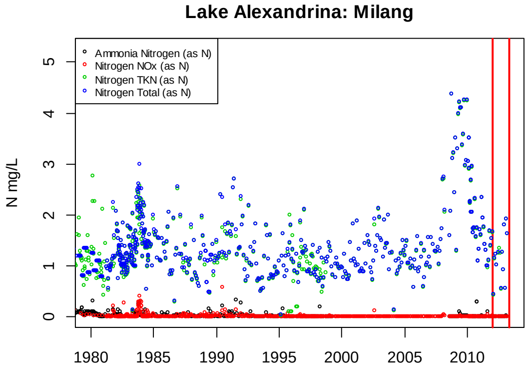


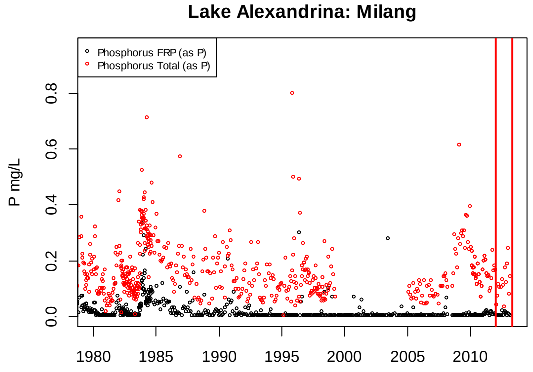


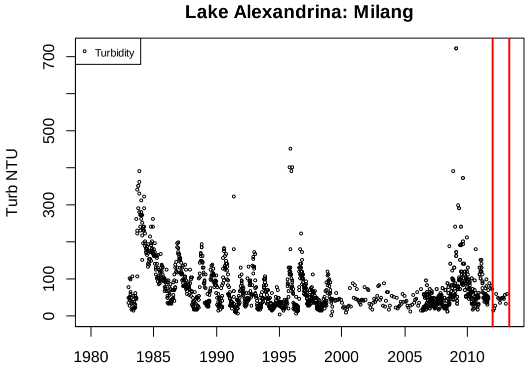


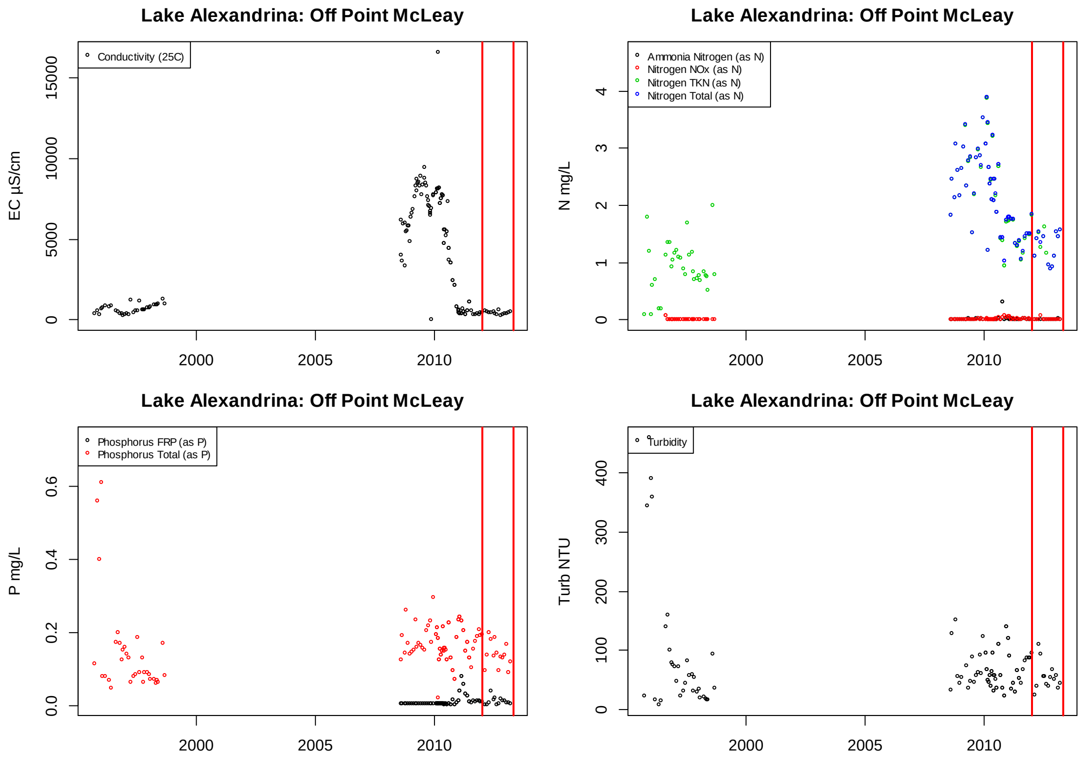












Time series of selected environmental parameters at sites in Lake Alexandrina

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

CSIRO Land and Water
Rod Oliver
t +61 8 8303 8481
e rod.oliver@csiro.au
w http://www.csiro.au/Organisation-Structure/Divisions/Land-and-Water.aspx