Research Report 7

The Euston Lakes

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Final Report to MDBC

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Report Linkages

This individual Research Report forms a component of the larger report:

McCarthy, B., Gawne, B., Meredith, S., Roberts, J. and Williams, D. (2004). Effects of Weirs in the Mallee Tract of the River Murray. Murray-Darling Freshwater Research Centre, Mildura. Report to the Murray-Darling Basin Commission, Canberra.

Introduction

Background

The Euston Lakes system lies adjacent to the Euston weir pool, and two of its historically ephemeral lakes (Lake Benanee and Dry Lake) have become permanently inundated from the elevated river levels. The proposed drawdown of the Euston weir pool would result in water level decreases in these lakes, and hence they were selected for investigation into wetland response to drawdown. Given that a weir pool drawdown did not occur during the period of investigation, this Research Report provides baseline data relating to the ecology of the lakes in addition to examining the relationships between various parameters over the two-year study period.

Site Description

The Euston Lakes system is located ca. 10km east of the Euston (NSW) and Robinvale (Vic) townships in southwest NSW. It is situated on the River Murray floodplain and comprises 3 lakes – Lake Benanee (748 ha), Dry Lake (589 ha) and Lake Caringay (treeless inner portion 317 ha) - that connect to the River Murray via Taila, Washpen and Caringay Creeks (Figure 1A). The system also includes the floodplain areas surrounding each lake as well as a region of floodplain located between the lakes and the River Murray that contains numerous wetland basins and channels totalling 555 ha (Lloyd, 1996). Other characteristics of the lakes are presented in Research Report 8.

Hydrology – Past and Present

The hydrology of the Euston Lakes system has changed since the construction of the Euston weir in 1937. Prior to this time the Euston lakes only received significant inflows during winter-spring floods in the River Murray. Water entered Caringay Creek and the lakes would have filled from east to west with considerable overland flows during larger floods (Lloyd, 1996). Upon flood recession the lakes would drain to varying extents, and residual pools of water would remain in Lake Caringay (0.5 m) and Lake Benanee (1.5 m) where they would evaporate over the following summer (Lloyd, 1996). Dry Lake would drain almost completely upon flood recession with some small pools (0.5 m depth) remaining where Taila Creek crossed the lakebed (Lloyd, 1996).

The completion of the Euston weir in 1937 elevated water levels an additional 4.75 m (42.85 mAHD to 47.60 mAHD at a base flow of 4,000 $ML.d^{-1}$) upstream of the weir and altered the hydrology of the lakes and the riverine environment. The elevated weir pool extends ca. 50 river km upstream before the river becomes free-flowing again. The inlet to Taila Creek is located 14 km upstream of the weir and has become permanently inundated given that its sill is lower than the 47.60 mAHD weir pool level. This has resulted in the permanent inundation of Dry Lake and Lake Benanee. Water levels in the lakes currently rise during flood periods but remain at the base pool level following flood recession. Hence, the lakes no longer undergo a seasonal drying phase. For Lake Caringay, the construction of levee banks on Caringay Creek and a branch of Washpen Creek in 1960 has prevented that lake receiving inflows and allowed horticultural development on the lakebed.

During in-channel floods, the pattern of flooding is largely from west to east. Inflows enter Taila Creek and flow into Dry Lake and then the terminal Lake Benanee via an additional section of Taila Creek (Figure 1).

These hydrologic changes have modified significantly the regional groundwater system of the Euston Lakes area. Groundwater levels around the lakes have risen as a result of the elevated river levels and permanent inundation of Dry Lake and Lake Benanee since 1937 (Williams, 2000; Salotti and Williams, 1996). Groundwater levels around Lake Caringay are currently higher than its lakebed (Williams, 2000).

Ecological Impacts

The permanent inundation of Dry Lake resulted in the death of the extensive River Red Gum forest covering the lake area (590 ha), the remnants of which remain today. For Lake Benanee, a band of River Red Gum trees located along the margin of the lake died after being permanently inundated, and the remnants indicate the previous bank line of the lake. The River Red Gum and black box trees surrounding each of these lakes are located above the water line and are considered to be in moderate to good health due to the floodwaters they continue to receive (King, 1996). In contrast, most of the River Red Gum and black box trees along the foreshore of Lake Caringay have died or were close to death as of 1996 as a result of floodwater exclusion since 1960. It was predicted at that time that the remaining living trees would be dead within 10-15 years if water continued to be prevented from entering the lake (King, 1996).

The loss of the wetting and drying cycles in all lakes of the Euston Lakes system through different aspects of river regulation has come at an ecological cost to the wetlands. These cycles drive the food webs and ecological processes of ephemeral wetlands (e.g. Qiu and McComb, 1995, 1996; Boulton and Jenkins, 1998). Natural ephemeral systems that receive a flood pulse typically receive nutrient-rich floodwaters and the previously dried wetland sediments and established terrestrial vegetation further contribute nutrients to the water column (Baldwin and Mitchell, 2000). The high nutrient loads result in increased primary production and a trophic cascade of energy through the different trophic levels. Bacteria and algae utilise the nutrients and sunlight to fix atmospheric carbon and make it available to higher consumers such as zooplankton and macroinvertebrates, and ultimately fish and birds. Flooding provides important cues for many species such as fish, and also provides appropriate conditions for invertebrate emergence from dormant egg banks in the lakebed sediments and the germination of the seed banks.

A public discussion paper by Lloyd (1996) on the operation and management of the Euston Lakes system highlighted some of the ecological changes that the lakes have undergone as witnessed by landowners surrounding the lakes. Lake Benanee remained an important breeding site for Golden Perch (*Macquaria ambigua*) until the 1970s when Common Carp (*Cyprinus carpio*) became established in the lakes. The proliferation of Common Carp in the lakes since this time is believed to have resulted in the loss of ribbonweed beds from both Lake Benanee and Dry Lake, and an increase in lake turbidity. These changes also coincided with a loss of nesting sites for black and pied cormorants and black swans in the mid-1970s (Lloyd, 1996).

Objectives

1. To obtain baseline ecological data on surface water chemistry, phytoplankton and zooplankton in Lake Benanee and Dry Lake.

2. To examine the relationships between the parameters and subjects examined.

Methods

Site Selection

Three sampling sites were selected at Dry Lake and Lake Benanee based on accessibility and maximising the spatial coverage of the each lake (Figure 1B). Each site was sampled on 14 occasions from 1/8/01 – 16/6/03.

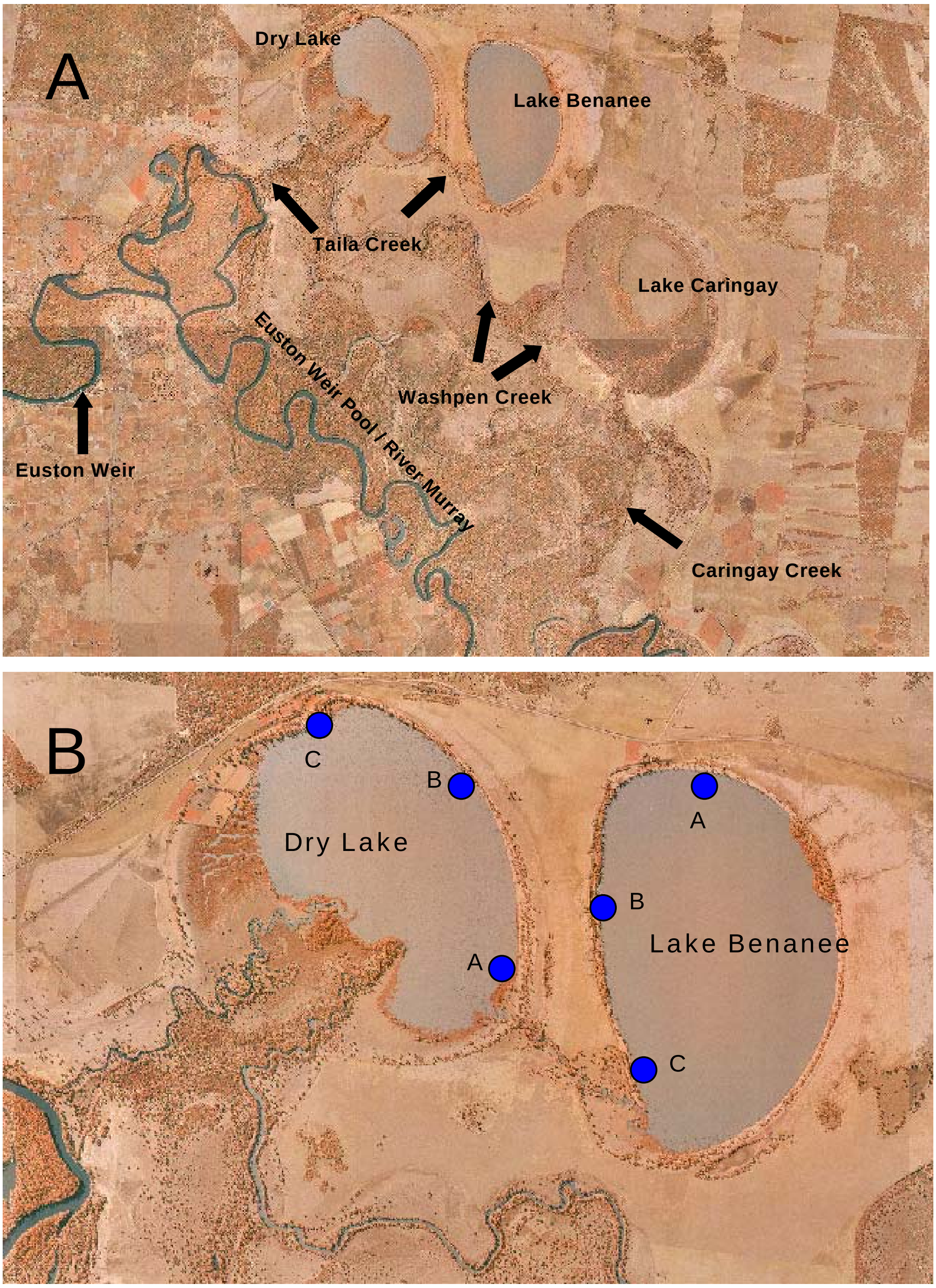


Figure 1. Infrared aerial orthophoto showing (A) Overview of the Euston Lakes system highlighting the position of Lake Benanee and Dry Lake relative to the creek system and Euston weir and weir pool, and (B) details of Lake Benanee, Dry Lake and the sampling sites. Source: River Murray Mapping (MDBC 2nd edition).

Physical Attributes

Physical attributes of the Euston Lakes system (e.g. lake area, perimeter length) were measured from the River Murray Mapping series (MDBC, 2nd Edition) with ArcView GIS 3.2 software. The Bureau of Meteorology provided wind run data (Mildura weather station) for the study period.

Water Physico-Chemistry, Phytoplankton and Sediments

Electrical conductivity ($\mu S.cm^{-1}$@25^{o}C), turbidity (NTU), temperature (^{o}C), dissolved oxygen ($mg.L^{-1}$) and pH were measured *in situ* at each lake site with a Horiba U-10 Water Quality Checker (Australian Scientific) at a depth of 0.1 m. A 10 L water sample was collected and samples taken for total suspended solids, phytoplankton chlorophyll, phytoplankton species identification, total nitrogen, total phosphorus, oxides of nitrogen, filterable reactive phosphorus and ammonia (from 9/4/02). Sediment samples were collected as a core to 5 cm sediment depth. The phytoplankton communities from 5/8/02-16/6/03 (four sampling occasions) were identified as detailed in Research Report 3. Further details relating to sample processing and methods of analysis are presented in Research Reports 2 and 3.

Water level was measured relative to a fixed point at Site C in Lake Benanee and Site B in Dry Lake (Figure 1B).

Zooplankton

Zooplankton were collected from the open water at each site by filtering 80 L (3 sub samples) of water through a 50 µm plankton net and preserving the zooplankton in 70% ethanol. Microcrustacea were typically identified and counted by emptying the sample contents into a 36-quadrat dish and examining six quadrats. Fewer quadrats were counted on occasion when microcrustacea abundances were high. Rotifers were identified and counted by examining five 0.02 mL transects of a Sedgwick Rafter Cell (1 mL). In each case counts were adjusted to represent individuals per litre of lake water. The zooplankton communities from 5/8/02–16/6/03 (four sampling occasions) are presented.

Zooplankton were identified to genus or species level where possible using the keys listed in Hawking (2000); particularly Bayly (1992), Smirnov and Timms (1983) and Shiel (1995).

Community Analysis

Multivariate analysis of the community data (phytoplankton and zooplankton) was conducted with PC-Ord (MjM Software, v4.27). The community data set was fourth root transformed to reduce the influence of abundant taxa. Outliers were occasionally identified with the Sorensen (Bray-Curtis) distance measure as being >2 standard deviations from the mean but none were deleted due to the results being consistent across sites for that time period and the outliers being within 2.5 standard deviations of the mean. The Sorensen distance measure was used in the ordination and classification analyses because it is robust and particularly suited to community data sets (both abundance and presence/absence) (Faith *et al*., 1987).

Ordinations were generated with non-metric multi-dimensional scaling (NMDS). The output with the minimum number of axes was selected for an acceptable stress level (<20%). Multi-response permutation procedure was used to statistically test whether defined groups contained significantly different species compositions.

Results

Physical Attributes

A summary of some of the physical attributes of the Euston Lakes system is presented in Table 1.

Table 1. Physical attributes of the Euston Lakes system.

Wetland	Area (ha)	Perimeter (km)	Length (km)	Width (m)
Dry Lake (inc. western mudflats)	589	20.03	N/A	N/A
Lake Benanee	748	10.62	N/A	N/A
Lake Caringay (inner portion)	317	6.67	N/A	N/A
Lake Caringay (inc. floodplain)	1506	14.09	N/A	N/A
Taila Ck (R.Murray-Dry L.)	21.7	N/A	6.2	30-40
Taila Ck. (Dry L.–L.Benanee)	8.7	N/A	2.6	25-35
Caringay Ck (R.Murray-L.Caringay)	-	N/A	13.3	20
Washpen Ck (L. Caringay-Dry L.)	-	N/A	14.2	40

Water Level and Physico-Chemistry

Water levels in each lake varied within a 0.46 m range over the study period (1/8/01 - 16/6/03) (Figure 2). For Lake Benanee water levels were referenced to the sill level of 47.08 mAHD recorded by SKM (in prep.) (assumes that the highest point of the sill was measured by both parties). For Dry Lake the water level was adjusted to best estimate the referenced mAHD gauge at the Euston weir. For the four months prior to the first sampling occasion on 1/8/01 the Euston weir pool remained within the range of 47.55-47.66 mAHD with a mean level of 47.59 mAHD. We therefore assumed a constant river and lake water level at this time and referenced the first data point of Dry Lake as 47.60 mAHD (estimate only). The close matching of the weir pool and Dry Lake water levels (Figure 2) suggests a strong hydraulic connection between the two.

The Euston weir pool underwent several small drawdowns over the study period; the largest in February 2002 lowered 0.31 m in response to water releases from the weir pool to satisfy downstream irrigation demands. Water levels in Dry Lake responded rapidly to changes in river water level compared to Lake Benanee. In the latter, a clear summer-autumn decrease in water level was evident relative to river levels, demonstrating a constriction of flow along the section of Taila Creek joining the two lakes. This pattern was observed in the absence of river level change in summer-autumn 2002-3, demonstrating that losses from Lake Benanee arising from evaporation, seepage and extraction had exceeded inflows during the summer-autumn periods. Water in the inlet channel is ca. 0.5 m deep and the channel is dominated by emergent macrophytes (*Typha* sp.) that restrict the rate of inflow. This was particularly evident in the summer-autumn period of 2001-02 when the Euston weir pool drawdown of 0.31 m had the effect of further reducing inflows into Lake Benanee, and a considerable drawdown of the lake occurred.

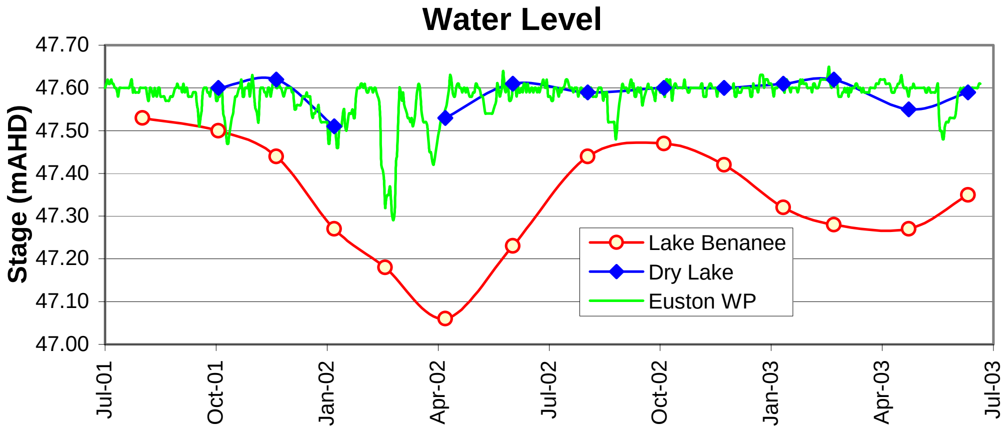


Figure 2. Water levels of Lake Benanee, Dry Lake and the Euston weir pool, August 2001-June 2003. Note that Lake Benanee and the weir pool site are referenced to mAHD and the Dry Lake site is an estimated stage only. The missing data point for Dry Lake in February 2002 was due to the lake being dry at the gauge.

Sill Level on Taila Creek

A natural sill was noted in Taila Creek (near Lake Benanee) on 18/2/02 during the 0.31 m drawdown of the Euston weir pool. At this time water was flowing very slowly along Taila Creek into Lake Benanee (Dry Lake remained connected with both Lake Benanee and the river) and much of the creek bed was no longer submerged. At one location the deepest point along a perpendicular transect of Taila Creek was 0.10 m. SKM (in prep.) measured this sill as 47.08 mAHD, and we referenced the water level of Lake Benanee to this point (Figure 2). Based on the SKM (in prep.) sill level of 47.08 mAHD, a large amplitude drawdown of the Euston weir pool (47.60 mAHD) would reduce water levels in Lake Benanee by a maximum of 0.52 m (less if the water level in the lake is lower than 47.60m AHD as was the case throughout this study). Evaporation, seepage and extraction would reduce levels further after this time in the absence of inflows.

Large sections of the lakebed of Dry Lake were also exposed on 18/2/02 as a result of the 0.31 m drawdown of the Euston weir pool. This is consistent with the shallow (0.5 m) character of the wetland and the observations that it predominately drains upon flood recession. The observation that flows continued into Lake Benanee at this time provides evidence that Dry Lake remained connected with the Euston weir pool during a 0.31m drawdown of the Euston weir pool despite its contraction in surface area.

Electrical Conductivity

Electrical conductivity (EC) in the two lakes consistently exceeded river EC, particularly for the terminal Lake Benanee (Figure 3). The Euston weir pool site has been included as a reference to assist in the interpretation of lake dynamics. Electrical conductivity generally increased in Lake Benanee during the study period from 748 to 1194 µS.cm^{-1} (mean increase of 0.6 uS.cm^{-1} per day for entire study period), whereas levels in Dry Lake tended to decrease, remaining in the range of 170-460 µS.cm^{-1} (Figure 3). EC levels in Lake Benanee increased mostly during the summer-autumn period when temperatures were high and evapo-concentration greatest, with restricted inflows occurring at this time. When water levels increased during winter, however, the lower EC inflows temporarily reduced salt concentrations within the lake. In contrast, EC levels decreased progressively in Dry Lake from December 2001 to June 2003. This pattern was also reflected in the Euston weir pool, suggesting that greater proportions of the riverine flows had been sourced from less saline upstream water storages, rather than tributary inputs, as a result of the drought.

The 0.31m drawdown of the Euston weir pool in February 2002 did not create any outflows from Lake Benanee and therefore did not provide any reduction in electrical conductivity through flushing. Electrical conductivity actually increased at this time due to evapo-concentration of salts and a reduction in low-EC inflows. The larger error bars in Lake Benanee (Figure 3) reflect those times where the site closest to the Taila Creek inlet (Site C) recorded a lower EC due to recent inflows.

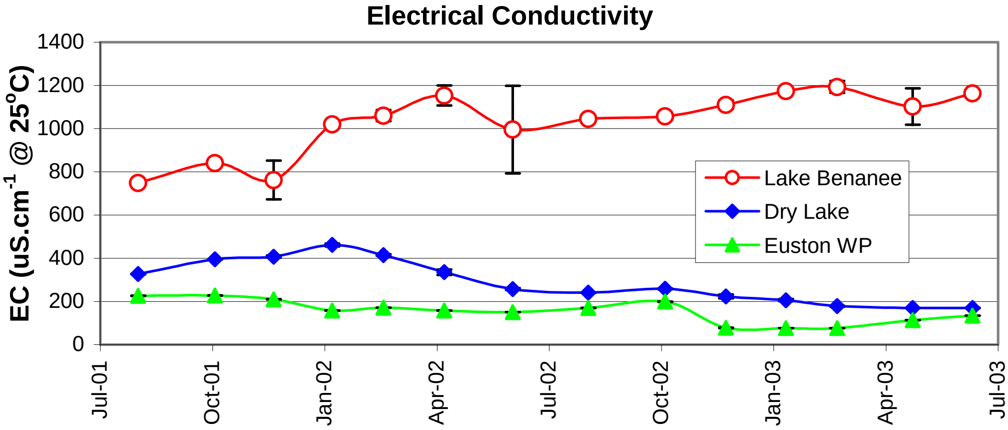


Figure 3. Mean electrical conductivity (uS.cm^{-1}@25°C) in Lake Benanee, Dry Lake and the Euston weir pool, August 2001-June 2003. Error bars = ± 1 S.E.

Turbidity

Water turbidity was greatest and most variable in the shallow Dry Lake, ranging from 175-940 NTU over the study period. In the deeper Lake Benanee, turbidity ranged from 94-352 NTU (Figure 4).

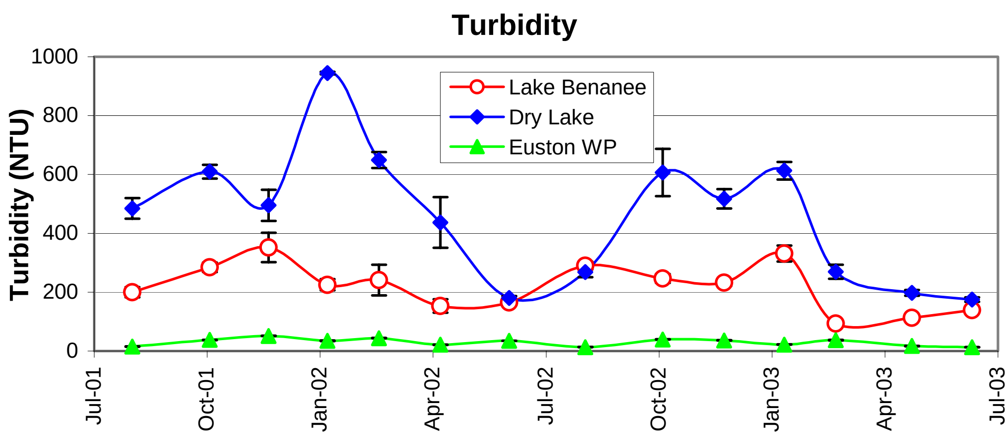


Figure 4. Mean turbidity in Lake Benanee, Dry Lake and the Euston weir pool, August 2001-June 2003. Error bars = ± 1 S.E.

Lake turbidity was largely wind driven, particularly for the shallow Dry Lake (Figure 5). Turbidity was correlated with the 2 m wind run for Mildura. This is the closest Bureau of Meteorology station to the Euston Lakes that measures wind run, and it is assumed that conditions at Mildura on a given day would approximate those at Euston. The wind run for the 24 hours on the date of sampling reflects the horizontal distance the wind moved on that day at a height 2 m from the ground.

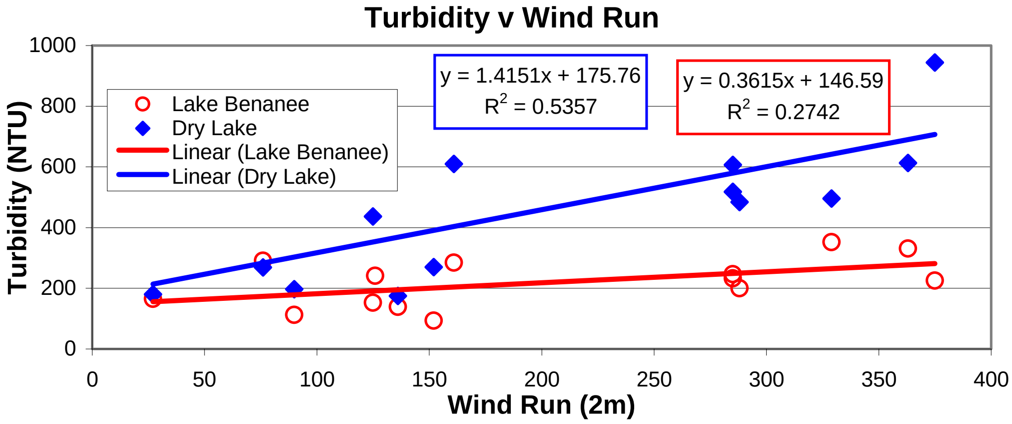


Figure 5. Turbidity (NTU) v wind run (2 m elevation) at Lake Benanee and Dry Lake, August 2001-June 2003.

Suspended Solids

The pattern of total suspended solids over time mirrored the turbidity results (not depicted) due to strong relationships between total suspended solids and turbidity for each lake (Figure 6). Organic matter comprised between 11-14% and 13-21% of the total suspended solids of Dry Lake and Lake Benanee, respectively.

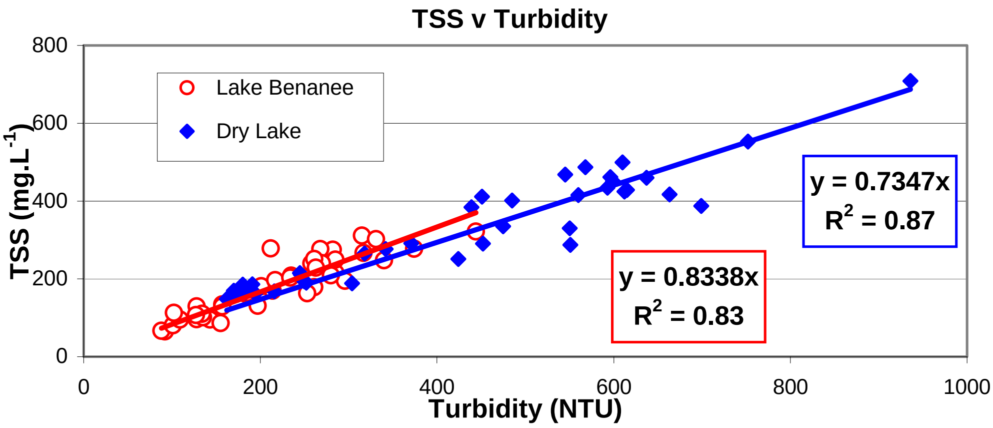


Figure 6. Total suspended solids (TSS) versus turbidity at Lake Benanee and Dry Lake, August 2001-June 2003.

Temperature

Surface water temperatures fluctuated with seasonal air temperatures and were recorded within the range of 12-33^{o}C for each lake. Temperatures were measured from 1430-1730 and were generally warmer in the shallow Dry Lake where the buffering capacity is lower than for the deeper Lake Benanee (Figure 7).

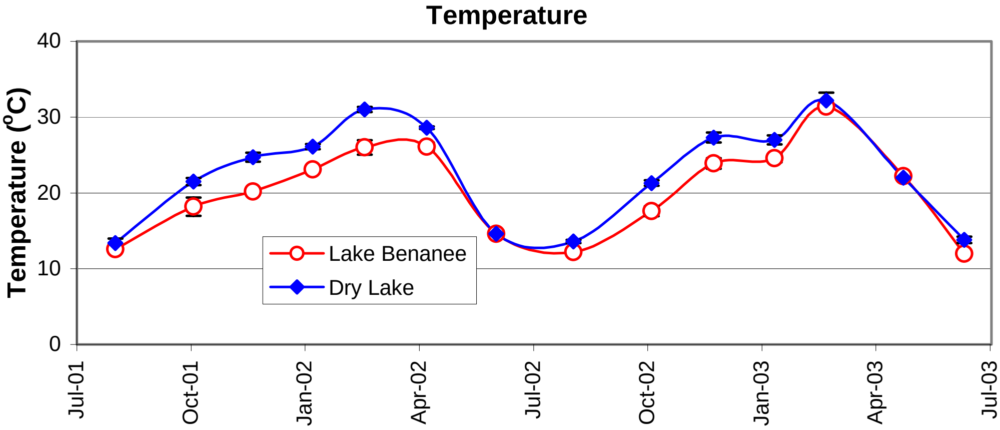


Figure 7. Mean surface water temperatures at Lake Benanee and Dry Lake, August 2001-June 2003. Note that temperatures were measured from 1430-1730 hours. Error bars = ± 1 S.E.

Dissolved Oxygen and pH

Dissolved oxygen concentrations recorded in the Euston Lakes remained high (min. 83% saturation) during the study period. Concentrations ranged from 7.1-11.68 mg.L^{-1} and 6.92-13.83 mg.L^{-1} in Lake Benanee and Dry Lake, respectively. Concentrations varied due to seasonal temperature changes, with the highest concentrations being recorded in the winter months.

The pH of the lake surface waters remained alkaline throughout the study period (not shown), ranging from 8.5-8.9 and 8.3-9.25 in Lake Benanee and Dry Lake, respectively. pH exceeded 9 on one occasion only (June 2003).

Nutrients

Surface water concentrations of total nitrogen (TN), oxides of nitrogen (NOx), ammonia (NH_3), total phosphorus (TP) and filterable reactive phosphorus (FRP) over time are presented in Figure 8. Lake Benanee typically contained higher concentrations of total nitrogen, total phosphorus and particularly FRP than Dry Lake, whilst Dry Lake initially contained higher levels of NOx and NH_3. The TN concentrations in Lake Benanee were generally conserved over time whereas levels in Dry Lake decreased, potentially through low TN river water entering the lake. Nitrous oxide concentrations decreased over time in all lakes suggesting nitrogen uptake by biotic and abiotic mechanisms or a loss to the atmosphere through denitrification. Ammonia was examined from April 2002 and concentrations remained consistently low in each lake (<12 µg.L^{-1}). Phosphorus levels remained similar in Lake Benanee throughout the period of study in comparison with Dry Lake where concentrations decreased toward river levels over time.

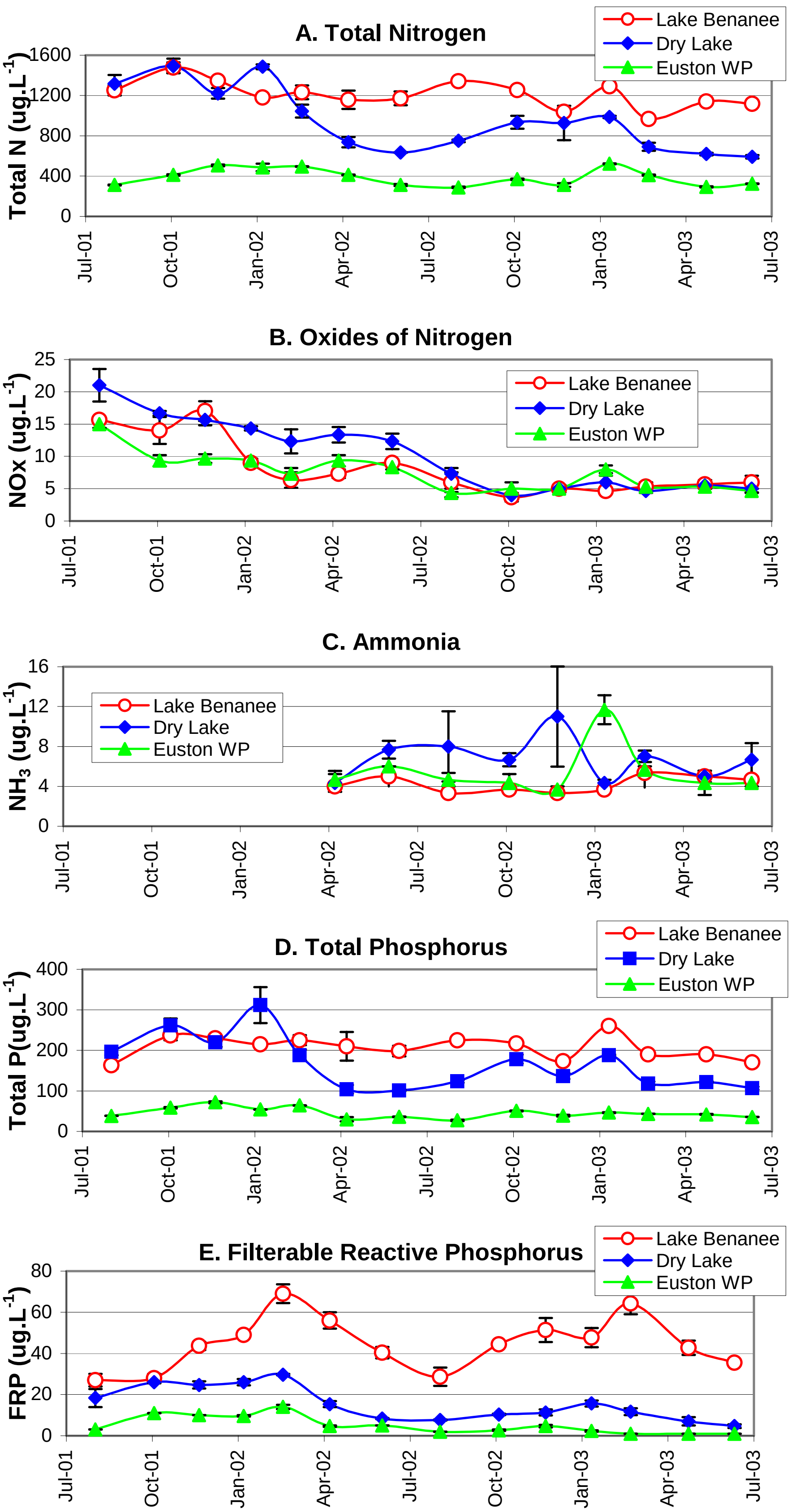


Figure 8. Surface water concentrations of (A) total nitrogen, (B) oxides of nitrogen, (C) ammonia, (D) total phosphorus and (E) filterable reactive phosphorus in Lake Benanee, Dry Lake and the Euston weir pool, August 2001-June 2003. Error bars = ± 1 S.E.

The proportion of the total nitrogen and phosphorus pools available for primary production over time was investigated using the dissolved inorganic nitrogen (NOx + NH_3) and dissolved inorganic phosphorus (estimated as FRP) as estimates of "bioavailable" nutrients. For Lake Benanee, the dissolved inorganic nitrogen (DIN) comprised 0.6-1.2% (mean 0.9%) of the Total Nitrogen pool and DIP comprised 11.8-33.9% (mean 21.9%) of the Total Phosphorus pool. For Dry Lake, DIN comprised 1.1-3.2% (mean 1.9%) of the Total Nitrogen pool and DIP 4.4-15.8% (mean 9.0%) of the Total Phosphorus pool. The dissolved inorganic nitrogen proportions are generally lower than for the riverine flows at Euston weir pool (2.5-4.6%, mean 3.2%). The lake dissolved inorganic phosphorus proportions are similar (Dry Lake) or greater (Lake Benanee) than the Euston weir pool (2.3-21.9%, mean 10.5%).

To investigate potential nutrient limitations of primary production, DIN:DIP ratios were examined in each lake over time (Figure 9). Ratios in Lake Benanee and Dry Lake remained within the ranges of 0.16-0.35 and 0.7-2.8, respectively, and were consistently lower than for the riverine flows at the Euston weir pool. The very low ratios are less than the Redfield Ratio of 16:1 (the natural ratio of nitrogen to phosphorus in a living cell) and suggest that either nitrogen is limiting primary production in the lakes or that both nitrogen and particularly phosphorus are abundant. Given that NOx and NH_3 concentrations each reached levels below 5 $\mu g.L^{-1}$ toward the end of the study period, nitrogen is likely limiting primary productivity in the Euston Lakes. It is difficult to make a more definitive statement regarding limitation given that the nutrients available in a water body at a particular time do not reflect rates of nutrient turnover or transformations within a nutrient pool. Hence, it is feasible that a nutrient may be present at low concentrations but at a level available to primary producers, and that buffering mechanisms may rapidly maintain this concentration such that the nutrient does not limit growth. The trend of decreasing nitrogen concentrations, however, increases the likelihood that nitrogen is limiting primary production in the lakes.

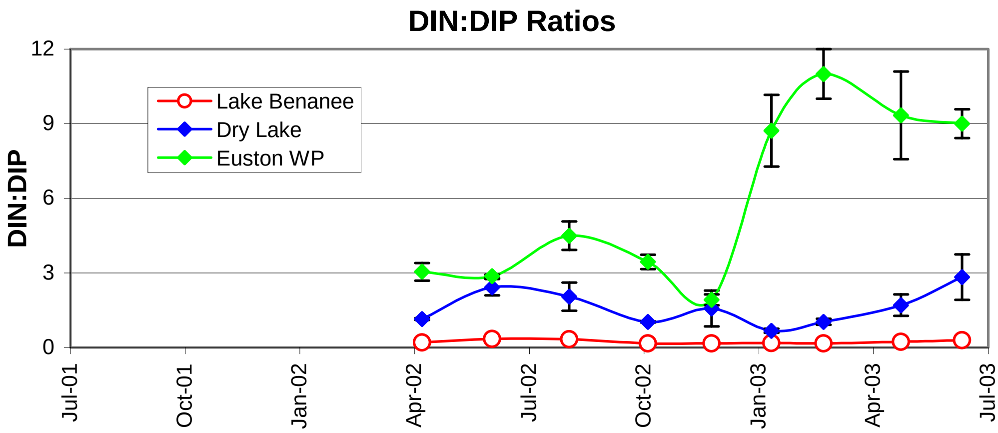


Figure 9. Dissolved inorganic nitrogen:phosphorus ratios in Lake Benanee, Dry Lake and the Euston weir pool, April 2002-June 2003. Error bars = ± 1 S.E.

Nutrients v Total Suspended Solids

The relationships between the suspended solids and nutrients differed within each lake. Relationships between each nutrient and the organic, inorganic and total suspended solids (TSS) of each lake were examined and the three coefficient of determinations (R^2 values) of the correlations for each lake were similar. Hence, only the total suspended solid concentrations are depicted. Total Phosphorus was strongly correlated with TSS in Dry Lake (R^2=0.74) but modestly correlated in Lake Benanee (R^2=0.28)(Figure 10). Total Nitrogen concentrations in comparison were strongly correlated with TSS in both Dry Lake (R^2=0.67) and Lake Benanee (R^2=0.53)(Figure 11), suggesting that nitrogen was particle associated in each lake.

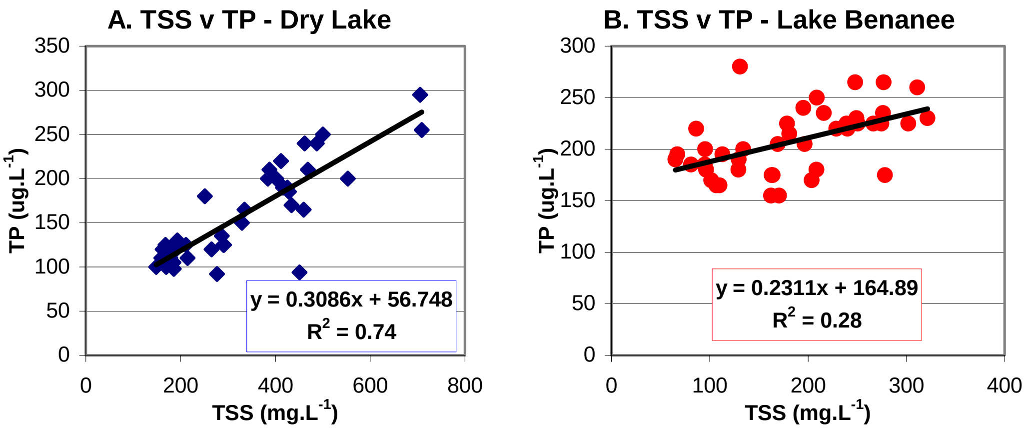


Figure 10. Relationship between total suspended solid concentrations and Total Phosphorus concentrations in (A) Dry Lake and (B) Lake Benanee, August 2001-June 2003.

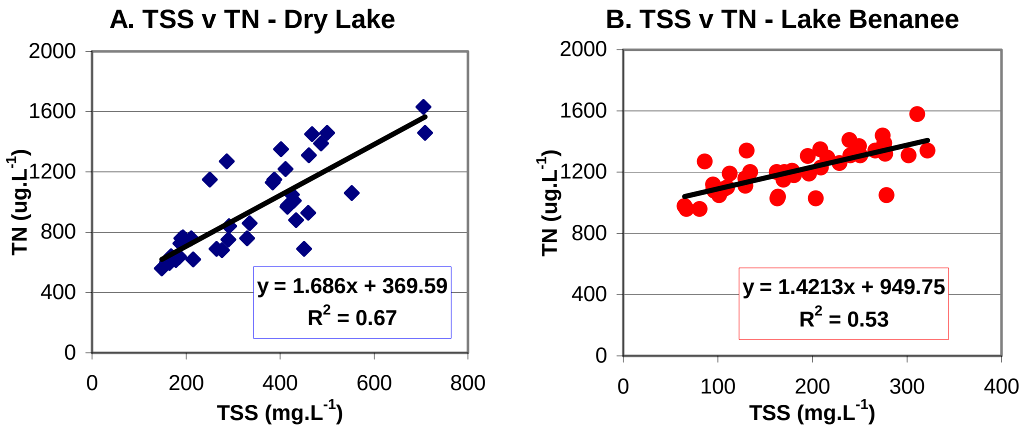
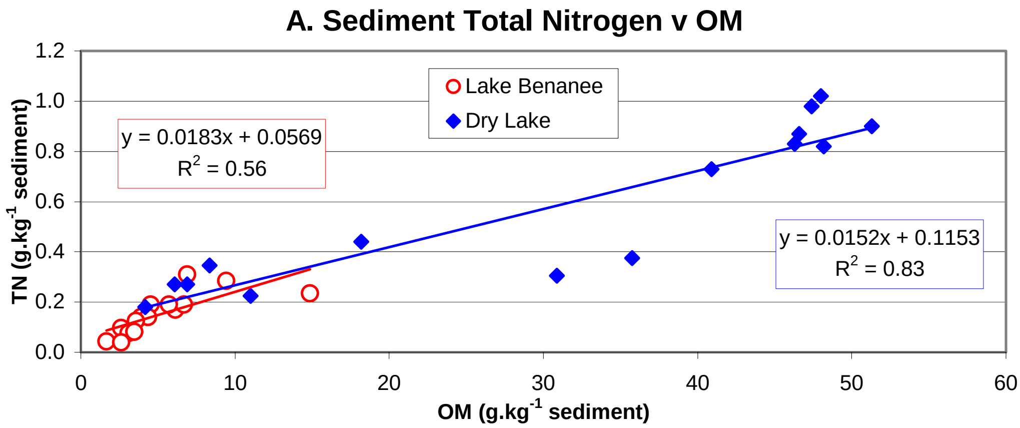


Figure 11. Relationship between total suspended solid concentrations and Total Nitrogen concentrations in (A) Dry Lake and (B) Lake Benanee, August 2001-June 2003.

Sediments

The sediments from the littoral margins of Lake Benanee contained high proportions of fine sands and comprised between 0.3-0.8% organic matter over the study period. In contrast, clays dominated the Dry Lake sediments, which contained 1.9-3.6% organic matter.

The organic matter and total nitrogen concentrations of the sediments were very strongly correlated in Dry Lake and strongly correlated in Lake Benanee (Figure 12A), whilst organic matter and total phosphorus concentrations were strongly correlated in Dry Lake and weakly correlated in Lake Benanee.



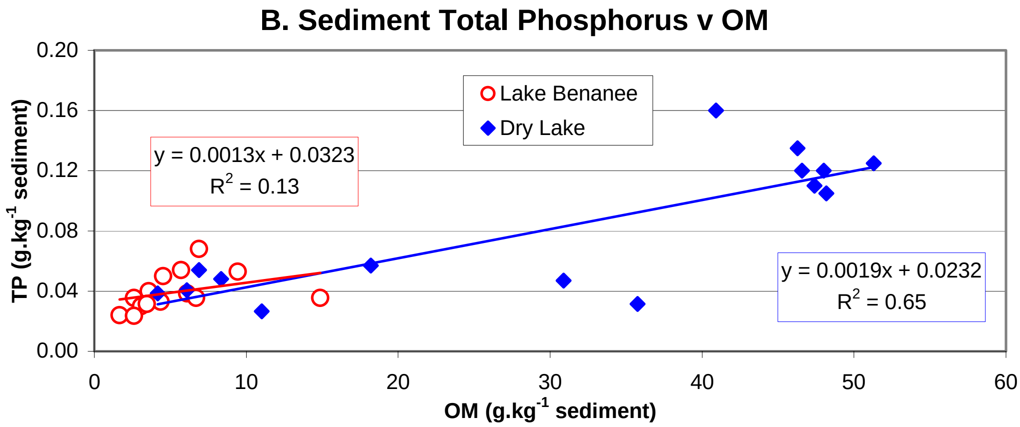


Figure 12. Relationship between the organic matter content of the sediment and (A) Total Nitrogen and (B) Total Phosphorus concentrations in the sediment of Lake Benanee and Dry Lake, August 2001-June 2003.

Phytoplankton

Biomass

Phytoplankton biomass was estimated by measuring the total chlorophyll pigment (TCP) in the surface waters of each lake (Golterman and Clymo, 1971). The use of TCP rather than phaeophytin-corrected chlorophyll is well justified in this case given that the “viable” chlorophyll component generally remained over 90% in both lakes throughout the study period (minimum 75% viability recorded). Phytoplankton biomass in Dry Lake was initially greater than for Lake Benanee and the river but decreased during the study period to levels comparable with the other sites (Figure 13).

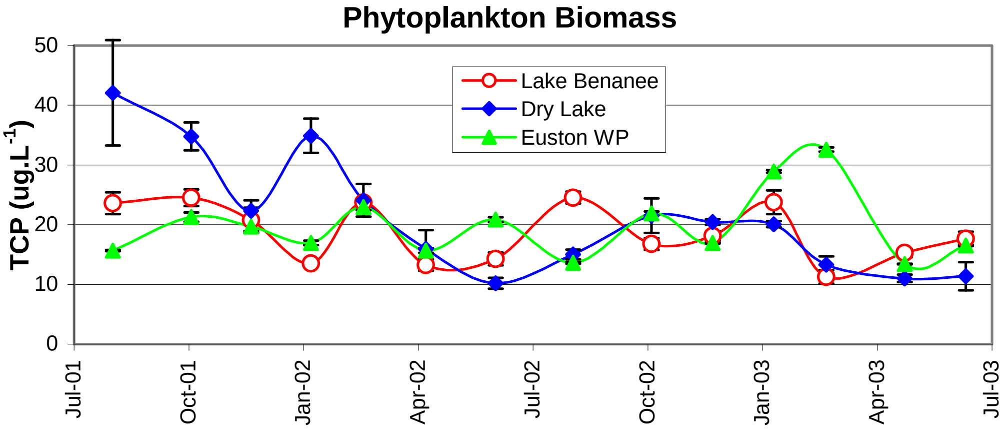


Figure 13. Phytoplankton biomass estimated by total chlorophyll pigment (TCP) in Lake Benanee, Dry Lake and the Euston weir pool, August 2001-June 2003. Error bars = ± 1 S.E.

Phytoplankton Taxa and Abundance

A total of 63 phytoplankton taxa were identified in the Euston Lakes from four sampling occasions from August 2002 – June 2003. Lake Benanee and Dry Lake contained 40 and 51 taxa, respectively.

Mean phytoplankton cell counts in Lake Benanee and Dry Lake were 678 cells.mL^{-1} (range 35 - 1,860 cells.mL^{-1}) and 399 cells. mL^{-1} (range 91 - 690 cells.mL^{-1}), respectively. The mean counts for the main phytoplankton groups in each lake are listed in Table 2 and the five most abundant taxa for each lake are listed in Table 3. A full list of the phytoplankton taxa is included in Appendix 1.

Table 2. Mean (±S.E) cell counts for major phytoplankton groups.

Phytoplankton Group	Lake Benanee	Dry Lake
Cyanophyta	422 ± 191	320 ± 153
Chlorophyta	176 ± 60	25 ± 8.5
Bacillariophyceae	24 ± 7.6	43 ± 22
Euglenophyta	26 ± 19	2.3 ± 0.4
Pyrrophyta	23 ± 15	0.2 ± 0.2
Cryptophyta	6.3 ± 2.3	8.8 ± 3.7
Crysophyta	0.0 ± 0.0	0.0 ± 0.0

Table 3. Five most abundant taxa (% of total count) from each lake.

Lake Benanee	Dry Lake
Anabaena flos-aqua (41.4%)[1]	*Anabaena* sp. (36.4%)[1]
Crucigenia sp. (17.5%)[2]	Anabaena circinalis (31.4%)[1]
Anabaena aphanizomenioides (8.2%)[1]	*Rhopalodia* sp. (5.6%)[3]
Anabaena sp. (7.4%)[1]	Coelosphaerium sp. (4.8%)[1]
Oocystis gigas (5.0%)[2]	Aphanizomenon gracile (2.6%)[1]

1=Cyanophyta, 2=Chlorophyta, 3=Bacillariophyceae

Cyanophyta (cyanobacteria) was the dominant phytoplankton group in each lake (Figure 14). The highest mean concentration of cyanobacteria in Lake Benanee was 1,419 cells.mL^{-1} in

February 2003, and was primarily due to *Anabaena flos-aqua* (1,070 cells.mL^{-1}) (Figure 14A). In Dry Lake, the mean concentration of cyanobacteria was 586 cells.mL^{-1} in November 2002 due to elevated counts of *Anabaena circinalis* at a single site (1,494 cells.mL^{-1}), and 537 cells.mL^{-1} in June 2003 due to elevated counts of *Anabaena* sp. (mean 400 cells.mL^{-1}) at all sites of the lake (Figure 14B).

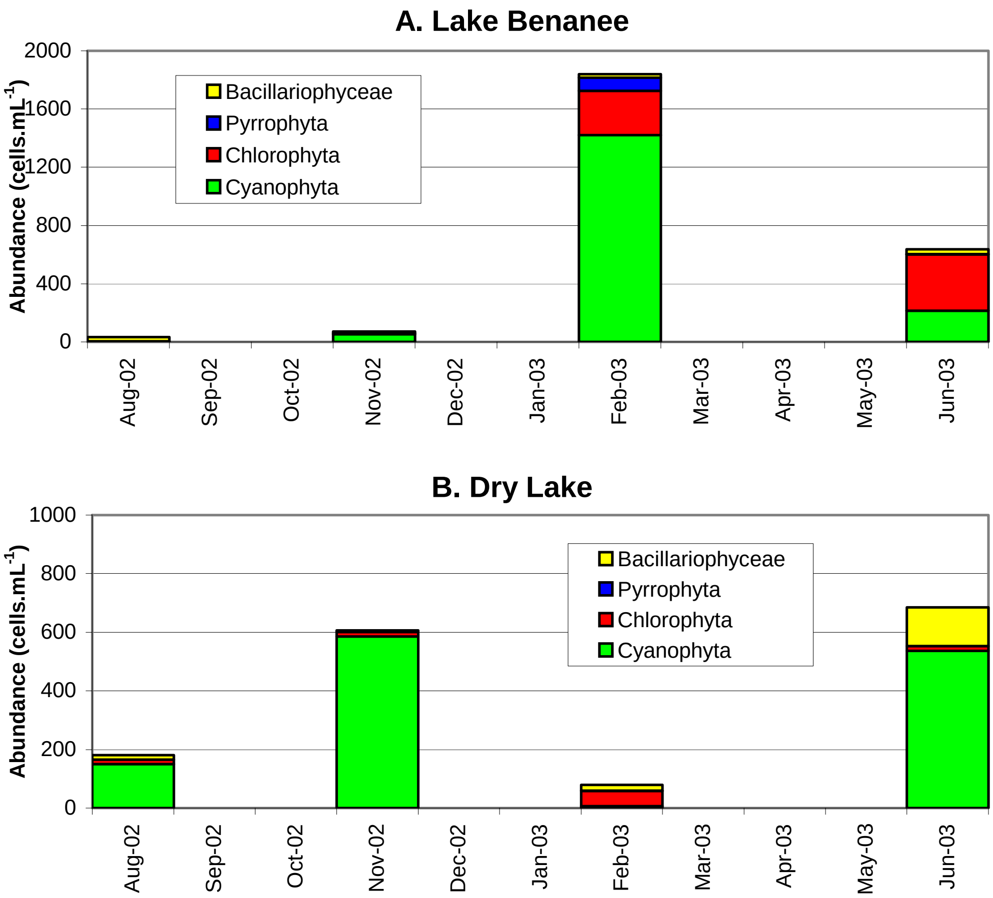


Figure 14. Concentrations of the main phytoplankton groups in (A) Lake Benanee and (B) Dry Lake, August 2002-June 2003.

The NMDS ordination of the phytoplankton communities from each site-time revealed reasonably distinct phytoplankton communities between the lakes (Figure 15). Multi-response permutations procedures (a nonparametric procedure to test whether designated groups differ in multivariate space) revealed that the phytoplankton communities at Lake Benanee and Dry Lake were statistically different to one another based on abundance (P<0.001) and presence/absence (P<0.001) data. On two occasions (February 2003 and June 2003) the phytoplankton communities at the three sites within each lake were similar to one another. However, in August 2002 and November 2002 the within-lake variability was high, demonstrating the difficulty in representatively sampling large lake systems.

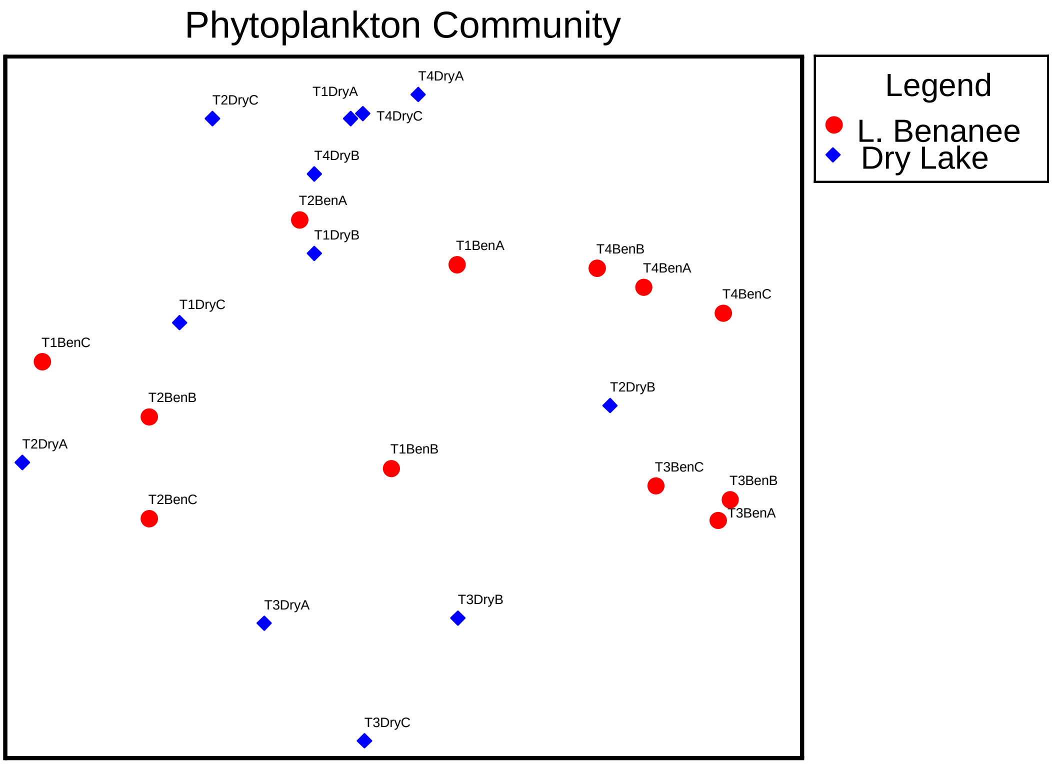


Figure 15. Non-metric multi-dimensional scaling ordination of the phytoplankton communities from each site (A, B & C) of Lake Benanee (Ben) and Dry Lake (Dry) on four sampling occasions (T1=5/8/02, T2=25/11/02, T3=25/2/03, T4=16/6/03). 3-D ordination, stress=13.4%.

Zooplankton

A total of 28 zooplankton taxa were recorded in the Euston Lakes, with Lake Benanee and Dry Lake each comprising 20 and 21 taxa, respectively (Appendix 2). Mean zooplankton abundances in Lake Benanee and Dry Lake were 1512 and 746 individuals.L^{-1}, respectively. For Lake Benanee, rotifers were dominant (89%) followed by copepods (11%) and cladocerans (0.3%). Rotifers also dominated the zooplankton of Dry Lake (83%) followed by copepods (16%) and cladocerans (1%) (Table 4). Further details on the zooplankton taxa and abundances are provided in Appendix 2.

Table 4. Mean (±S.E) abundance (individuals.L^{-1}) of the main zooplankton groups.

Phytoplankton Group	Lake Benanee	Dry Lake
Rotifera	1348 ± 628	617 ± 200
Copepoda	159 ± 40	120 ± 28
Cladocera	4.9 ± 1.4	8.6 ± 2.1
Ostracoda	0.02 ± 0.01	0

The rotifer taxon *Filinia cf. opoliensis* was the most dominant zooplankton in Lake Benanee and Dry Lake from August 2002 – June 2003, being recorded at relatively high concentrations in each lake in February 2003 only. Other well-represented species and their proportions of the total abundance are summarised in Table 5.

Table 5. Five most abundant zooplankton taxa (% total abundance) from each lake.

Lake Benanee	Dry Lake
Filinia cf. opoliensis (49.2%)[1]	Filinia cf. opoliensis (34.7%)[1]
Brachionus cf. angularis (14.8%)[1]	Keratella cf. australis (17.9%)[1]
Filinia cf. australiensis (11.9%)[1]	Filinia cf. australiensis (16.4%)[1]
Copepod Nauplii (8.6%)[2]	Copepod Nauplii (15.1%)[2]
Brachionus cf. keikoa (5.8%)[2]	Brachionus cf. angularis (2.6%)[1]

1=Rotifer, 2=Copepod

Zooplankton communities from the three sites within each lake were generally similar to one another (Figure 16), suggesting that three samples per lake may be reasonably sufficient to follow seasonal changes in the zooplankton communities. Community compositions changed seasonally in Lake Benanee and Dry Lake where the communities of each lake remained reasonably similar to one another for each sampling time. The zooplankton communities of February 2003 were most distinct from the other times, particularly for Lake Benanee (Figure 16). Despite the similarities between the lakes, multi-response permutation procedures revealed that the zooplankton communities were statistically different between the lakes based on abundance (P=0.043) and presence/absence (P=0.039) data.

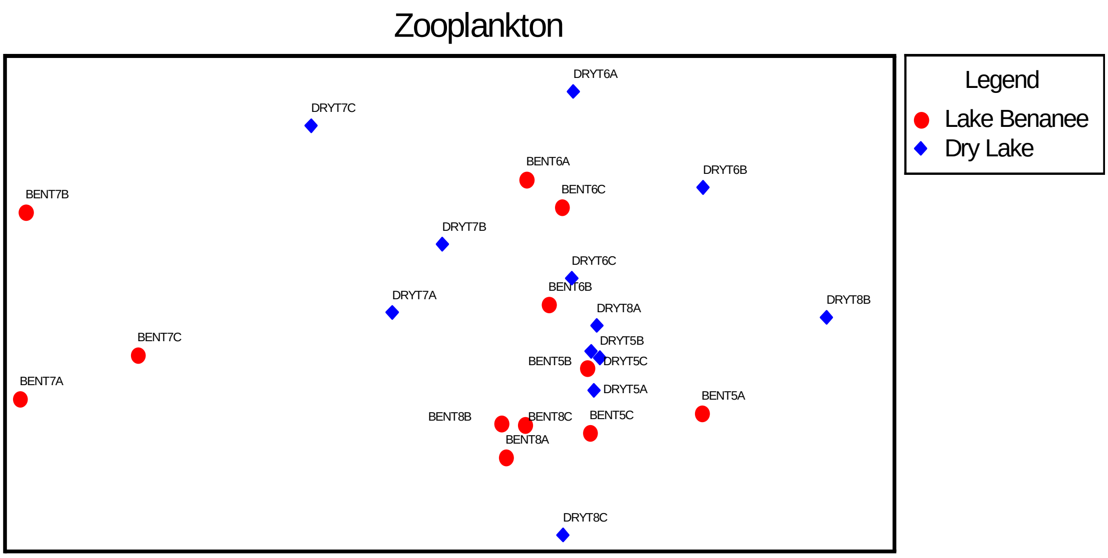


Figure 16. Non-metric multi-dimensional scaling ordination of the zooplankton communities from each site (A, B & C) of Lake Benanee (Ben) and Dry Lake (Dry) on four sampling occasions (T5=5/8/02, T6=25/11/02, T7=25/2/03, T8=16/6/03). 2-D ordination, stress=13.4%.

Discussion

Local Hydraulics

Water levels variations in Dry Lake, Lake Benanee and the Euston weir pool indicate a strong hydraulic connection between the Euston weir pool and Dry Lake, but an impeded connection in the section of Taila Creek between Dry Lake and Lake Benanee. Water levels in Dry Lake mirrored those of the Euston weir pool throughout the study period, whereas levels in Lake Benanee decreased below these levels over the summer months. The 0.31 m drawdown of the Euston weir pool in February 2002 further restricted inflows into Lake Benanee due to the decreased head difference, resulting in the lake lowering to 47.06 mAHD or less (Euston weir pool full supply level is 47.60 mAHD).

A large number of macrophytes (*Typha* sp) in the channel between Dry Lake and Lake Benanee are thought to be responsible for the restriction of inflows along this 2.6 km section of Taila Creek. The channel width remains reasonably broad, typically 25-35 m, with *Typha* sp. extending across the creek in places. A similar constriction was noted for Bottle Bend Lagoon near Buronga, NSW (McCarthy *et al*., 2003). It is speculated that drought conditions and the consequent lack of significant flooding in the Murray River since 2000 has allowed for the proliferation of macrophytes in areas where they may not necessarily persist under more variable conditions. This was certainly evident in the free-flowing regions of the River Murray (Research Report 6) where macrophytes were present but were absent two years previous (Gawne *et al.,* 2002; Treadwell, 2002).

The constriction of inflows along Taila Creek has allowed water levels in Lake Benanee to fluctuate on a seasonal basis, which likely provided ecological benefits. Whilst the range of fluctuation in 2003 (0.25 m) may not have resulted in the desiccation of sediments and biofilms along the lake banks due to wind and wave action, this likely occurred in 2002 during the 0.46 m lowering in Lake Benanee. Regions of normally submerged sand flats with biofilm growth became exposed at this time. In Dry Lake, large areas of lakebed became exposed with the 0.31 m drawdown of the Euston weir pool. Such changes are important for the transformation of nutrients and resetting of biofilm successional sequences (Mullen, 1998; Burns and Walker, 2000).

These observations have implications for the Euston Lakes during a potential drawdown manipulation of the Euston weir pool. They reveal that drawdowns may not necessarily provide any flushing of Lake Benanee or export of salt from the lakes if timed to occur during the warmer months. However, a winter drawdown when lake levels are high may result in backflows from Lake Benanee along Taila Creek and into the River Murray. The amount of salt exported by these actions is difficult to assess, but EC is likely to be reduced by a maximum of ca. 25% given that this represents the estimated change in the volume of Lake Benanee during a flushing event (and assumes low EC inflows during refilling). A natural flood event remains the most effective flushing mechanism, with the amount of salt being exported from Lake Benanee being a function of the elevation level of the flood.

Considerable flushing of Dry Lake likely occurred during the 0.31 m drawdown of the Euston weir pool in February 2002. Whilst flow direction along the section of Taila Creek between the River Murray and Dry Lake was not examined at this time, water levels in Dry Lake decreased considerably. In April 2002 after Dry Lake had refilled, surface water concentrations of EC, total nitrogen, total phosphorus and filterable reactive phosphorus had all decreased markedly, becoming closer to concentrations in the Euston weir pool, providing strong evidence for a significant flushing in this lake.

Water Physico-Chemistry

The increasing electrical conductivity in Lake Benanee over the study period (from 748 to 1163 $\mu S.cm^{-1}$ in 685 days) is a significant issue given the diversions for stock and domestic use, and sometimes for irrigation. The high levels are typical of a terminal wetland system and reflect the evapo-concentration of salts within the lake and the lack of flushing.

From an ecological perspective, elevated salt concentrations occur naturally in wetlands of this type and would increase well above these levels during natural drying episodes. Some native animals and plants may actually rely on these high concentrations for persisting in ephemeral environments and possibly use EC as a cue for commencing dormant stages. Others, however, would likely be negatively affected, resulting in shifts in biotic composition (Hart *et al*., 1991). For example, Baldwin *et al*. (2002) noted that an EC level of 1000 $\mu S.cm^{-1}$ was sufficient to switch off methanogenesis in wetland sediments, whilst microbial diversity began to decrease at levels of 10,000 $\mu S.cm^{-1}$.

The higher turbidity (and suspended solids concentrations) in Dry Lake - particularly on windy days – is likely a reflection of the shallow nature of the wetland and its clay-dominated sediments. In contrast, Lake Benanee is deeper, contains littoral sediments dominated by fine sand, and is less susceptible to sediment resuspension as a result of wind and wave action. Turbidity levels within the lakes were consistently greater than for the Euston weir pool, and likely account for the higher TN and TP concentrations in the lakes given the strong positive correlations between TSS and these nutrients.

Nutrient Dynamics

ANZECC (2000) trigger thresholds of water quality standards are unavailable for the lakes of NSW due to the recognition of inherent difficulty of applying a single trigger value to cover the diversity of lake systems. Figures are available for freshwater lakes and reservoirs of south-east Australia but these thresholds are typically well below the NSW thresholds for lowland rivers and are consequently not used for the lakes.

Oxides of nitrogen (NOx) concentrations decreased in both lakes over time. This pattern has been observed in other semi-arid deflation basins between flood flows suggesting that NOx is being utilised or progressively lost through denitrification (Scholz *et al*., 2001). Ammonia concentrations also remained relatively low during the second half of the study period when this nutrient was examined. In contrast to these bioavailable sources of nitrogen, filterable reactive phosphorus remained available in Dry Lake (5-30 $\mu g.L^{-1}$) and particularly Lake Benanee (27-69 $\mu g.L^{-1}$) throughout the study period. The very low DIN:DIP ratios in Dry Lake (max. ratio 2.83) and Lake Benanee (max ratio 0.35) suggest that nitrogen is likely limiting primary production in the system.

Concentrations of TN, TP and FRP were consistently greater in both lakes compared to the Euston weir pool. This is most likely due to the turbidity levels being higher in the lakes, given the strong positive correlations of TSS with TN and TP.

Phytoplankton

The phytoplankton communities of Dry Lake and Lake Benanee were significantly distinct from one another, although the high within-lake variability in August 2002 and November 2002 shows that this result may not be unexpected. The high within-lake variability reveals the heterogenous nature of phytoplankton communities, particularly in large lake systems where populations may be influenced by many factors including inflows and wind. The result also highlights the importance of obtaining adequate replication and spatial coverage to representatively sample lake phytoplankton at a particular time. Cost effective ways of doing this may be to obtain composite samples within several areas, or obtaining additional samples across a lake and analysing them to a lower resolution.

The dominance of blue-green algae (Cyanophyta) in the lakes is not unexpected given their ecological adaption to dominate in low nitrogen environments through their ability to fix atmospheric nitrogen. The low proportion of diatoms (Bacillariophyceae) in the lakes, particularly Lake Benanee, is consistent with species of this group being reliant on turbulent flows/mixing to maintain their position in the water column.

Zooplankton

The zooplankton communities of Dry Lake and Lake Benanee were significantly distinct from each other, despite general patterns of zooplankton community change being quite similar.

The reasonable similarity in the patterns of community change between the lakes shows that the zooplankton communities are likely responding to seasonal changes, despite the lakes differing substantially with regard to their depth, EC and turbidity.

The collection of zooplankton samples from open water areas at three different regions of the lake was generally sufficient to capture the within-lake variability of the zooplankton communities, unlike the case for phytoplankton. Rotifers were the most dominant zooplankton group followed by the copepods, of which *Boeckella triarticulata* was the most abundant species in each lake. This species is considered the most common and widely distributed calanoid copopod (Shiel, 1990), and it present throughout the River Murray including Lake Hume and Lake Alexandrina.

Emergent Macrophytes

During the study period the emergent macrophyte *Typha* sp. became more dominant along the eastern shore of Dry Lake, with dense stands growing in areas that were initially well exposed in August 2001 (e.g. water level gauge at Site B in Figure 1). This macrophyte was also dominant in the section of Taila Creek between Dry Lake and Lake Benanee – an area noted to be absent of macrophytes in 1996 (Lloyd, 1996).

Conclusions and Recommendations

Dry Lake and Lake Benanee have become permanently inundated since the construction and operation of the Euston weir. One of the factors for the selection of the Euston weir pool as a site for a trial weir pool drawdown was that Dry Lake would drain almost completely with a 1 m drawdown whilst Lake Benanee would lower approximately 0.5 m before a natural sill would prevent further draining of the wetland. The ecological responses of these wetlands to the changed hydrologic regime were to be investigated before, during and after a drawdown manipulation at the Euston weir pool. Whilst a trial did not occur, this study has collected strong baseline data from the lakes over a two-year period against which any future investigations can be compared.

It is recommended that an integrated management plan be adopted for the Euston Lakes system that incorporates a hydrologic regime that more closely resembles the pre-river regulation conditions. A key action would involve preventing the lakes system from being connected permanently to the weir pool. This could be achieved through changed weir pool management (e.g. drawdown manipulations) or through the installation of regulators. Changed weir pool management may allow a lowering of the groundwater table within the floodplain and reduce the risk of salinisation (and potentially acidification) of the lakes system during a drying event. In the second instance, consideration may need to be given to monitoring the groundwater system during drying episodes so as to assess the salinisation risk. As other components of this project have highlighted, changes in hydrologic management may impact adjacent landowners who use the lakes and creeks for stock watering, fencing, stock and domestic supply and irrigation. The work by SKM (in prep.) will be important in evaluating these impacts on landowners.

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Appendix 1: Phytoplankton taxa of the Euston Lakes.

Phytoplankton taxa	LAKE BENANEE		DRY LAKE	
	Mean ind.L^{-1}	% of total	Mean ind.L-1	% of total
Cyanophyta				
Anabaena affinis	0.0	0.0	3.6	0.9
Anabaena aphanizomenioides	55.9	8.2	0.0	0.0
Anabaena circinalis	33.7	5.0	125.4	31.4
Anabaena flos-aqua	280.9	41.4	3.9	1.0
Anabaena solitaria	0.7	0.1	3.7	0.9
Anabaena sp.	50.4	7.4	145.3	36.4
Aphanizomenon gracile	0.0	0.0	10.2	2.6
Aphanizomenon issatschenkoi [50um fil.mL^{-1}]	0.0	0.0	5.7	1.4
Coelosphaerium sp.	0.0	0.0	19.3	4.8
Geitlerinema sp. [50um fil.mL^{-1}]	0.2	0.0	0.0	0.0
Phormidium sp. [50um fil.mL^{-1}]	0.2	0.0	0.0	0.0
Pseudanabaena limnetica	0.0	0.0	2.1	0.5
Stichosiphon sp.	0.2	0.0	0.5	0.1
Chlorophyta				
Ankistrodesmus falkatus	11.4	1.7	0.2	0.0
Ankistrodesmus fusiformis	1.7	0.3	0.2	0.0
cf. *Ankyra lanceolata*	0.5	0.1	0.0	0.0
Chlorohormidium sp.	0.0	0.0	6.3	1.6
Closterium dianae	0.0	0.0	0.2	0.0
Closterium kutzingii	0.0	0.0	0.2	0.0
Crucigenia sp.	118.8	17.5	3.1	0.8
Eudorina sp.	0.0	0.0	1.5	0.4
Fusola sp.	1.0	0.1	1.3	0.3
Monoraphidium mirabile	0.8	0.1	6.3	1.6
Oedogonium sp.	0.3	0.0	0.0	0.0
Oocystis gigas	34.0	5.0	0.7	0.2
Oocystis sp.	6.3	0.9	1.7	0.4
Pediastrum tetras	0.0	0.0	0.8	0.2
Scenedesmus dimorphus	0.0	0.0	0.7	0.2
Sphaerocystis sp.	0.0	0.0	1.4	0.3
Spirogyra sp.	0.0	0.0	0.2	0.0
Staurastrum playfairi	0.0	0.0	0.1	0.0
Tetraedron sp.	0.0	0.0	0.2	0.0
Tetrastrum heteracuntum	1.2	0.2	0.0	0.0
Euglenophyta				
Euglena sp.	25.4	3.8	2.1	0.5
Phacus sp.	0.0	0.0	0.1	0.0
Strombomonas sp.	0.5	0.1	0.1	0.0
Trachelomonas sp	0.5	0.1	0.0	0.0
Pyrrophyta				
Gymnodinium sp.	21.8	3.2	0.0	0.0
Peridinium sp.	1.1	0.2	0.2	0.0
Cryptophyta				
Cryptomonas sp.	6.2	0.9	3.2	0.8
Rhodomonas sp.	0.1	0.0	5.6	1.4
Bacillariophyceae				
Aulacoseira granulata / Aul. ambigua	1.7	0.3	3.3	0.8
Cyclostephanos tholiformis	0.6	0.1	0.0	0.0
Cyclotella meneghiniana / Stephanodiscus sp.	2.8	0.4	0.0	0.0
Diploneis sp.	0.0	0.0	0.2	0.1
Encyonema sp.	0.3	0.0	0.0	0.0
Epithemia sp.	0.2	0.0	0.4	0.1
Eunotia sp.	2.1	0.3	1.1	0.3
Fragilaria sp.	4.2	0.6	3.1	0.8
Gyrosigma attenuatum	0.1	0.0	0.6	0.1
Navicula cf. *cryptotenella* / cf *viridula*	2.4	0.4	2.0	0.5
Navicula sp.	0.0	0.0	0.9	0.2
Nitzschia agnita	0.2	0.0	0.6	0.1
Nitzschia cf. *lorenciana* (cf *reversa*)	3.5	0.5	0.8	0.2
Nitzschia palea	0.0	0.0	5.5	1.4
Nitzschia cf *vermicularis*	0.0	0.0	0.2	0.1
Nitzschia sp. 1 **(star)**	0.5	0.1	0.0	0.0
Nitzschia sp.	0.2	0.0	1.2	0.3
Pinnularia sp.	0.0	0.0	0.2	0.0
Rhopalodia sp.	5.5	0.8	22.3	5.6
Surirella sp.	0.2	0.0	0.5	0.1
Synedra acus	0.0	0.0	0.3	0.1
Tryblionella sp.	0.0	0.0	0.2	0.0

Appendix 2. Zooplankton taxa of the Euston Lakes.

Zooplankton Group	Taxa	Lake Benanee		Dry Lake	
		Mean ind.L^{-1}	% of total	Mean ind.L^{-1}	% of total
Copepoda: Centropagidae	Boeckella triarticulata	21.71	1.44	4.86	0.65
	Calamocia ampulla	7.37	0.49	2.23	0.30
Copepoda: Cylopoida	Copepodite	0.34	0.02	0.05	0.01
	Mesocyclops sp.	0.00	0.00	0.33	0.04
	Acanthocyclops spp.	0.00	0.00	0.01	0.00
Copepoda:	Nauplii	129.38	8.56	112.50	15.09
Cladocera: Bosminadae	Bosmina meridionalis	2.34	0.16	4.46	0.60
Cladocera: Moinidae	Moina sp.	1.89	0.13	3.93	0.53
Cladocera: Daphniidae	Ceriodaphnia sp.	0.13	0.01	0.10	0.01
	Daphnia lumholtzi	0.47	0.03	0.01	0.00
	Simocephalus sp (juvenile)	0.00	0.00	0.01	0.00
	cf. Pleuroxus sp.	0.02	0.00	0.04	0.01
	cf. Alona sp.	0.00	0.00	0.04	0.01
	Chydrous sp.	0.00	0.00	0.00	0.00
Ostrocoda:	Ilocypris sp.	0.01	0.00	0.00	0.00
	Limnocythere porphretica	0.01	0.00	0.00	0.00
Rotifera: Brachionidae:	Brachionus cf. angularis	223.13	14.76	0.00	0.00
	Brachionus cf. keikoa	88.13	5.83	76.88	10.31
	Brachionus calyflorus gigantus	58.13	3.84	0.00	0.00
	Brachionus urceolaris	1.88	0.12	0.00	0.00
	Keratella cf. australis	22.50	1.49	133.13	17.86
	Keratella procurva	7.50	0.50	1.88	0.25
	Keratella cf. slacki	0.00	0.00	18.75	2.52
Rotifera: Filinidae:	Filinia cf. australiensis	180.00	11.91	121.88	16.35
	Filinia cf. opoliensis	744.38	49.24	258.75	34.71
Rotifera: Asplanchnidae	cf. Asplanchna spp.	22.50	1.49	0.00	0.00
Rotifera: Lecanidae	cf. Lecane sp.	0.00	0.00	1.88	0.25
Rotifera: Trichocecidae	Trichocerca sp.	0.00	0.00	3.75	0.50