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A COMPARISON OF PHYTOPLANKTON COMMUNITY
ASSEMBLAGES IN ARTIFICIALLY AND NATURALLY MIXED
SUBTROPICAL WATER RESERVOIRS

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Running Header: Phytoplankton assemblages in reservoirs

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SUMMARY

1. The effect of mechanical and natural mixing of water on phytoplankton community assemblages was compared in one reservoir with a destratification unit operating during the wet summer months (North Pine Reservoir) with two adjacent reservoirs without artificial mixing (Wivenhoe and Somerset Reservoirs) over six years in subtropical Australia.
2. All three reservoirs were dominated by cyanobacteria, with the same three genera representing 75 to 80% of the abundance, i.e. *Aphanocapsa/Merismopedia/Cyanodictyon* group, *Cylindrospermopsis raciborskii* (Wołoszyńska) Seenayya et Subba Raju and *Planktolyngbya*. Associations between the dominant genera were consistent across all three reservoirs although there were reduced seasonal differences in abundance in North Pine Reservoir compared with the other reservoirs.
3. Peaks in abundance of the solitary filamentous species *C. raciborskii* and *Planktolyngbya* occurred earlier and the densities of the colonial species *Aphanocapsa/Merismopedia/Cyanodictyon* were lower in the reservoir where the destratification unit was switched on in spring compared with the naturally mixed reservoirs, possibly reflecting the differential effect of artificial mixing on colonial versus solitary filamentous species.
4. Phosphate concentrations were positively correlated with algal densities in the two naturally mixed reservoirs but not the artificially mixed reservoir where phosphate concentrations at the surface were near the limit of detection (0.06 $\mu\text{M P}$). Artificial mixing may therefore promote the growth of species able to utilise and store low concentrations of phosphate, such as *C. raciborskii*.

INTRODUCTION

The damming of river waters to create reservoirs and other water impoundments has substantially altered phytoplankton species assemblages. Cyanobacterial species often dominate, including potentially toxic species, such as *Microcystis aeruginosa* and *Cylindrospermopsis raciborskii*, which pose a potential human health risk (Sivonen & Jones, 1999). This shift has been attributed to two important factors: longer water residence times that allow the relatively slow-growing cyanobacteria to become established, and a stable water column, allowing species capable of regulating their buoyancy to out-compete other algal species in accessing sufficient levels of light and nutrients (Oliver & Ganf, 2000). A long water residence time also increases nutrient accumulation. This accumulation directly and indirectly promotes phytoplankton growth, particularly in waterways with high levels of anthropogenic nutrients (e.g. agriculture, sewage). Temperature also plays a key role, with reservoirs in subtropical and tropical regions having more sustained annual blooms of cyanobacterial species than temperate regions (McGregor & Fabbro, 2001).

A number of strategies have been developed throughout the world to reduce cyanobacterial blooms in water reservoirs. These include reducing anthropogenic nutrient inputs, using aerators to mix the water column, and adding chemicals to kill algal cells (e.g. copper sulfate) (Chorus & Mur, 1999; Hrudey *et al.*, 1999).

Reduction of nutrient inputs to reservoirs may not, however, result in an immediate reduction in phytoplankton biomass. Often there is a sufficiently high internal nutrient load that phytoplankton blooms are promoted for many years (Padisák & Reynolds, 1998; Jones & Poplawski, 1998).

Mechanical mixing of water has been a successful management tool for scum-forming cyanobacterial species such as *Microcystis* which rely on buoyancy regulation to compete for the available light (Visser *et al.*, 1996). However, it has proven less successful for another nuisance cyanobacterium, *C. raciborskii*; the use of mechanical aeration increased, rather than decreased mean abundance (Antenucci *et al.*, 2005). Mechanical mixing is only likely to be effective in reducing algal biomass when the population is light limited. Otherwise the increased availability of nutrients remineralised from the sediments may promote algal growth. In order to determine the effect of artificial mixing on algal assemblages, this study compared algal species dominance and physical factors/nutrients in a mechanically mixed water reservoir with two adjacent naturally mixed reservoirs to determine how mixing affects algal assemblages, and the physical factors and nutrients likely to control their growth.

METHODS

The study was conducted at three water reservoirs, North Pine, Somerset and Wivenhoe which are located in subtropical, southeast Queensland, Australia, and provide drinking water to the city of Brisbane and a number of regional towns and cities (1.2 million people). The catchments for these reservoirs are typically unprotected, and are dominated by cattle grazing pasture (>50%), with approximately 20% natural vegetation.

North Pine Reservoir (Lake Samsonvale, 27° 15' S, 152° 55' E) is the smallest of the reservoirs with an area of 21.8 km² and 215,000 ML at full reservoir volume (Table 1, Fig. 1). An artificial destratification system was installed near the reservoir wall and

began operating in 1995. The system is typically switched on in mid-September prior to summer and runs continuously until the end of April each year. The destratification system consists of two diffusers, made of polyethylene pipe, each being approximately 550 m long. Each diffuser discharges at least 47 L s^{-1} air at the depth of the diffuser and was installed 1 m above the sediment surface. Somerset Reservoir ($27^{\circ} 7' \text{ S}$, $152^{\circ} 33' \text{ E}$) has a surface area of 42.1 km^2 and a volume of 380,000 ML when full (Table 1). It is located upstream of Wivenhoe Reservoir ($27^{\circ} 24' \text{ S}$, $152^{\circ} 36' \text{ E}$) which is the largest of the three reservoirs with a surface area of 107.5 km^2 and a full reservoir volume of 1,165,000 ML (Fig. 1). Wivenhoe Reservoir receives input water from controlled releases at Somerset Reservoir as well as unregulated inputs from the Upper Brisbane River. Water residence times were calculated based the reservoir volume divided by the annual discharge. Most of the water discharge occurred on a regular basis for drinking water and hydroelectric supplies, and 1999 and 2001 were the only years with additional overflow water discharge during rain events. Additionally, Somerset Reservoir had one overflow event in 2000. All reservoirs have a similar mean depth (Table 1).

Water samples were collected from four sites up the length of each reservoir (five sites from North Pine Reservoir) fortnightly for phytoplankton counts from July 1997 until June 2003 (Fig. 1). Dissolved nutrients were collected monthly at the site 100 m from the reservoir wall in each reservoir (only from July 1997 to June 2002). A 3 m long hosepipe sampler (5 cm dia.) was used to collect a depth-integrated sample. After mixing in a bucket, a subsample of 250 mL was collected in a polyethylene bottle for phytoplankton counts. 1 mL of 100% Lugols solution was added to give a final concentration of 1%, and samples were stored in the dark until counted. A

subsample of water for nutrients was filtered through a 0.45 µm membrane filter and frozen. Profiles of temperature, conductivity, pH, oxygen and turbidity were also measured through the water column with an automated logger.

In the laboratory, samples were identified to species level where possible under phase-contrast microscopy. Cells were counted by either direct counting or pre-settling, then counting of fixed samples using a Sedgewick Rafter counting chamber. A minimum of 30 fields and 100 algal units were counted to yield a final result of $\pm 20\%$ of the true cell concentration (Lund *et al.*, 1958). Taxonomic identification of cyanobacterial genera can be difficult, particularly for the order Chroococcales (McGregor & Fabbro, 2001). Due to changes in taxonomic naming and resolution for various genera over the period of the study, counts for the following genera were combined: *Aphanocapsa*, *Merismopedia* and *Cyanodictyon*; *Monoraphidium* and *Ankistrodesmus*; *Geitlerinema* and *Limnothrix*. Ammonium, nitrate, phosphate and silicate were analysed using standard colorimetric methods (American Public Health Association, 1995).

An analysis of variance (ANOVA) was performed using SAS software to compare total phytoplankton abundance (log-transformed) in the three reservoirs. All multivariate statistical analyses were performed with PRIMER 5 software (Plymouth, UK, <http://www.primer-e.com/>). An analysis of similarity (ANOSIM) was performed on phytoplankton species composition data (fourth square-root transformed) for the reservoir wall site and for all sites to test whether there were statistical differences across reservoirs. An analysis of similarity (ANOSIM) was also performed on log-transformed surface and bottom dissolved nutrients, surface and bottom temperature,

bottom oxygen and surface mixed layer depth (SML, based on 0.25°C temperature change between 1 m depth intervals) for the reservoir wall site to test whether there were statistical differences across reservoirs.

Mantel's Test was performed to correlate the physical and chemical data with the algal abundance data for each sampling period across the five years, and to test for relationships between multivariate patterns (BIOENV, RELATE).

Mean phytoplankton abundance data for the three reservoirs were also separated into two periods, mid-September to the end of April, when the destratification unit at North Pine Reservoir was on (referred to as the wet summer season), and May to mid-September, when the destratification unit was off (referred to as the dry winter season) for each site. Data for all genera, and genera with mean abundances greater than 1000 cells mL⁻¹ in each reservoir were then averaged over the five years for both individual sites within the reservoir, and for whole reservoirs, and multi-dimensional scaling (MDS) plots were generated using fourth square root-transformed data.

RESULTS

Comparison of algal assemblages in reservoirs

A total of 115 phytoplankton genera/species were identified in the three water reservoirs, however the dominant genera in all reservoirs were cyanobacteria. In North Pine Reservoir, six of the eight most abundant species/genera were cyanobacteria, compared to five of eight for Somerset Reservoir, and five of eight for Wivenhoe (Table 2). These top three most abundant genera/genera groups represented approximately 80% of the total phytoplankton abundance.

Overall, there were no significant differences in total phytoplankton densities among the three reservoirs ($P > 0.05$). When all sampling sites were considered, the phytoplankton species composition was not statistically different between reservoirs. However when only the reservoir wall site was compared, the phytoplankton species composition was statistically different ($P < 0.01$, ANOSIM) in North Pine Reservoir compared with Wivenhoe and Somerset Reservoirs.

The most dominant group was *Aphanocapsa/Merismopedia/Cyanodictyon* in all reservoirs (Table 2). Due to changes in taxonomic resolution over the period of the study it was impossible to differentiate between these genera, however they were all characterised by mucilaginous colonies of small cells. Over the last couple of years of the study, when taxonomic resolution had improved, *Aphanocapsa* was identified as by far the most dominant genus in this group.

The solitary filamentous cyanobacterium, *C. raciborskii* was the second most dominant species in North Pine Reservoir and the third most dominant in Somerset and Wivenhoe. Another solitary filamentous cyanobacterium, *Planktolyngbya*, had a similar abundance. The other cyanobacterial genera with a mean abundance >1000 cells mL^{-1} were *Pseudanabaena*, *Aphanothece* and *Aphanizomenon*, although *Aphanizomenon* was only present at >1000 cells mL^{-1} in North Pine Reservoir.

In addition to the dominant cyanobacterial species, two grouped chlorophyte genera, *Monoraphidium/Ankistrodesmus*, were also present in substantial numbers (Table 2). The diatom *Aulacoseira* was especially abundant in Somerset Reservoir, while

Achnantheidium was abundant in North Pine Reservoir. The chrysophyte, *Chroomonas* was also present at abundances >1000 cells mL⁻¹.

Multidimensional scaling was used to assess the dissimilarity between the dominant genera in each reservoir (Fig. 2). The patterns of association were generally comparable between reservoirs. The *Aphanocapsa/Merismopedia/Cyanodictyon* group was distinctly different from all other genera in all three reservoirs.

C. raciborskii and *Planktolyngbya* had similar patterns, however the other solitary filamentous cyanobacterium, *Pseudanabaena*, did not group with *C. raciborskii* and *Planktolyngbya* in any of the three reservoirs. Groupings were not obviously along taxonomic or functional lines (Reynolds *et al.*, 2002). Somerset Reservoir had less obvious groupings of taxa than the other two reservoirs.

Seasonal and site differences in alga assemblages

The differences in the abundance of the most dominant genera were compared for wet and dry seasons (corresponding with the period that the destratification unit at North Pine Reservoir was on and off), at sites within each reservoir and between reservoirs (Fig. 3). North Pine Reservoir algal assemblages were distinctly different from both Somerset and Wivenhoe Reservoirs; in contrast there was no obvious difference between Somerset and Wivenhoe Reservoirs. Additionally, there were less seasonal differences at all sites in North Pine compared with Wivenhoe and Somerset reservoirs. There was no trend in species assemblages along the upstream transect in each reservoir.

There was a distinct successional pattern of abundance of the most dominant algal genera. The most abundant group of algal genera, *Aphanocapsa/Merismopedia/Cyanodictyon* had a peak in abundance in October in all three reservoirs, although the peak was less pronounced in the artificially mixed reservoir, North Pine Reservoir, than the other two reservoirs (Fig. 4). Both *C. raciborskii* and *Planktolyngbya* reached peak abundances two to three months later than *Aphanocapsa/Merismopedia/Cyanodictyon* in both Somerset and Wivenhoe Reservoirs. In contrast, *C. raciborskii* and *Planktolyngbya* reached peaks in abundance by October in North Pine Reservoir, coinciding with lower peak densities of *Aphanocapsa/Merismopedia/Cyanodictyon* at this time.

Comparison of physical and nutrient data across reservoirs

Dissolved nutrient concentrations were only measured at the reservoir wall sites in all reservoirs (Table 3). Nitrate concentrations were generally higher in the dry season than the wet season while the reverse was true for ammonium, at least in bottom waters. Nitrate and ammonium concentrations were generally higher in the bottom waters than surface waters although the variability was high. Phosphate concentrations were near the limits of detection ($>0.06 \mu\text{M}$) but higher in summer months in Wivenhoe and Somerset Reservoirs than in North Pine Reservoir. Oxygen levels in bottom waters were lower in the wet season than the dry season in all reservoirs, with a high variability within seasons. Water temperatures were similar in all reservoirs, while the depth of the surface mixed layer (SML) was greater in North Pine Reservoir in the wet season when the destratification unit was operating than the other two reservoirs. However, the SML was highly variable in all reservoirs.

The physical and chemical parameters significantly correlated ($P < 0.05$) with algal species assemblages at North Pine Reservoir were; surface and bottom temperature, surface and bottom nitrate and surface mixed layer although the correlation coefficient for all parameters was relatively low ($r = 0.40$) (Table 4). In Somerset Reservoir, surface and bottom temperature, dissolved oxygen, surface and bottom nitrate, surface phosphate and surface mixed layer depth were significantly correlated ($P < 0.005$) with algal species assemblages (overall $r = 0.76$). In Wivenhoe Reservoir, surface and bottom temperature, surface and bottom phosphate and surface nitrate were significantly correlated ($P < 0.005$) with algal species assemblages (overall $r = 0.82$).

DISCUSSION

Despite the presence of a destratification unit in North Pine Reservoir, the algal species assemblages and total cell abundances were similar to the two adjacent, naturally-mixed reservoirs, Wivenhoe and Somerset. Cyanobacteria was the dominant algal group, with only four genera/groups contributing $> 80\%$ of the total cell densities. The three dominant genera were both solitary filamentous forms (*C. raciborskii*, *Planktolyngbya*, *Pseudanabaena*) and colonial coccoid forms (*Aphanocapsa*/*Merismopedia*/*Cyanodictyon*). The dominance of these genera in this environment is consistent with the functional groups of freshwater phytoplankton typically found in warm, eutrophic lakes and reservoirs (Reynolds *et al.*, 2002). *Aphanothece*, *Aphanizomenon* and the *Aphanocapsa*/*Merismopedia*/*Cyanodictyon* group are within the K and L groups, according to Reynolds *et al.* (2002), i.e. preferring eutrophic waters with a summer epilimnium. *C. raciborskii* and *Planktolyngbya* are within the S functional group, i.e. preferring warm mixed layers.

Although these functional groupings were developed for temperate systems, Huszar *et al.* (2000) found that the groupings were still valid for tropical lakes.

C. raciborskii is a dominant cyanobacterial species in many tropical and subtropical reservoirs throughout the world, including Australia (Padisák, 1997; McGregor & Fabbro, 2000). Dominance of *Planktolyngbya* and *C. raciborskii*, along with *Aphanizomenon* and *Pseudanabaena* species, was also found in a large river impoundment in semi-arid Australia during periods of higher temperature, stratification and depletion of nutrients (Fabbro & Duivenvoorden, 2000).

There were differences in the successional patterns in abundance of the dominant genera between the naturally and artificially mixed reservoirs. Both *C. raciborskii* and *Planktolyngbya* reached peak abundances earlier in North Pine Reservoir than the other two reservoirs, coinciding with a lower *Aphanocapsa/Merismopedia/Cyanodictyon* abundance in North Pine Reservoir compared with the other two reservoirs. This period was within a month or so of the destratification unit being switched on in North Pine Reservoir each year, and suggests that it may have created conditions conducive to *C. raciborskii* and *Planktolyngbya* outcompeting the colonial genera *Aphanocapsa/Merismopedia/Cyanodictyon*. The two solitary filamentous genera, *C. raciborskii* and *Planktolyngbya*, were also shown to be more closely associated with each other than the colonial genera, *Aphanocapsa/Merismopedia/Cyanodictyon* in the similarity analysis. The effect of destratification is likely to be greater on colonial species that regulate buoyancy than solitary filamentous species. Other studies have shown that the colonial genus, *Microcystis* can be controlled using

artificial mixing (Visser *et al.*, 1996) although a comparison of *Microcystis* densities in North Pine Reservoir pre- and post destratification showed an increase, rather than a decrease in *Microcystis* (Antenucci *et al.*, 2005). Solitary filamentous species such as *C. raciborskii*, which are typically adapted to low light conditions (Shafik *et al.*, 2001) are less likely to be affected by the reduction in light availability due to mixing.

A key difference between the artificially and naturally mixed reservoirs was the correlation of algal assemblage with phosphate concentrations in the naturally mixed reservoirs. Phosphate is commonly the limiting nutrient for algae in freshwater reservoirs (Oliver & Ganf, 2000), and concentrations were low in the surface waters in all three reservoirs, although generally lowest in North Pine Reservoir. The lack of correlation in North Pine Reservoir may have two possible explanations: the result of destratification increasing the availability of remineralised phosphate in the sediment; or that mixing effectively decreased phosphate remineralisation in the sediment and the low phosphate concentrations in North Pine Reservoir promoted species capable of efficient phosphate utilisation and a high storage capacity for phosphorus. The first hypothesis is unlikely as a study taken during a one week period after commencement of destratification did not show any increase in phosphate in the surface waters or commensurate decrease in the bottom waters due to mixing (A. Posselt, pers. comm.).

Little is known of the capacity of the *Aphanocapsa/Merismopedia/Cyanodictyon* group or *Planktolyngbya* to store or utilise phosphate under low concentrations, however *C. raciborskii* is known to have a rapid uptake capacity for phosphate and is able to store phosphorus intracellularly for extended periods (Istvánovics *et al.*, 2000). Additionally, *C. raciborskii* is pre-adapted to low light conditions (Shafik *et al.*,

2001). The mean SML depth in North Pine Reservoir during the wet season, when the destratification unit was operating, was lower than that for Wivenhoe and Somerset Reservoirs. Although data on euphotic depths were not available for the study period, the euphotic depths for North Pine, Somerset and Wivenhoe Reservoirs in subsequent years (2003-2005) were 3.1 ± 0.6 m ($n = 31$), 3.0 ± 0.6 m ($n = 17$) and 3.8 ± 0.6 m ($n = 16$), respectively (O'Donohue, unpublished data). These euphotic depths are comparable with the summer SML depths for Wivenhoe and Somerset Reservoirs (2.8 ± 6.7 m and 2.6 ± 5.7 m, respectively), but less than that for North Pine Reservoir (10.4 ± 9.6 m). Despite the high variability in the SML depth values, these results suggest that phytoplankton in North Pine Reservoir are more likely to be light limited than those in Somerset and Wivenhoe Reservoirs. The combination of lower light availability and the ability to rapidly utilise phosphate during artificial mixing may therefore explain the competitive advantage that *C. raciborskii* gained in North Pine Reservoir.

Antenucci *et al.* (2005) in a study of North Pine Reservoir pre- and post-destratification installation have suggested that the dominance of *C. raciborskii* in North Pine Reservoir post-destratification was due to its ability to compete for light, as it has superior shade tolerance while low phosphorus availability was likely to play a more important role in promoting *C. raciborskii* prior to the destratification unit being installed. Based on the findings of the current study, a more likely scenario is that it is the interplay of low light and phosphate availability as a result of artificial mixing that is affecting *C. raciborskii* dominance.

The relatively high dissolved inorganic nitrogen (DIN) concentrations ($> 2.3 \mu\text{M}$) and high DIN:dissolved inorganic phosphorus molar ratios (42-53:1) in all three reservoirs suggests that phytoplankton are not nitrogen limited. This may explain why the non nitrogen-fixing colonial genera, *Aphanocapsa*/*Merismopedia*/*Cyanodictyon*, were dominating. *C. raciborskii* is capable of nitrogen fixation but grows more rapidly on DIN sources (Spröber *et al.*, 2003). The correlation between algal assemblages and nitrate concentrations in all three reservoirs may not, therefore, suggest causation.

In conclusion, the artificially mixed North Pine Reservoir reservoir did not have major differences in algal species assemblages compared with two adjacent naturally-mixed reservoirs. The main differences were on the timing and magnitude of spring and summer blooms of individual species, possibly due to competition for resources. Destratification increased mixing giving a competitive advantage to species such as *C. raciborskii* that are pre-adapted to low light conditions and rapidly assimilating and storing low phosphate concentrations. Further work is needed to understand the physiology and ecology of the most dominant colonial genus, *Aphanocapsa*, particularly as it relates to competition with toxic species, such as *C. raciborskii*.

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Figure legend:

Figure 1: Map of the three water reservoirs, North Pine, Somerset and Wivenhoe Reservoirs in southeast Queensland, Australia.

Figure 2: Multidimensional scaling (MDS) plots of the associations between genera within the three water reservoirs, North Pine, Somerset and Wivenhoe Reservoirs. Aph/Meri/Cyanod = *Aphanocapsa*/*Merismopedia*/*Cyanodictyon*. Ellipses show the genera most tightly grouped.

Figure 3: Multidimensional scaling (MDS) plot comparing the similarity of species dominance between sites, seasons and reservoirs. Ellipses show the reservoirs and seasons most closely grouped.

Figure 4: Mean (+ SD) cell density (cells mL⁻¹) for the three dominant phytoplankton genera/groupings averaged for each month of the year, from 1997 to 2003, for North Pine, Somerset and Wivenhoe Reservoirs.

Table 1: Physical attributes of the three water reservoirs, North Pine, Somerset and Wivenhoe.

Parameter	North Pine	Somerset	Wivenhoe
Reservoir area (km ²)	21.8	42.1	107.5
Full reservoir volume (ML)	215,000	380,000	1,165,000
Water residence time (y)	2	10	20
Mean depth (m)	10	9	11
Maximum depth (m) at:			
site 1	35	39	44
site 2	23	25	25
site 3	18	23	26
site 4	18	16	24
site 5	12	-	-
Catchment area (km ²)	347	1330	7020

Table 2: Mean (\pm SD) abundance (cells mL⁻¹) of the most abundant algal genera in the three water reservoirs. Only genera with cell counts >1000 mL⁻¹ for at least one reservoir are included. CYAN = cyanobacteria, CHLO = chlorophyte, CHRYS = chrysophyte, DIAT = diatom. Functional groups according to Reynolds *et al.* (2002) are given in brackets.

Genus	North Pine	Somerset	Wivenhoe
<i>Aphanocapsa/Merismopedia/</i>	59300 \pm 48800	55900 \pm 89900	45300 \pm 59300
<i>Cyanodictyon</i> (CYAN) (K, L _o , L _m)			
<i>Cylindrospermopsis raciborskii</i> (CYAN) (S _n)	28000 \pm 23700	8000 \pm 35500	18700 \pm 44900
<i>Planktolyngbya</i> (CYAN) (S _i)	15400 \pm 14900	15800 \pm 58600	19000 \pm 46800
<i>Monoraphidium/</i>	4700 \pm 13900	3900 \pm 17900	6400 \pm 83700
<i>Ankistrodesmus</i> (CHLO) (X _i , S _i)			
<i>Pseudanabaena</i> (CYAN) (S _i)	3800 \pm 5600	1800 \pm 9900	4900 \pm 11600
<i>Aphanothece</i> (CYAN) (K)	1930 \pm 5500	1500 \pm 28700	2400 \pm 12400
<i>Microcystis</i> (CYAN) (L _M)	3000 \pm 4900	700 \pm 1200	600 \pm 3000
<i>Aphanizomenon</i> (CYAN) (H _i)	2400 \pm 6200	300 \pm 1800	700 \pm 2900
<i>Achnantheidium</i> (DIAT)	1750 \pm 4100	100 \pm 900	200 \pm 700
<i>Chroomonas</i> (CHRYS) (Y)	800 \pm 600	1400 \pm 1600	1000 \pm 900
<i>Aulacoseira</i> (DIAT) (C)	400 \pm 400	1600 \pm 2200	600 \pm 1100

Table 3: Mean physical and chemical data (\pm SD) for the wet and dry seasons in North Pine, Somerset and Wivenhoe Reservoirs. Only data from reservoir wall sites in each reservoir is given. Cond. = conductivity

Parameter	Depth	North Pine		Somerset		Wivenhoe	
		Wet	Dry	Wet	Dry	Wet	Dry
Ammonium ($\mu\text{M N}$)	Surface	1.5 ± 1.8	1.4 ± 1.1	1.3 ± 1.3	1.4 ± 1.1	0.8 ± 0.4	0.8 ± 0.3
	Bottom	3.6 ± 3.5	2.2 ± 1.7	10.3 ± 12.7	1.8 ± 1.8	2.1 ± 4.2	1.0 ± 0.2
Nitrate ($\mu\text{M N}$)	Surface	3.3 ± 3.8	4.1 ± 2.6	1.8 ± 3.2	6.3 ± 1.4	1.6 ± 2.9	6.4 ± 4.0
	Bottom	6.6 ± 4.6	5.8 ± 3.4	4.6 ± 4.6	6.4 ± 3.6	5.4 ± 5.3	8.7 ± 4.9
Phosphate ($\mu\text{M P}$)	Surface	0.10 ± 0.19	0.10 ± 0.06	0.16 ± 0.16	0.13 ± 0.10	0.16 ± 0.26	0.19 ± 0.13
	Bottom	0.13 ± 0.10	0.13 ± 0.19	0.39 ± 0.32	0.16 ± 0.10	0.35 ± 0.42	0.29 ± 0.32
Silicate ($\mu\text{M Si}$)	Surface	32.0 ± 27.9	29.9 ± 27.0	76.3 ± 26.3	69.0 ± 26.7	72.2 ± 28.5	77.0 ± 35.9
	Bottom	37.6 ± 31.2	32.7 ± 28.6	86.1 ± 36.2	72.0 ± 28.9	81.1 ± 32.8	85.1 ± 34.0
Oxygen (mg L^{-1})	Bottom	3.18 ± 2.50	7.41 ± 0.95	1.38 ± 1.77	6.60 ± 0.73	3.35 ± 3.16	6.35 ± 2.06
Water temp ($^{\circ}\text{C}$)	Surface	24.85 ± 2.38	18.63 ± 1.94	21.79 ± 2.14	18.14 ± 1.54	26.52 ± 2.83	18.95 ± 1.81
	Bottom	23.12 ± 2.93	17.87 ± 1.94	21.79 ± 2.14	17.58 ± 1.98	20.11 ± 2.62	19.12 ± 2.56
Cond. (ms cm^{-1})	Surface	0.18 ± 0.03	0.19 ± 0.03	0.22 ± 0.03	0.21 ± 0.05	0.29 ± 0.05	0.32 ± 0.12
Surface mixed depth (m)		10.4 ± 9.6	12.4 ± 10.0	2.8 ± 6.7	12.9 ± 12.3	2.6 ± 5.7	15.0 ± 12.3
Mean monthly Rainfall (mm)		112 ± 78	52 ± 41	93 ± 82	48 ± 42	75 ± 50	34 ± 26

Table 4: Physical and chemical parameters significantly correlated (* $P < 0.05$) with algal assemblages in the three reservoirs, North Pine, Somerset and Wivenhoe

Reservoirs. ns = not significant

Parameter	North Pine	Somerset	Wivenhoe
Temperature			
Surface	*	*	*
Bottom	*	*	*
SML depth		*	*
ns			
Nitrate			
Surface	*	*	ns
Bottom	*	*	ns
Phosphate			
Surface	ns	*	*
Bottom	ns	ns	*
Ammonium			
Surface	ns	ns	ns
Bottom	ns	ns	ns
Dissolved oxygen			
Bottom	ns	*	ns

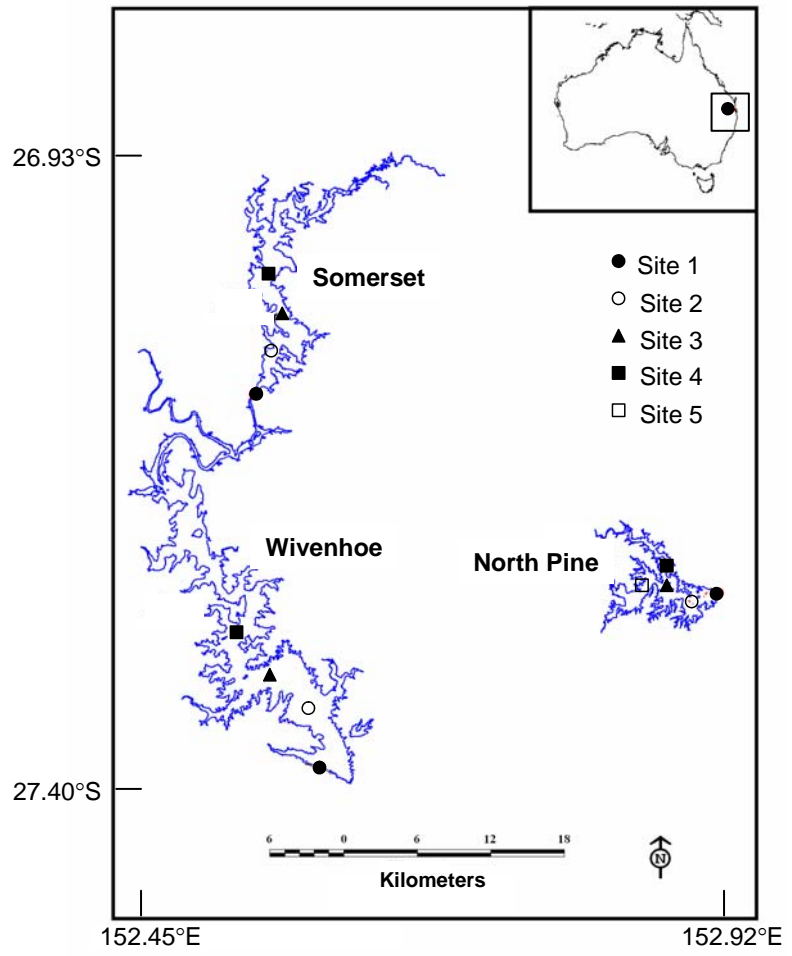


Fig. 1

Fig. 2

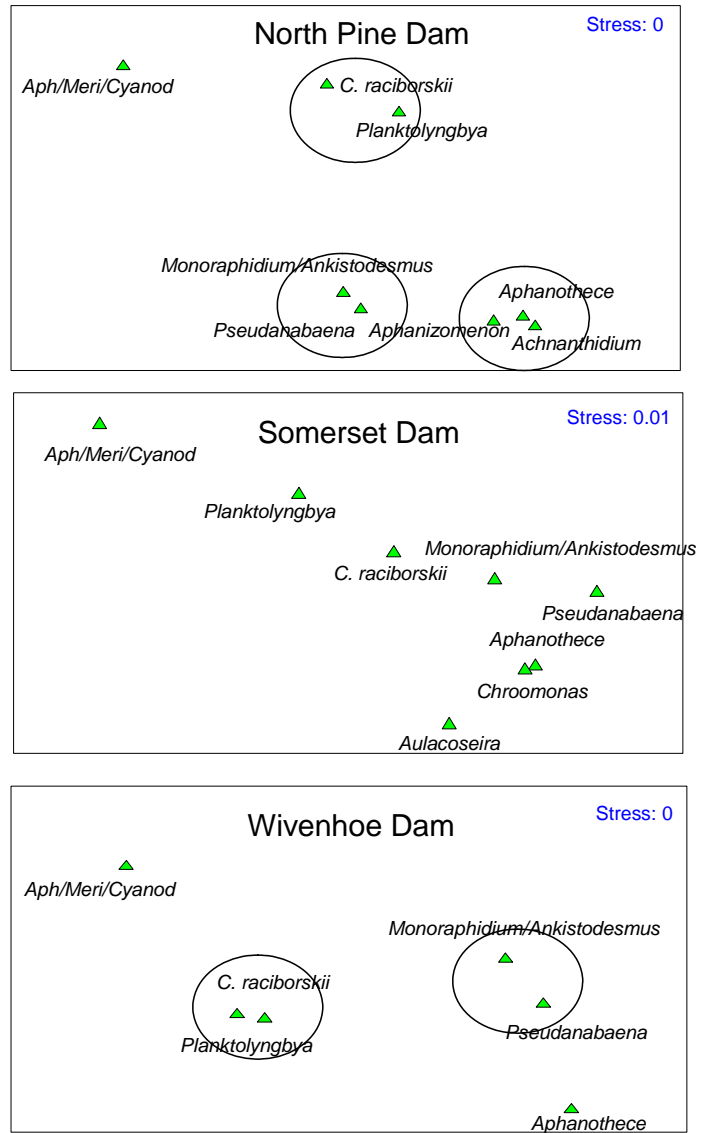
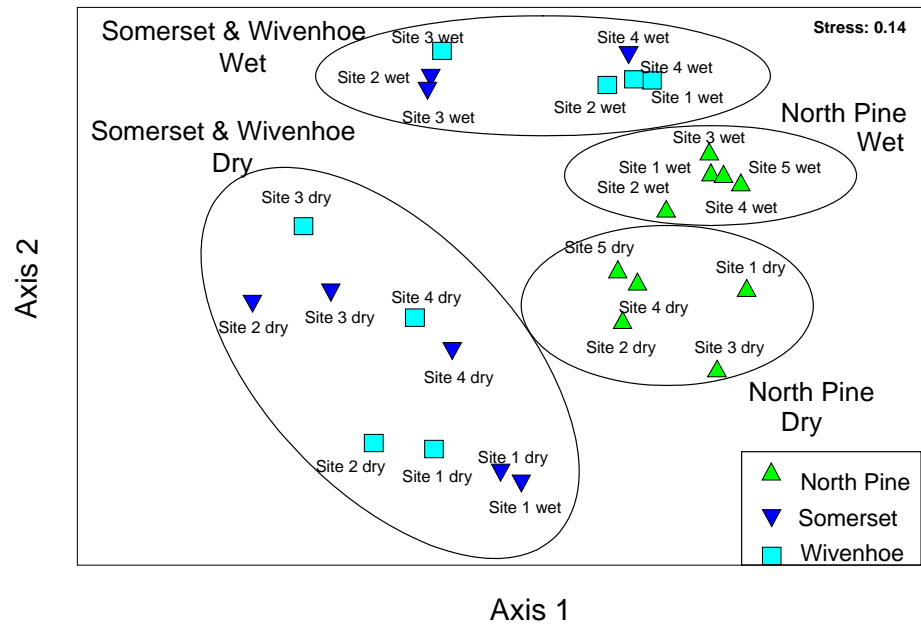


Fig. 3



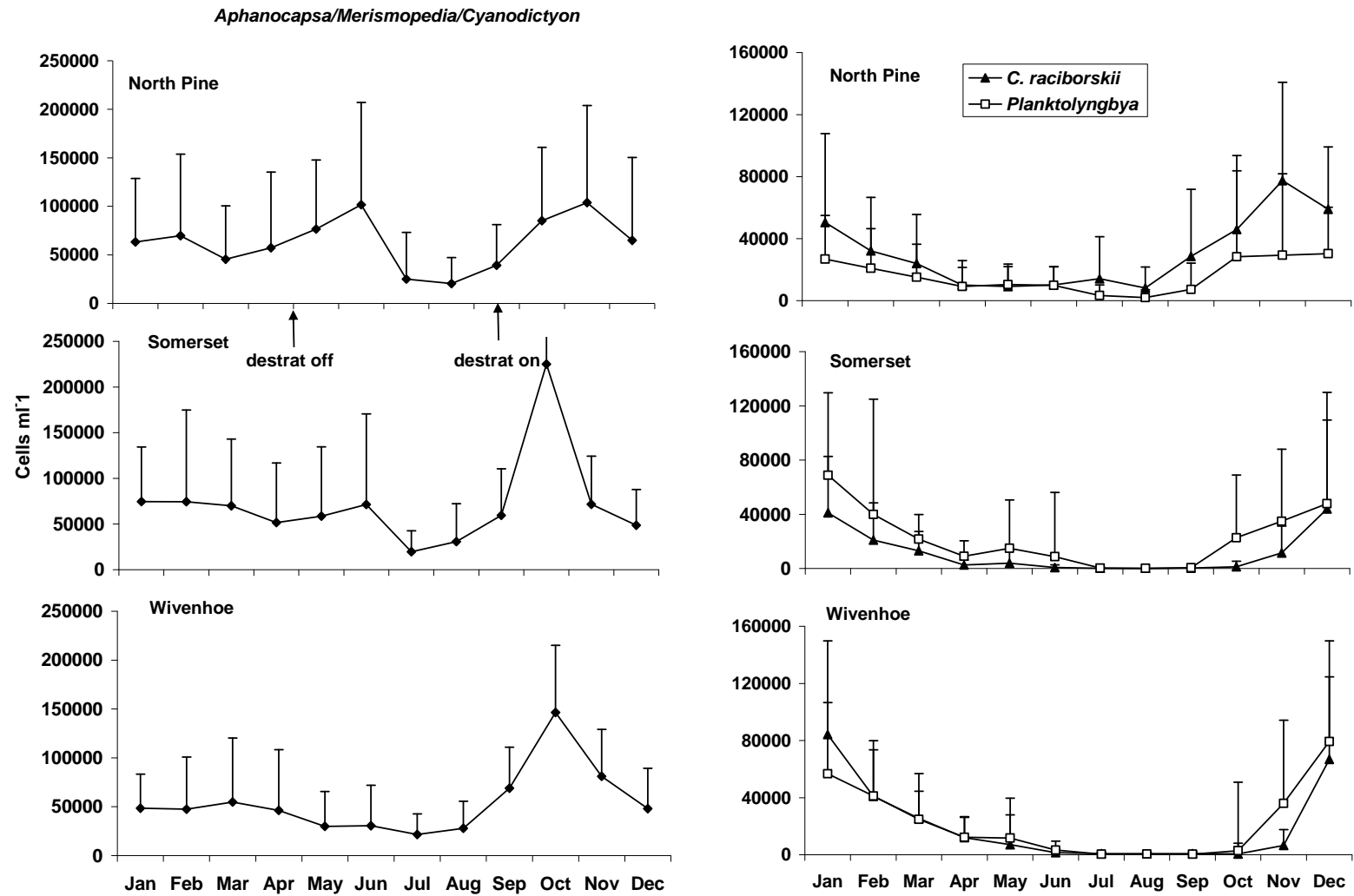


Fig. 4