
**The response of suspended microalgae to barrage releases
in the North Lagoon of the Coorong and Murray Mouth,
February 2012 – June 2012**

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Executive summary

The Coorong region is internationally recognised for its high biological diversity and is ecologically, economically and socially important for South Australia and the Murray-Darling Basin. Inflows from the River Murray via the Lower Lakes are not only an important source of freshwater to the region, but also an important source of energy for the aquatic ecosystem. Whilst there is a limited understanding of trophic interactions in the Coorong, diatoms are considered to be an important food source for Goolwa Cockles and blue-green algae are often considered non-preferred food sources for zooplankton in other systems. During the inflows of 2010-2011, the suspended microalgal community of the Coorong was dominated by blue-green algae, but as the flows continued, green algae and diatoms abundance increased. Thus, it was assumed that the microalgal community was shifting towards one that would have greater nutritional benefits for higher trophic levels. It was hypothesised that the sustained inflows of 2011-2012 would continue the shift in the microalgal community towards one dominated by diatoms rather than blue-green algae.

From 1 February 2012 to 7 June 2012, five sites in the North Lagoon of the Coorong, from the Goolwa Barrage to Parnka Point, were visited at approximately monthly intervals. At the five sites on each trip, electrical conductivity was measured at 0.25 m depth intervals through the water column. In addition, integrated water-column samples were collected and microalgal identification and abundance counts were conducted.

In 2012 the microalgal diversity was comparable to 2010-2011, whilst the abundance was higher in 2012. It appears that in 2012, the microalgal community of the Northern Coorong was largely governed by the Lower Lakes' community. The community was dominated by blue-green algae throughout the study period and diatom abundance was low. As salinities increased down the length of the Coorong, there was a distinct shift in the microalgal community at approximately 20 mS/cm. At Parnka Point, which connects the North and South Lagoons of the Coorong, the microalgal community was distinct from all other study sites. The community at Parnka Point was highly abundant and dominated by *Chlorella*, a genus that prefers shallow, mixed, nutrient rich conditions. Such high microalgal abundance is likely to have resulted from the availability of nutrients and perhaps reduced predation at

elevated salinities. The high abundance will reduce the amount of light available to support the growth of *Ruppia tuberosa*.

From this investigation it is recommended that:

- Barrage releases are managed to ensure favourable habitat conditions for submerged plants so that nutrients are incorporated into macrophyte biomass.
- Investigations are conducted to understand interactions between microalgae, zooplankton and higher trophic levels and interactions between microalgae, nutrients and submerged plants. This will allow target species/groups of microalgae to be identified, so that monitoring data can be assessed against clear targets.
- Long-term monitoring is conducted which builds an understanding of how microalgal communities (and nutrients) respond to different flow events (including non-flow periods). This needs to capture changes over larger spatial (South Lagoon) and temporal scales. It will improve the predictability of the response microalgal communities to flow scenarios and with clear targets, will be able to be used to assist the development of environmental water delivery plans and condition assessments.

Introduction

The Coorong is a coastal lagoon that contains high biological diversity. It is ecologically important for South Australia and the Murray-Darling Basin, Australia's largest drainage basin (1,063,000 km²). Together with the Lower Lakes, the Coorong was declared a *Wetland of International Importance* in 1985 under the Ramsar Convention. This status is recognition of the abundant and diverse ecological communities within the region. The region is an important refuge for a number of threatened freshwater fish species and an important feeding habitat for waterbirds. It also supports a substantial fishery, provides recreational pursuits and has a high cultural and aesthetic value.

While small volumes of water are provided to the South Lagoon of the Coorong (≈ 7 GL/year) from the Upper South East Drainage (USED) scheme, the majority of its inflows are received from Lake Alexandrina through five barrages constructed in the late 1930s (Figure 1). Inflows from Lake Alexandrina to the Coorong are controlled by opening gates in the five barrages. The River Murray carries the largest and most constant flow of water to the Lower Lakes. The Darling River also contributes significant flow, although this is more variable. Although several local streams discharge into the Lower River Murray and Lake Alexandrina, their overall contribution to total annual flow are small relative to River Murray inputs (Anon 2007).

Extraction of water upstream for irrigation and human use has severely reduced the amount of water passing into and through the Lower Lakes. Consumptive water use within the Murray-Darling Basin has reduced average stream-flow through the Murray Mouth from 12,233 GL/yr to 4,733 GL/yr (CSIRO 2008). Whilst lower than natural levels, these flows are not only an important as a source of freshwater to the Coorong, Murray Mouth and near shore environment, but also an important source of energy for the aquatic ecosystem (Cook *et al.* 2008).

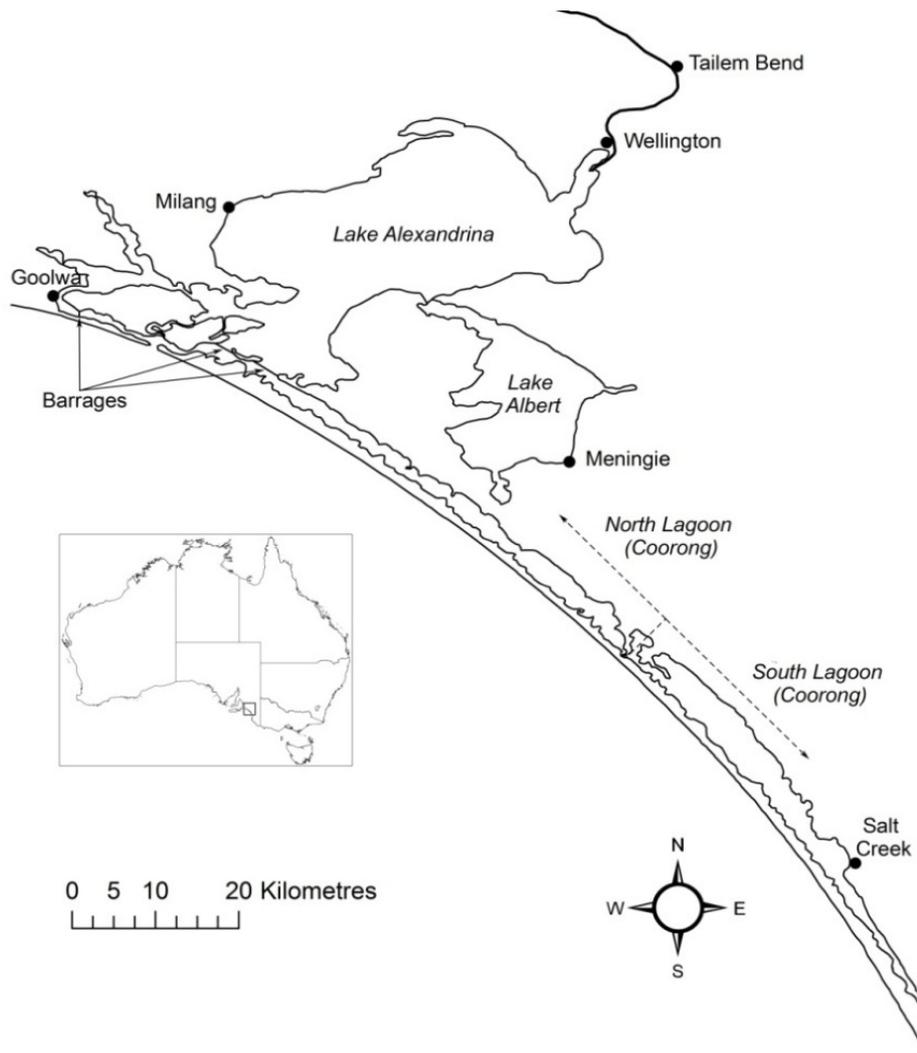


Figure 1. Map of the Lower River Murray, Lake Alexandrina, Lake Albert and the Coorong.

Cook *et al.* (2008) demonstrated that the Lower Lakes retained dissolved nutrients and exported organic nutrients to the Coorong, most likely within suspended microalgal biomass (technically phytoplankton, but referred to as microalgae for the purposes of this project). Consequently, inputs of water to the Coorong from the Lower Lakes are likely to provide energy for higher trophic levels and this would initially be through zooplankton communities and/or the microbial loop within the Coorong. Whilst there is currently a limited understanding of trophic interactions between microalgae and higher trophic levels in the Coorong, Bacillariophyta (diatoms) are considered to be an important food source for Goolwa Cockles (Seuront and Leterme 2010). In addition, there is evidence to suggest that Cyanobacteria (blue-green algae) are non-preferred food sources for zooplankton in other

ecosystems (Carney and Elser 1990; De Benardi and Giussani 1990; Henning *et al.* 1991). Aldridge and Brookes (2011) found that in response to large inflows to the Coorong in 2010-2011 the microalgal community was dominated by Cyanobacteria, but as the flows continued, Chlorophyta (green algae) and Bacillariophyta (diatoms) abundance increased. Thus it was assumed that the microalgal community was shifting towards one that would have greater nutritional benefits for the Coorong ecosystem.

Project objectives

Resulting from widespread rainfall in the Murray-Darling Basin, high inflows into the Coorong in 2010-2011 continued into 2011-2012. Microalgal communities have received little attention in the Coorong and so this provided the opportunity to build on the information of Aldridge and Brookes (2011). As the response of the microalgal community to different flow conditions is assessed, increased predictability in the response to various flows scenarios will be possible. It was hypothesised that the continued inflows of 2011-2012 would continue the shift in the microalgal community towards one dominated by Bacillariophyta rather than Cyanobacteria.

Methods

From 2 February 2012 to 7 June 2012, five sites in the North Lagoon of the Coorong, from the Goolwa Barrage to Parnka Point, were visited at approximately monthly intervals (Table 2 and Figure 2). One site was within the Murray Mouth (C5). C1 (Goolwa Barrage Downstream), C5 (Murray Mouth), C9 (Ewe Island) and C11 (Mark Point) were used by Aldridge and Brookes (2011). C12 (Parnka Point) was not used by Aldridge and Brookes (2011) and has little historical data since the response of microalgal communities to barrage inflows has been limited to sites closer to the barrages. C12 (Parnka Point) was included to provide more information on the response of the Coorong microalgal community as a whole. Indeed, Aldridge Brookes (2011) recommended a greater spatial coverage than that used in 2010-2011.

Table 2. Site coordinates for sampling locations in the North Lagoon of the Coorong and Murray Mouth region. Geodatic data used was WGS 84.

Site reference	Site description	Longitude (°E)	Latitude (°S)
C1	Goolwa Barrage Downstream	138.81736	-35.52717
C5	Murray Mouth	138.88164	-35.55719
C9	Ewe Island	138.96111	-35.56747
C11	Mark Point	139.07572	-35.63422
C12	Parnka Point	139.39600	-35.90197

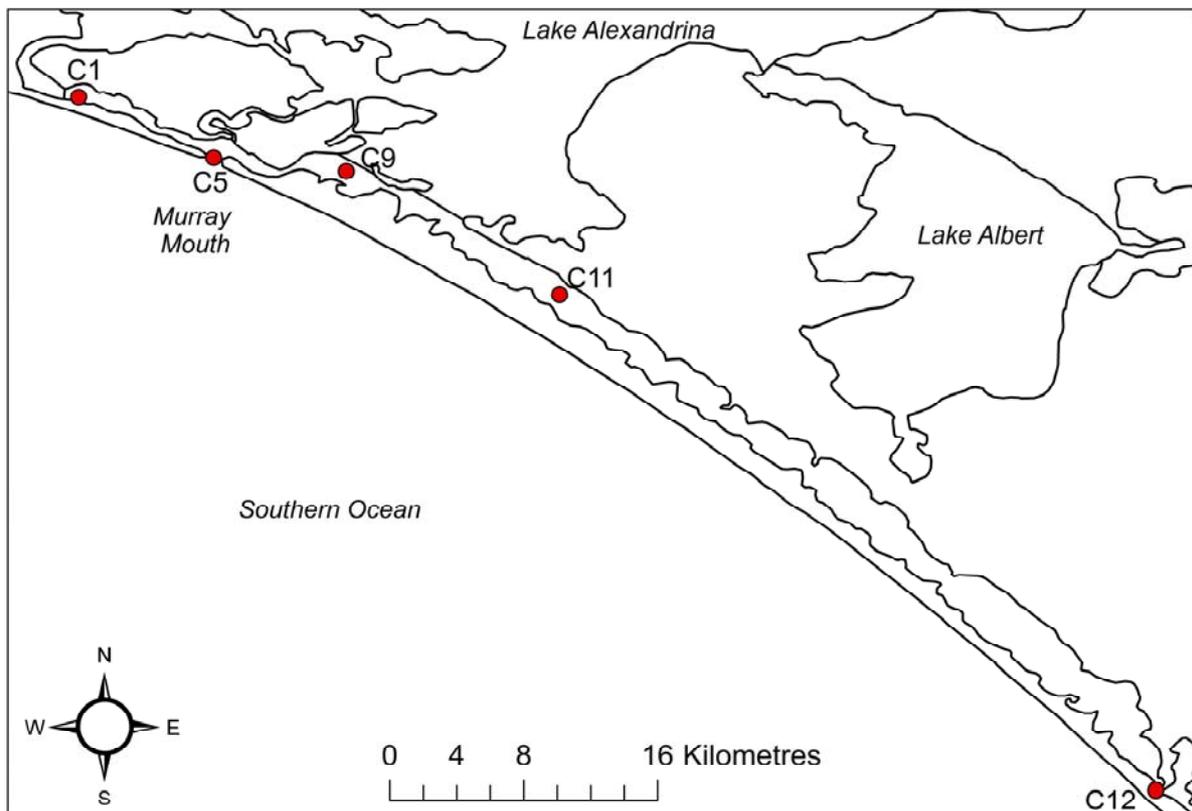


Figure 2. Map of sampling locations in the North Lagoon of the Coorong and Murray Mouth region. C1 – Goolwa Barrage (Downstream); C5 – Murray Mouth; C9 – Ewe Island; C11 – Mark Point; and C12 – Parnka Point.

At the five sites on each trip, a calibrated Hydrolab DS-5X (Hach) multi-probe was lowered through the water column and measurements were recorded at approximately 0.25 m intervals for specific electrical conductivity (

Figure 3). Integrated water-column samples were collected using a polyvinyl chloride tube with an internal diameter of 5.4 cm. Tubing was lowered through the water column to approximately 0.15 m above the sediment surface, sealed on top and water was retrieved into a plastic container. For each site this was repeated 3 times and a composite sample was collected (

Figure 3). All samples were immediately stored in the dark below 3 °C until analysis. Samples were returned to the Australian Water Quality Centre (a National Association of Testing Authorities accredited laboratory) for microalgal identification and abundance counts.



Figure 3. Photos of field work for microalgae in the Coorong. Top left: lowering multi-probe through the water column. Top right: recording readings from multi-probe. Bottom left: collecting integrated water samples. Bottom right: collecting microalgal samples.

Statistical analyses

Multivariate statistical analyses were conducted using PC-Ord (version 4) to determine changes in microalgal community composition during the barrage release and to identify any relationship with electrical conductivity. A Nonmetric Multidimensional Scaling (NMS) ordination (Sorensen) was carried out as this was considered suitable for the data of this project (a large number of zero values). This analysis involved creating a main matrix containing cell numbers of each genus at each site for each sampling trip and overlaying this with a second matrix containing the same data-set as well electrical conductivity. A successful two-dimensional ordination was conducted, with a stress level of 7.8.

Ordinations are used to order objects (in this case, sites on a particular day) characterised by the values of multiple variables (in this case, microalgal genera). On an ordination graph, the closer the objects, the more closely related the variables of the objects. These objects can be related to secondary variables (in this case electrical conductivity), with the length and direction of vectors used to symbolise the strength of the relationship between the objects and secondary variables. Similarly, vectors can be used to symbolise which primary variables are indicative of the observed patterns.

Results

Electrical conductivity

On 2 February 2012 the electrical conductivity increased from C1 (Goolwa Barrage Downstream: 2,466 $\mu\text{S}/\text{cm}$) to C11 (Mark Point: 20,043 $\mu\text{S}/\text{cm}$) (Figure 4). This general trend was observed at all other sampling times, with far greater electrical conductivity also observed at C12 (Parnka Point: average electrical conductivity of 81,966 $\mu\text{S}/\text{cm}$ during the study period). There was a general decrease in electrical conductivity in the study region during the study period, particularly at C5 (Murray Mouth), C9 (Ewe Island) and C1 (Goolwa Barrage Downstream). At C11 (Mark Point) and C12 (Parnka Point) there was a decrease in electrical conductivity to 2 May 2012 with a subsequent increase to 7 June 2012.

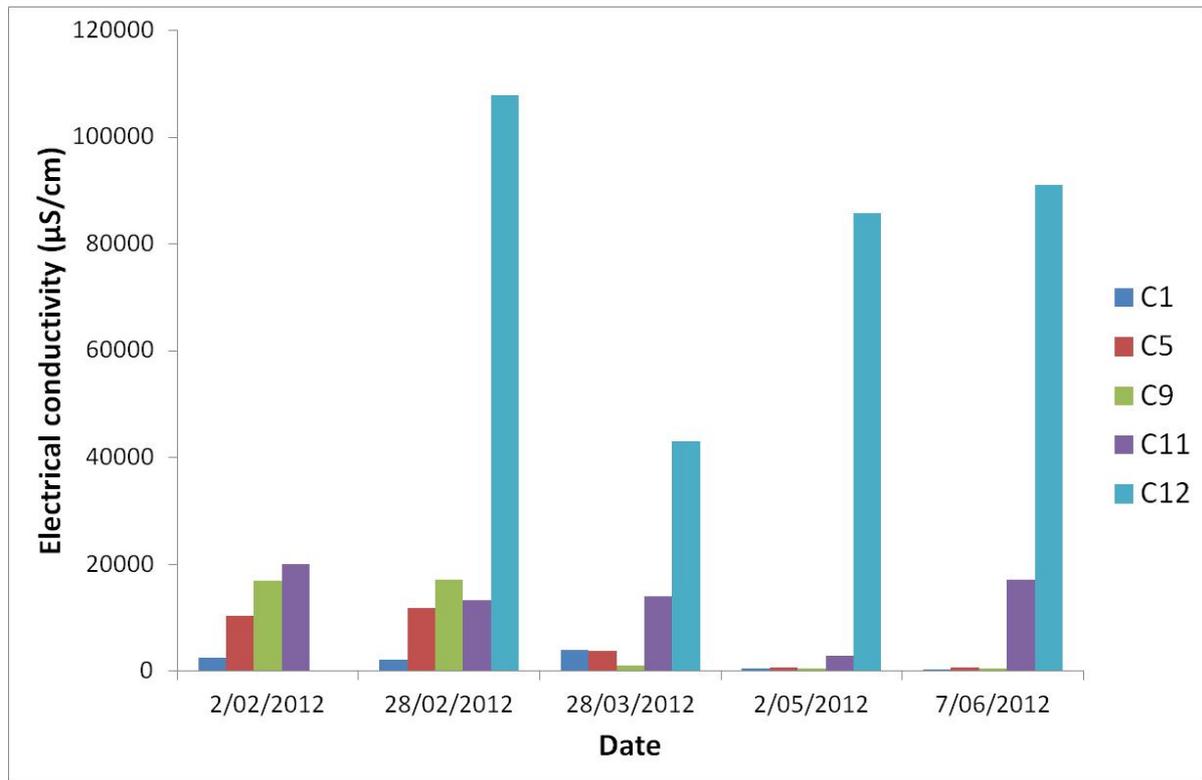


Figure 4. Changes in electrical conductivity in the North Lagoon of the Coorong and Murray Mouth, February 2012-June 2012.

Microalgal community shift

Spatial differences in the microalgal community were closely associated with differences in electrical conductivity (Figure 5). The microalgal community at C12 (Parnka Point) was distinctly different to that of other sites and this was associated with the higher salinity observed at C12 (Parnka Point). In addition, there appeared to be little change in the microalgal community at C12 (Parnka Point) during the study period, with *Chlorella* (green algae) an indicator species for this community. At the beginning of the study period the microalgal communities at C1 (Goolwa Barrage Downstream) and C11 (Mark Point) were different from each other with C5 (Murray Mouth) and C9 (Ewe Island) a mix of the C1 (Goolwa Barrage Downstream) and C11 (Mark Point) communities. At this time, C1 (Goolwa Barrage Downstream) was associated with *Planktolyngbya*, whilst C11 (Mark Point) was associated with *Synechocystis*, both of which are blue-green algae. However, as barrage flows continued *Synechocystis* became absent from the microalgal community and the microalgal community of C5 (Murray Mouth), C9 (Ewe Island) and C11 (Mark Point) became similar to that of C1 (Goolwa Barrage Downstream). Consequently, one microalgal

community existed between Goolwa Barrage and Mark Point between 28 March 2012 and 2 May 2012. However, by 7 June 2012 the community at C11 (Mark Point) was more similar to that of C12 (Parnka Point), but remained a combination of the communities found at C12 (Parnka Point) and other North Lagoon sites.

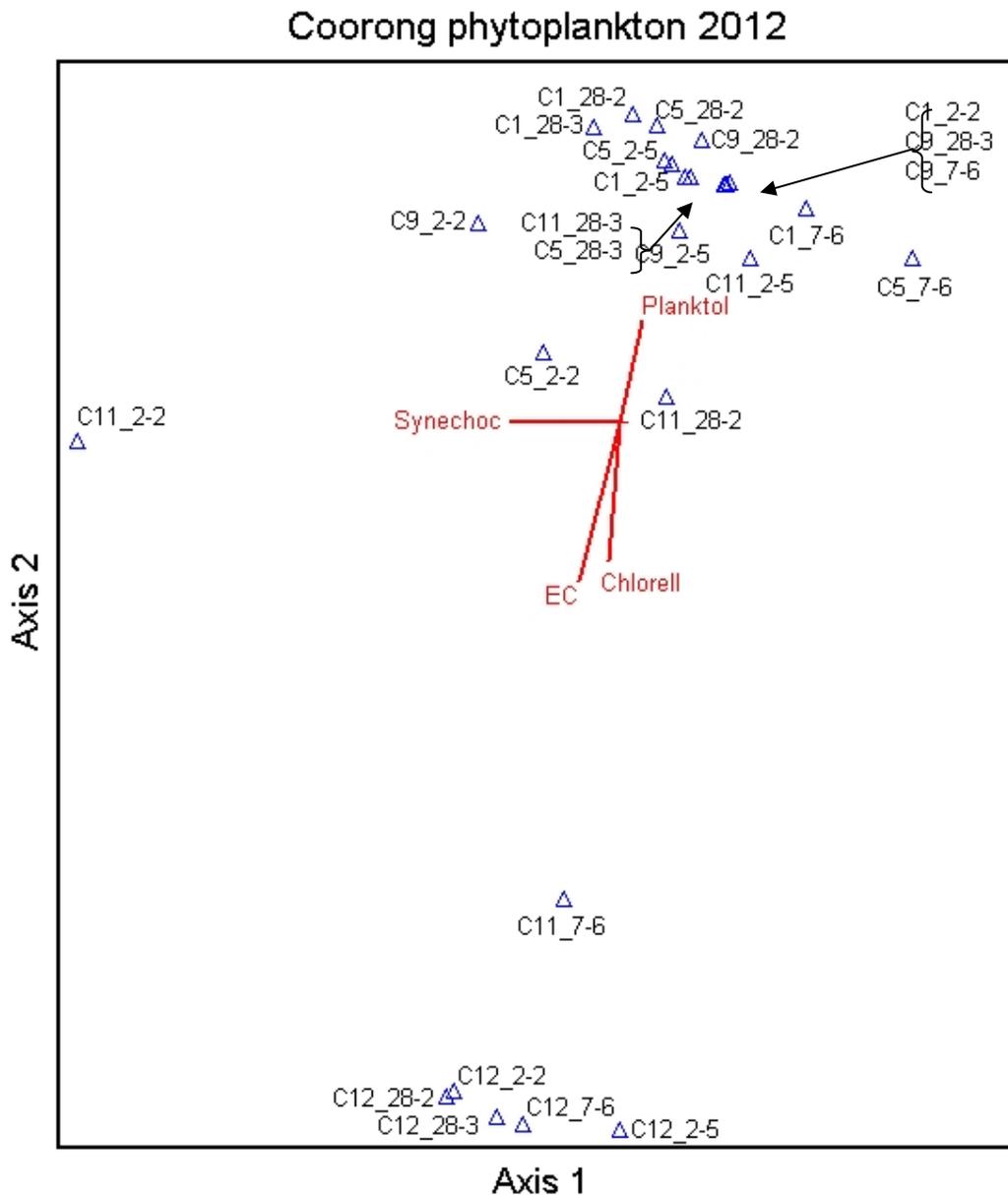


Figure 5. NMS Ordination (Sorensen) of changes in Coorong microalgal community February 2012-June 2012. Triangles represent microalgal communities at a particular site (labelled as site ID) and date (dd-m). Vectors show the relationship of the microalgal community to electrical conductivity (EC) and indicator genera of changes, with a r^2 of 0.51. Indicator genera include Planktol (*Planktolyngbya*), Synechoc (*Synechocystis*) and Chlorella (*Chlorella*).

Microalgal community abundance and diversity

From 2 February 2012 to 7 June 2012 the microalgal abundance (cells/mL) at C1 (Goolwa Barrage Downstream), C5 (Murray Mouth), C9 (Ewe Island) and C11 (Mark Point) was dominated by Cyanobacteria (blue-green algae), varying between 30,600 cells/mL (C5, Murray Mouth, on 7 June 2012) and 551,000 cells/mL (C1, Goolwa Barrage Downstream, on 29 March 2012) (Figure 6). The most dominant species were *Planktolyngbya* and *Aphanocapsa*, both of which had an inverse relationship with electrical conductivity, with neither occurring above 20,000 $\mu\text{S}/\text{cm}$ (Figure 7). At C11 (Mark Point), Chlorophyta (green algae) made up a greater portion of the community on occasions, with 49% of the total cell numbers on 29 February 2012 and 94% on 7 June 2012 (Figure 6). Whilst Bacillariophyta (diatoms) abundance was low, it increased slightly through the study period at C1 (Goolwa Barrage Downstream), C5 (Murray Mouth), C9 (Ewe Island) and C11 (Mark Point), with an average abundance of 2.4 cells/mL on 2 February 2012 and 8.5 cells/mL on 7 June 2012.

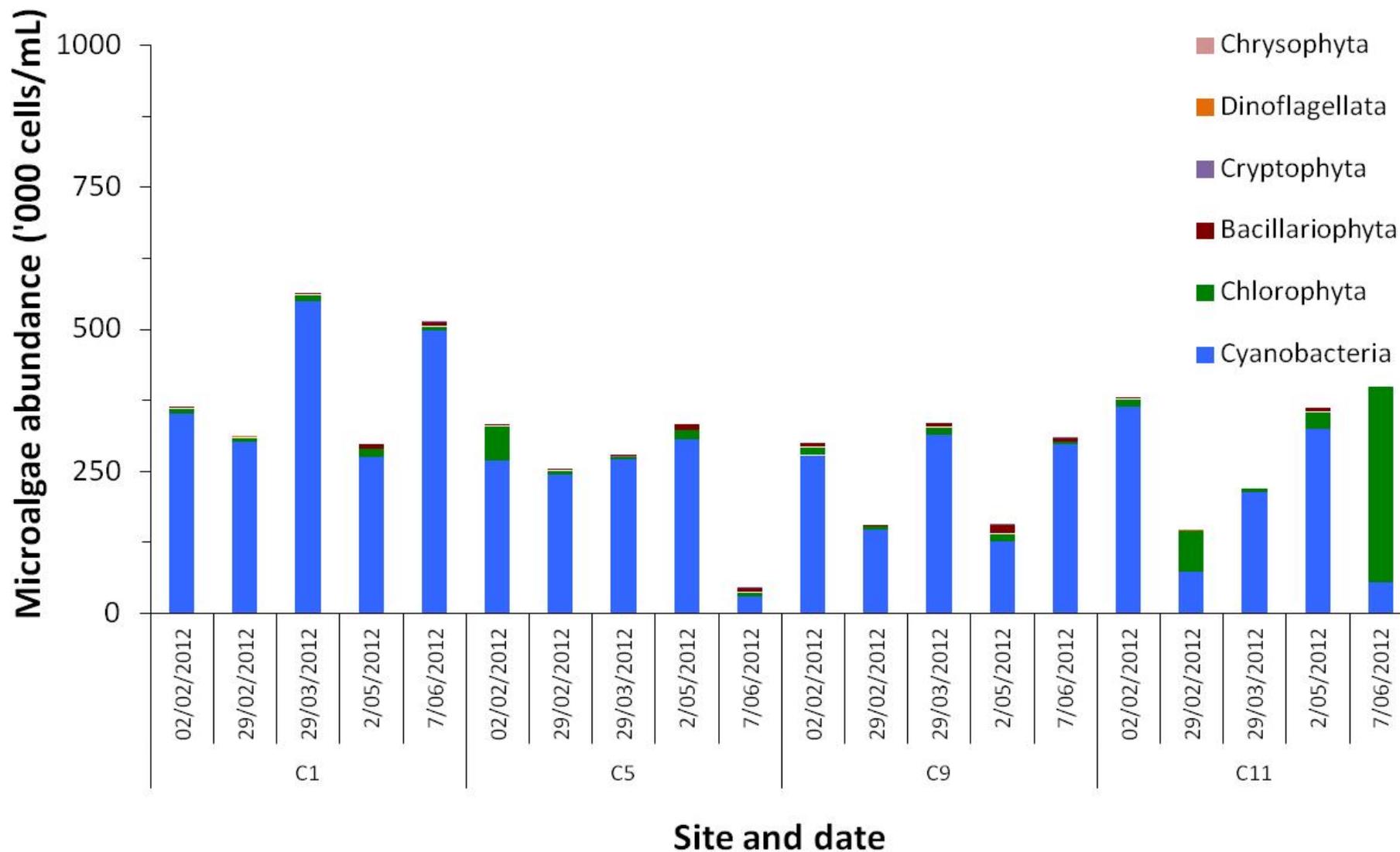


Figure 6. Changes in the abundance of microalgal groups in the North Lagoon of the Coorong and Murray Mouth (C1-C11), February 2012-June 2012

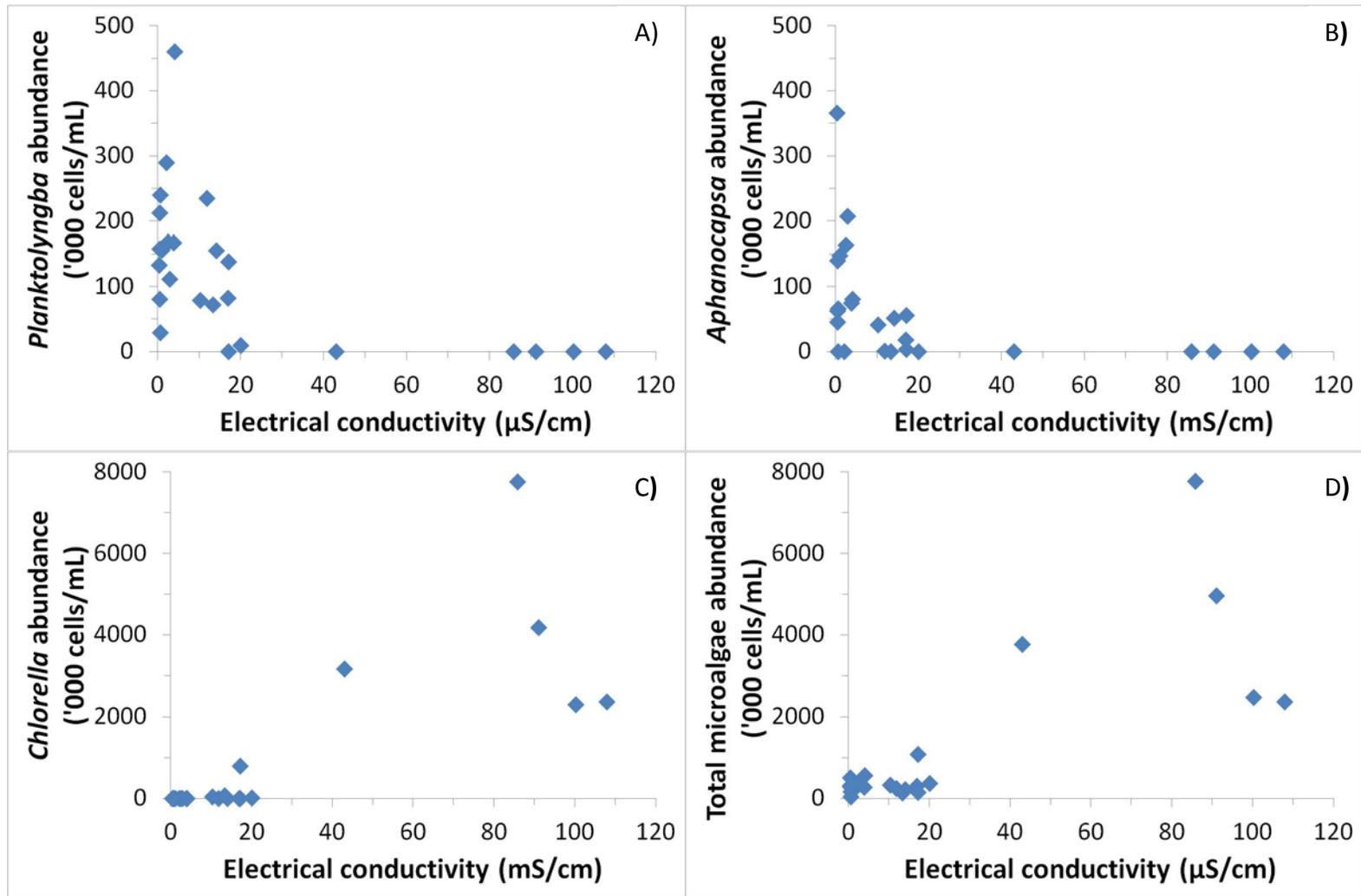


Figure 7. Influence of electrical conductivity on microalgal abundance. Shown are *Planktolyngbya* (A) and *Aphanocapsa* (B), *Chlorella* (C) and total abundance (D).

At C12 (Parnka Point) there was an increase in Bacillariophyta abundance between 2 February 2012 (11.3 cells/mL) and 2 May 2012 (20.1 cells/mL), after which Bacillariophyta were absent (Figure 8). The total microalgal abundance at C12 (Parnka Point) was much greater than all other sites, with abundance increasing from 2,480,000 cells/mL on 2 February 2012 to 7,780,000 cells/mL on 2 May 2012. In addition, unlike all other sites the microalgal abundance at C12 (Parnka Point) was dominated by Chlorophyta (green algae), in particular *Chlorella*. *Chlorella* had a positive relationship with electrical conductivity, with abundance increasing rapidly above 20,000 $\mu\text{S}/\text{cm}$ and peaking at approximately 86,000 $\mu\text{S}/\text{cm}$ (Figure 7). This was also the case for total microalgal abundance owing to the dominance of *Chlorella* at electrical conductivities above 20,000 $\mu\text{S}/\text{cm}$.

Although microalgal abundance was greatest at C12 (Parnka Point), the microalgal diversity was lowest (Figure 9). At C12 (Parnka Point), the diversity varied considerably between sampling periods, but consisted largely of Dinoflagellata, Chlorophyta and Bacillariophyta. At C1 (Goolwa Barrage Downstream), C5 (Murray Mouth), C9 (Ewe Island) and C11 (Mark Point), the microalgal diversity was largely dominated by Cyanobacteria and Chlorophyta and to a lesser extent Bacillariophyta. However, on occasions there were Dinoflagellates and Cryptophytes. There was a general decrease in diversity from C1 (Goolwa Barrage Downstream) to C11 (Mark Point) at the start of the study period, but this was less pronounced towards the end of the study period.

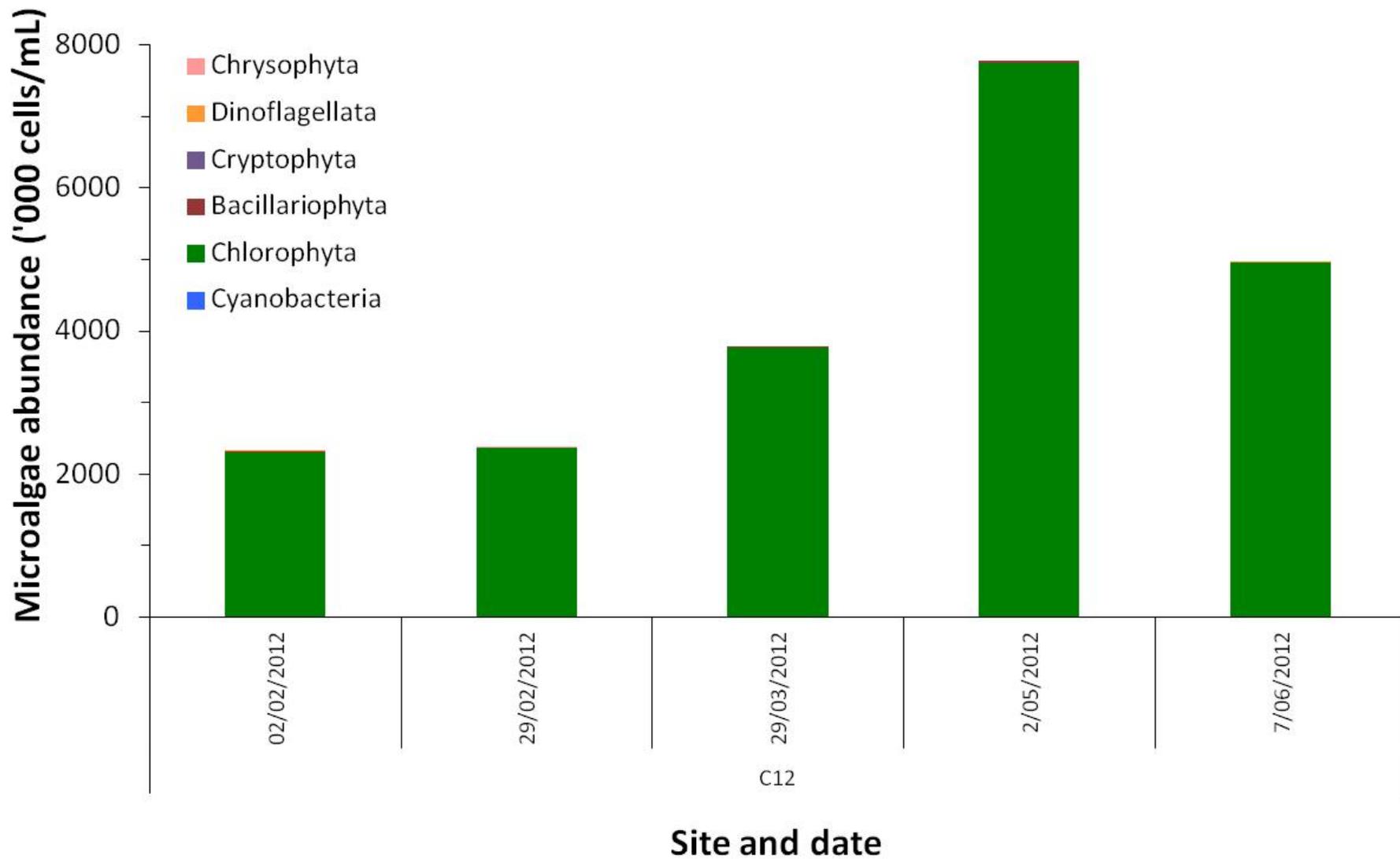


Figure 8. Changes in the abundance of microalgal groups in the North Lagoon of the Coorong and Murray Mouth, February 2012-June 2012.

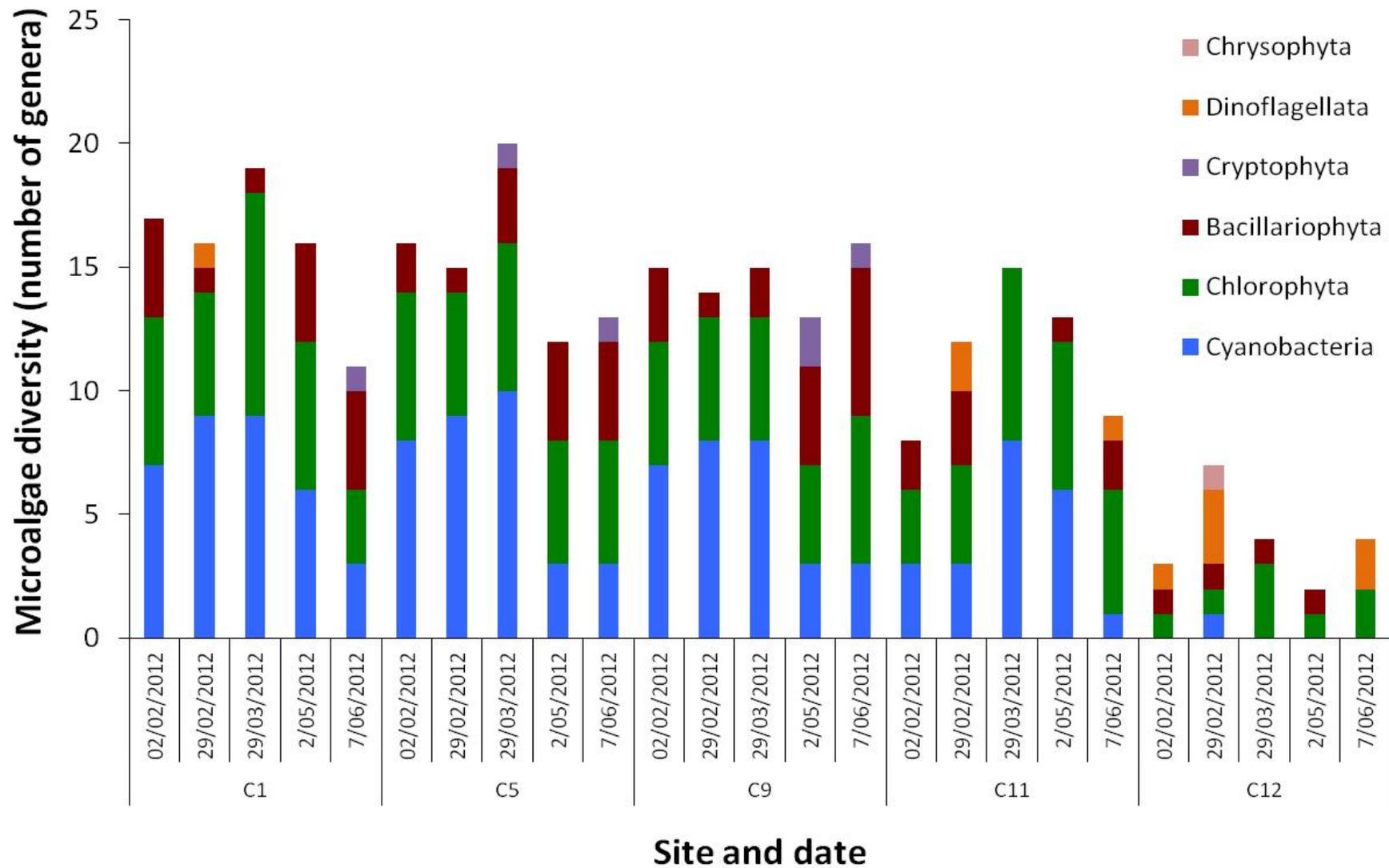


Figure 9. Changes in the diversity of microalgal groups in the North Lagoon of the Coorong and Murray Mouth, February 2012-June 2012.

Discussion

Changes in microalgal community structure in response to inflows

During an extended drought period in the Murray-Darling Basin, during which inflows to the Coorong were limited, both microalgal abundance and diversity were low (Seuront and Leterme 2010; Aldridge and Brookes 2011). This was presumably associated with low nutrient availability (Nayar and Loo 2009; Seuront and Leterme 2010). However, widespread rainfall in 2010-2011 resulted in increased inflows to the Coorong resulting in increased abundance and diversity of the microalgal community (Aldridge and Brookes 2011). This was associated with reduced salinity and increased loads of nutrients from the basin (Aldridge and Brookes 2011). In 2010-2011, the microalgal community was initially dominated by Chlorophyta, followed by domination of Cyanobacteria due to the movement of microalgae from the Lower Lakes (Aldridge and Brookes 2011). However, as the flow continued Cyanobacteria abundance decreased and Chlorophyta and Bacillariophyta abundances increased. It was hypothesised that this trend would continue into 2011-2012 as a result of continued inputs of nutrients, particularly silica which is essential for the growth of Bacillariophyta. Whilst this may stimulate secondary productivity (via zooplankton), microalgae-zooplankton interactions are not yet understood for the Coorong. However, it was assumed that such a response would have greater nutritional benefits for the Coorong ecosystem as Bacillariophyta are considered to be an important food source for Goolwa Cockles (Seuront and Leterme 2010) and Cyanobacteria are considered non-preferred food sources for zooplankton in other systems (Carney and Elser 1990; De Benardi and Giussani 1990; Henning *et al.* 1991).

In 2012 the microalgal diversity was comparable to 2010-2011, but the abundance was higher in 2012. In 2012 the community was dominated by Cyanobacteria throughout the study period and Bacillariophyta abundance was low. The most dominant Cyanobacteria were *Aphanocapsa* and *Planktolyngbya*. *Synechocystis* was also abundant at C5 (Murray Mouth), C9 (Ewe Island) and C11 (Mark Point) at the beginning to the study period, most likely resulting from the input of water from upstream of the barrages as *Synechocystis* has been abundant upstream of the barrages previously (Aldridge *et al.*, 2009). *Aphanocapsa* and *Planktolyngbya* are picocyanobacteria that were abundant in the main bodies of Lake Alexandrina and Lake Albert during the preceding drought, often reaching bloom numbers

(> 15,000 cells/mL) (Aldridge *et al.* 2009). After a small release of Lake Alexandrina water into the Coorong (approximately 30-40 GL over 15 days) in 2004, Geddes and Tanner (2007) reported abundant numbers of freshwater microalgae at Tauwitchere Barrage and Pelican Point. This included *Aphanocapsa* and *Planktolyngbya*, which were flushed in from Lake Alexandrina. During 2012 this was also observed, although the zone of influence was greater (beyond C11, Mark Point) in 2012 than 2004 due to the much larger inflow volumes. It appears that because of the increasing salinity gradient along the length of the North Lagoon many of these freshwater species did not survive at C12 (Parnka Point) and so the microalgal community at C12 (Parnka Point) was distinct from all other study sites.

The microalgal community of the North Lagoon of the Coorong in 2012 was largely governed by the Lower Lakes' community. This was also observed by Geddes (1987) and Aldridge and Brookes (2011), with the community dominated by Chlorophyta or Cyanobacteria during high inflows and Bacillariophyta becoming more dominant as flows recede. Within this study, inflows from the barrages remained elevated, perhaps explaining the observed stable community structure with abundant Cyanobacteria low Bacillariophyta abundance.

The influence of salinity on community structure

The high abundances of *Aphanocapsa* and *Planktolyngbya* in the North Lagoon of the Coorong during the study period most likely resulted from inputs from the Lower Lakes, with high numbers persisting in the Lower Lakes beyond the drought period. As fresh Lower Lakes' water mixes with more saline Coorong water, freshwater species are lost from the community with none found above an electrical conductivity of approximately 20 mS/cm. At these salinities there was an apparent switch in the community, which became dominated by *Chlorella*. Very high abundances of *Chlorella* were observed at sites with electrical conductivities above approximately 20 mS/cm. Such high abundances may result from reduced competition, reduced predation by zooplankton, elevated nutrient levels or a combination of all three.

Nutrients and microalgal biomass

According to Reynolds (2002), *Chlorella* prefers mixed, nutrient rich conditions, although this classification was based on freshwater species. The high abundances of *Chlorella* that were observed would only be possible with the availability of nutrients. Within a waterbody nutrient levels are a function of external inputs (River Murray and Salt Creek inflows), internal inputs (release from sediments) and internal demands (microalgae, macrophytes, bacteria etc). The high inflows in recent years combined with low abundances of submerged plants (namely *Ruppia tuberosa*) that currently exist in the Coorong mean that it is likely that more nutrients are available to support the growth of microalgae. This creates a negative feedback loop for submerged plants: increased nutrient availability may result in increased biomass of microalgae, reducing light availability for submerged plant growth (Scheffer *et al.* 1993; Jasser 1995). Furthermore, the loss of macrophytes can lead to increased rates of sediment resuspension, further decreasing light availability. Indeed, increased nutrient availability has been associated with a transition between turbid, microalgae dominated ecosystems to clear, macrophyte dominated ecosystems. Although achievable, the transition back to clear, macrophyte dominated ecosystems is often difficult due to the complex feedback loops that exist (Scheffer *et al.* 1993).

Recommendations

- Barrage releases are managed of to ensure favourable habitat conditions for submerged plants so that nutrients are incorporated into macrophyte biomass.
- Investigations are conducted to understand interactions between microalgae, zooplankton and higher trophic levels and interactions between microalgae, nutrients and submerged plants. This will allow target species/groups of microalgae to be identified, so that monitoring data to be assessed against clear targets.
- Long-term monitoring is conducted that builds an understanding of how microalgal communities (and nutrients) respond to different flow events (including non-flow periods). This needs to capture changes over larger spatial (South Lagoon) and temporal scales. It will improve the predictability of the response microalgal communities to flow scenarios and with clear targets, will be able to be used to assist the development of environmental water delivery plans and condition assessments.

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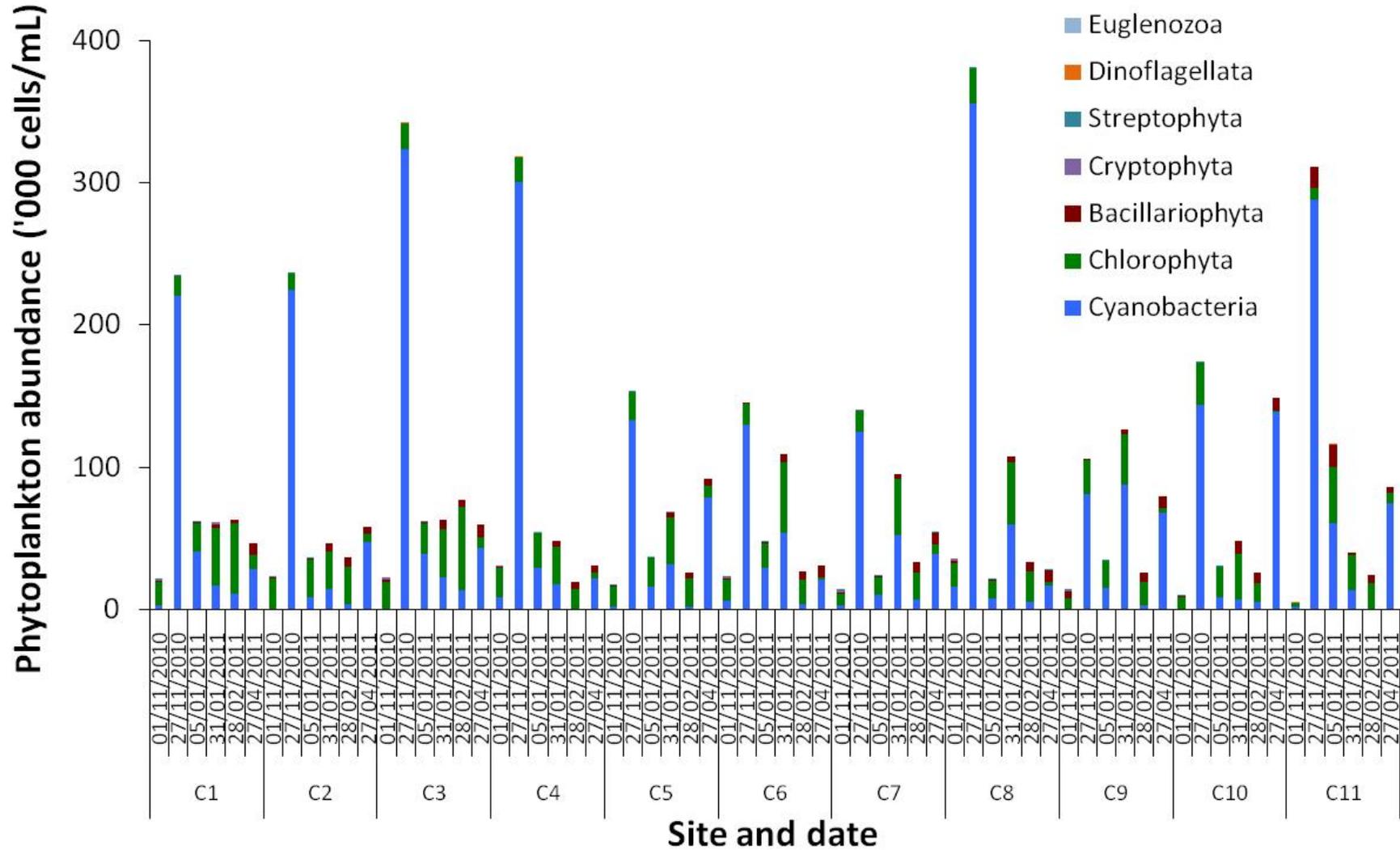
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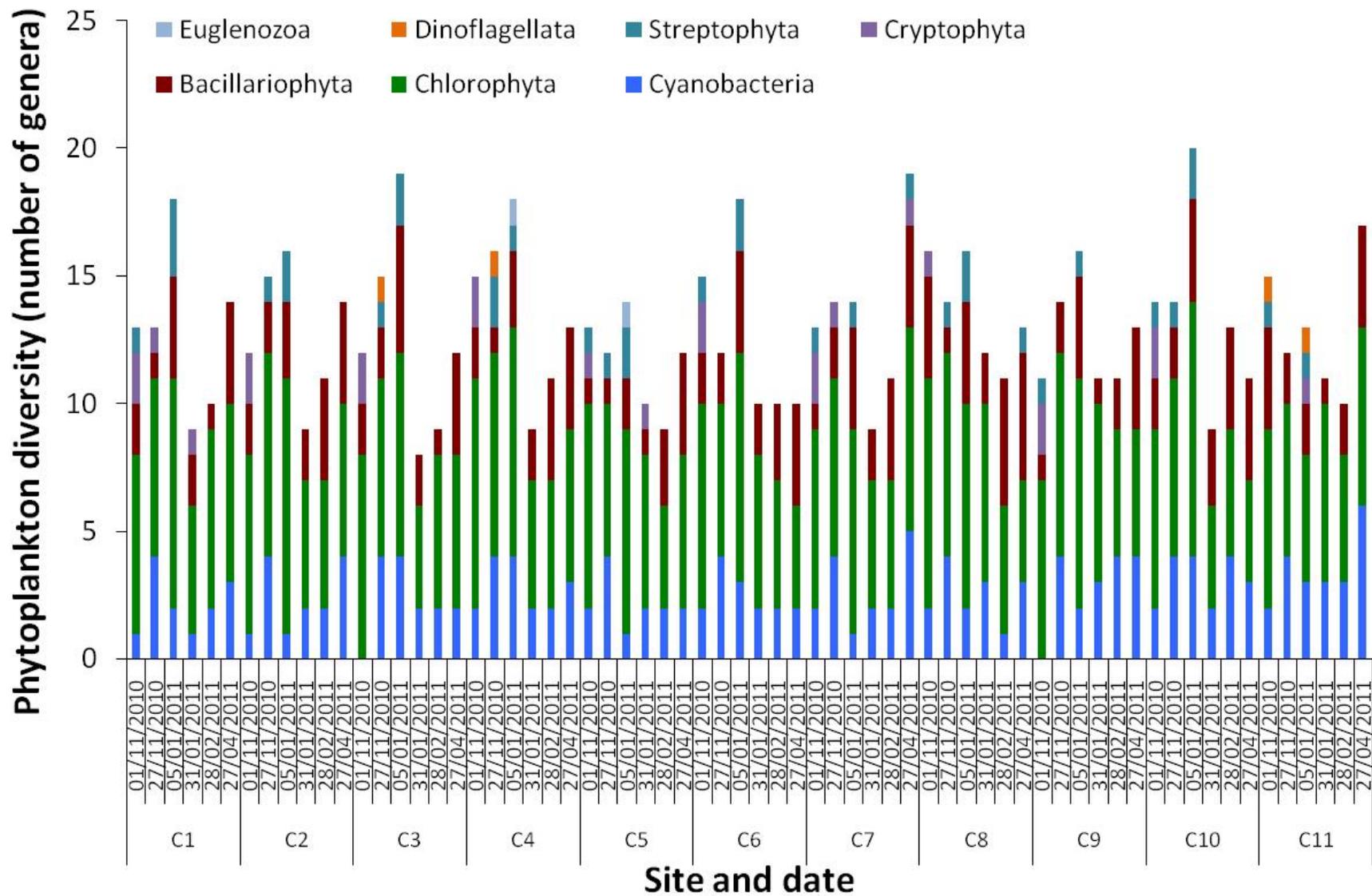
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Appendix 1 – results from Aldridge and Brookes (2011)





Changes in diversity of phytoplankton groups in the North Lagoon of the Coorong and Murray Mouth, November 2010-May 2011.