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Assessment of the effectiveness of the Lake Goollelal floating islands for nutrient control.

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Prepared for,
Friends of Yellagonga Inc.

Mine Water and Environment
Research Centre

Final Report No. 2020-01

1. MINE WATER AND ENVIRONMENT RESEARCH CENTRE

Founded at Edith Cowan University in 2008, the Mine Water and Environment Research (MiWER) Centre is headed by A/Prof Mark Lund. The research group has a focus on mine waters; particularly pit lakes formed from open-cut mining. The group's research also extends to the ecology and rehabilitation of all inland water bodies, natural and constructed. MiWER's aim is to further understanding of freshwater science using creative, cutting-edge technologies and innovative approaches for practically improving resource sustainability and environmental condition.

MiWER is also a member of the Centre for Ecosystem Management at Edith Cowan University. More information on MiWER and our current and previous projects can be found at www.miwer.org.



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2. ACKNOWLEDGEMENTS

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3. FRONTISPIECE



Plate 1: Floating Islands in a dam bordering Lake Goollelal in June 2019

This report should be referenced as follows.

Lund, M.A., Polifka, J. (2020). *Assessment of the effectiveness of the Lake Goollelal floating islands for nutrient control*. Mine Water and Environment Research Report No. 2020-01, Edith Cowan University, Perth, Australia. 36pp. Unpublished report to the Friends of Yellagonga Inc.

4. EXECUTIVE SUMMARY

1. The Friends of Yellagonga Inc. have designed and are trialling a treatment system for nutrient and metal concentrations in Lake Goollelal. The design uses previously constructed small dams situated on the edge of the lake. Approximately 5% of the dam is covered by floating islands of rushes. The dam had a hydraulic residence time of 86 days in December 2019 which offers plenty of time for treatment to occur. A solar panel is used to pump water from a smaller dam connected to the lake into the treatment area.
2. The floating island trial was sampled in June/July and in December in 2019. Samples were collected at the inlet (before the islands), amongst the islands (middle) and after the islands at the outlet and in the lake opposite the outlet. Additionally, three piezometers were installed in the dam walls opposite the inlet and outlet and on the land side. Samples were analysed for a range of nutrients and metals. Sediment traps were installed in the inlet, middle and outlet areas.
3. No significant difference ($P>0.05$) was found in nutrient and metal concentrations at the lake, inlet, outlet and middle sites but there was a significant difference to the groundwater. The lack of difference between sites suggests that the floating islands were not influencing water quality in a measurable way. The dam walls were effective at preventing lake water entering the dam and the high water levels in the dam were believed to be sufficient to prevent groundwater entering the dam from the landside.
4. Despite the floating islands not proving to be effective at nutrient or metal removal, the reasons for this may be due to the relatively small area of plants, the depth of the dam and low concentrations of metals and nutrients. It is not recommended to increase the plant area/number of islands to increase efficiency at Lake Goollelal as water quality within the lake is sufficiently good that there is little to be gained from the system. Although the design proved to be ineffective, there is still potential that could be explored at other sites with substantial nutrient or metal pollution problems.

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6. INTRODUCTION

Yellagonga Regional Park occupies an area of around 1,400 ha overlying the Gngangara Mound and consists of Lake Goollelal, Wallubuenup Swamp, Beenyup Swamp, and Lake Joondalup. This interdunal chain of wetlands is a surface expression of the unconfined aquifer which flows in an east to west direction through the park (Newport et al. 2011a). Over the past forty five years, research at the Yellagonga wetlands has focussed on nutrient enrichment, metal contamination and the presence of acid sulphate soils (Congdon and McComb 1976a; Congdon 1985, 1986; Congdon and McComb 1976b; Cumbers 2004; Davis et al. 1993; Gordon et al. 1981; Khwanboonbumpen 2006; Kinnear and Garnett 1999; Kinnear et al. 1997; Lund 2003, 2007; Lund et al. 2000). Nutrient and water budgets for Lake Joondalup have identified a significant quantity of water and nutrients entered Lake Joondalup via flow through from the southern portion of the Yellagonga wetlands chain (Congdon 1985, 1986; Cumbers 2004). More recently, a water quality monitoring program has found nutrient enrichment and metal contamination, which exceed ANZECC/ARMCANZ (2000) national water quality guidelines (Lund et al. 2011; Newport et al. 2011a; Newport and Lund 2012, 2013b, 2014b). An investigation in the southern section of Wallubuenup Swamp identified the presence of ASS at the Drain^{Goollelal} site and this was identified as the main source of metal contamination of the lakes (Newport et al. 2011b; Newport and Lund 2013a, 2014a). Monitoring of the wetlands after 2014 has revealed that metal contamination has slowly dropped to levels generally below trigger values (Gonzalez-Pinto and Lund 2015, 2016; Gonzalez-Pinto et al. 2017).

Lake Goollelal in Yellagonga Regional Park has been experiencing increased incidents of nuisance midge (Chironomidae) outbreaks since 2008, although earlier sporadic outbreaks have occurred (Lund and Gonzalez-Pinto 2016). Drivers of midge outbreaks have been identified as increased levels of nutrients, particularly P, leading to algal blooms and more recently extended periods of lower water levels (due to low rainfall) resulting in higher water temperatures and faster midge growth rates. Although P levels are generally not very high by Perth lake standards they can reach high concentrations during periods where water levels are low (Lund et al. 2014). The Friends of Yellagonga have constructed a series of floating islands in a dam on the western shore of Lake Goollelal to treat lake water pumped directly from the lake (using solar power) and then exiting back into the lake. Floating islands usually consist of emergent aquatic macrophytes suspended on a structure allowing them to float in the wetland – this aims to harness the beneficial effects of littoral emergent macrophytes on nutrient control and increase surface area available for treatment (Stewart et al. 2008). Unlike littoral emergent plants, the roots of the plants on floating islands sit in the water column. The roots in the water therefore become a surface for bacterial communities. The uptake and processing of nutrients by root microbes is believed to be an important pathway for removal of nutrients from the water by floating islands (Stewart et al. 2008).

Yeh et al. (2015) reviewed the use of floating islands and concluded that much of the reported effectiveness was on the basis of laboratory trials and that few field scale trials had been undertaken. There are a range of proprietary designs on the market for floating islands but the design used at Lake Goollelal is not one of these and further does not contain a layer of bedding material (which often contains materials designed to enhance performance).

This study aims to investigate the effectiveness of the floating islands in Lake Goollelal for removing nutrients from the lake waters. Additionally, removal of metals/metalloids will also be measured as this may be another important benefit of the islands.

7. STUDY AREA

Yellagonga Regional Park lies on the coastal limestone belt of the Swan Coastal Plain and is in the north-west corridor of Perth approximately 20 km north of Perth's central business district. The park covers about 1,400 ha and contains a chain of wetlands beginning south of the park at Lake Goollelal through to Lake Joondalup in the north and includes Wallubuenup Swamp (divided by Woodvale Drive) and Beenyup Swamp. The wetlands are nestled in an interdunal depression with a high plateau sloping to the west and generally flat to slightly undulating slopes to the east. (Kinnear et al. 1997). The park is managed by the Department of Biodiversity, Conservation and Attractions and Cities of Wanneroo and Joondalup, under the Yellagonga Regional Park Management Plan (Dooley et al. 2003).

Lake Goollelal is considered a permanently inundated lake and contains floc overlying peat sediments, (Bryant 2000; Goldsmith et al. 2008; Sommer 2006) previously incorrectly described as metaphyton by Rose (1979) and Boardman (2000). The surrounds of Yellagonga Regional Park have been subject to agriculture and more recently urban development. Lake Goollelal has private properties and public open space bounding the water's edge but fringing vegetation generally remains in reasonable condition.

A series of dams were constructed as water reservoirs on the western side of the lake, by excavation (down to 2 m) and earthen (clay) levee to the lake. There are three dams, the smallest and the floating island dam are connected to each other and the lake via two 90 mm (diameter) mounted high in the walls (the current condition of these connections was not examined). Solar panels are used to pump water from the first dam into the floating island dam – this water comes from the dam and not directly from the lake. Sampling was undertaken at the inlet, middle (under the floating islands) and outlet, as well as a site in the lake opposite the outlet. Water in the floating island dam flows overland across the wall back into the lake.

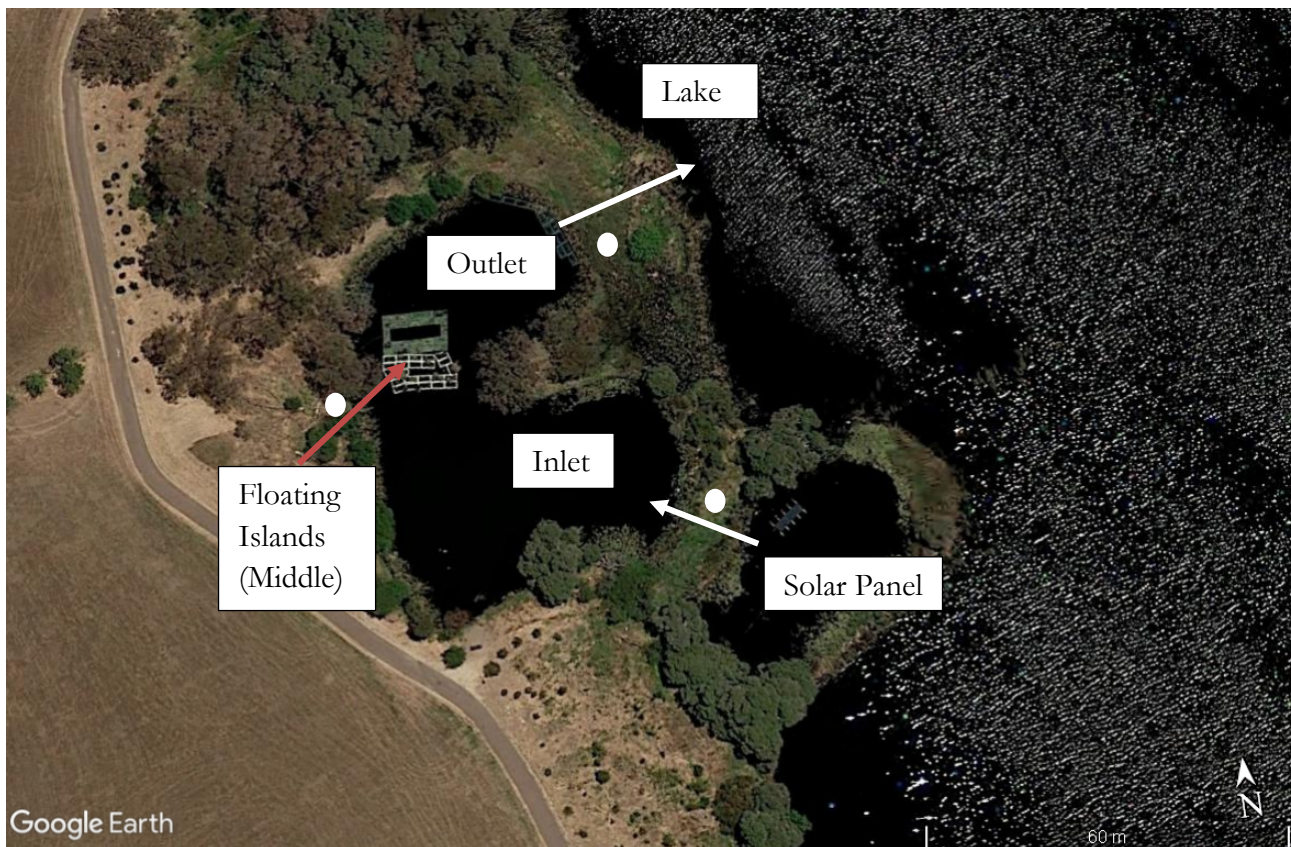


Figure 1. 2018 aerial photograph of the Lake Goollelal dams that are the site of the floating island experiment (Google Earth Pro 2019). White circles indicate piezometers, white arrows indicate direction of flow.

Floating islands are made of a 1 by 2 m rectangle of PVC piping with a coarse mesh suspended between the sides that is used to support the plants (*Baumea preissii* and *Baumea articulata*). Sixty-five islands had plants (with another 25 awaiting planting). This means that the floating islands covered 130 m² out of an estimated dam area of 2567 m² (5% coverage). As shown in Figure 1 the islands were attached together and effectively formed an almost continual barrier across the dam by utilizing a narrowing in the dam. On each sampling occasion, we measured the velocity of water (using a Marsh McBirney flow meter) out of the solar pump (mean 0.972 m s⁻¹, no obvious difference between months), then multiplied this by the cross-section area of the pipe (0.04 m dia) to obtain mean flow rates (1.22 L s⁻¹). Using BOM data on average solar hours per day for the month of June and December, the daily inflow was estimated (June 23,748 L and December 52,334 L). Daily inflows were then used to determine the hydraulic residence time (estimated mean depth of 1.75 m – gives a volume of 4,492,250 L) at June of 189 days and December of 86 days. These are long hydraulic residence times for treatment systems (more typically <7 days), which means there is lots of time for the water to be treated by the floating islands. Photographs of key aspects of the site are shown in Figure 2.

a) Dam containing solar panels



b) Inlet



c) Outlet



d) Piezometer (Inlet)



Figure 2. Photographs of key sites and aspects of the floating island experiment in Lake Goollelal.

8. METHODS

8.1 SAMPLING

The dam was divided into 4 sections, prior to the islands (*inlet*), the islands (*middle*), post the islands (*outlet*) and in the *lake* near the outflow (receiving environment). The water was measured *in situ* at all 4 sections twice a week between 17/6/2019 and 11/7/2019 and again in 9/12/2019 to 19/12/2019 at the surface and bottom of the water column for pH, conductivity, dissolved oxygen, ORP, temperature using a multiprobe (Quanta). Drinking water hoses attached to buoys at the surface (0.2 m deep) and bottom running back to the shore were used for sample collection using a bilge pump (run for several minutes prior before collection to purge the tubes). Water samples were collected on these occasions for nutrient and metal analysis from all sections. Additionally, three piezometers (<1 m deep; 60 mm dia. PVC pipe, slotted for the bottom 0.3 m) will be installed by hand around the dam to assess the significance of any groundwater movement into the floating island dam, groundwater was sampled fortnightly (using the Quanta and for nutrients and metals).

The potential for thermal stratification of the dam was examined using two temperature loggers (Hobo loggers, Onset Corp., USA) mounted at the water surface and at depth in the middle section. Strong temperature gradients in the dam could result in bottom water in the dam not mixing with inflowing water. Bottom samples were only analysed during periods when stratification would prevent the dam mixing.

A major mechanism believed responsible for the removal of P is incorporation into biofilms which subsequently slough off the roots and accumulate as sediment, alongside dead plant material. Samples of sediment were collected from inflow, outflow and island areas for analysis of organic content, and concentrations of total P and N and metals. Deposition of biofilms, organic matter and other particles will be measured using a set of 3 replicate sedimentation traps (88 mm dia. 0.343 m long PVC pipes arranged vertically with sealed bottoms, attached approximately 0.1 m apart on a weight) on the sediment at each of the three sites. The June/July 2019 sediment collectors were left in place for 67 days and the December samples for 11 days. Sediment collected was weighed as dry weight and organic content (Loss on Ignition) was measured.

In the laboratory, an unfiltered aliquot (subsample) of each water sample was frozen for later determination of total nitrogen (TN¹) and phosphorus (TP). A filtered (0.5 µm Pall Metrigard filter paper) aliquot was then frozen for later determination of sulphate (SO₄), chloride (Cl), nitrate/nitrite (NO_x-N), filterable reactive phosphorus (FRP-P), ammonia (NH₃-N) and dissolved organic carbon (DOC; measured as non-purgeable organic carbon). Another filtered aliquot was acidified with nitric acid (to a pH <2 approximately 1% v/v) and then kept at 4°C for later determination by ICP-AES/MS of a range

¹ All nutrients are measured as the key elements ie. TN-N, TP-P, NO_x-N, FRP-P and NH₃-N, but will be referred to hereafter without the -N or -P. Ammonia also includes ammonium. NO_x includes both nitrate and nitrite.

of metals (Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, Pb, Se, U & Zn) – note that range of metals/metalloids measured was increased to include B, Cu, Pb compared to previous years. Alkalinity was measured on an unfiltered aliquot for each site according to the titration methodology in APHA (2017).

All chemical analyses were performed at the School of Science Analytical Facility (Edith Cowan University) as per APHA (2017).

8.2 DATA ANALYSIS

In the data analysis, concentrations that were below detection limits were assigned a value of half the detection limit and included in the calculation. This approach tends to strike a middle ground between being overly conservative and not conservative.

Water quality variables were analysed using principal components ordination (PCO) (PRIMER-E Ltd 2006). Prior to ordination, metal and nutrient data were \log_{10} transformed, but physico-chemical were not, all data were normalised and a resemblance matrix created using Euclidean distance. Statistically significant ($p < 0.05$) differences between *a priori* groups was tested with one-way PERMANOVA².

² Multivariate ordination is commonly used in ecological research, such as principal coordinate analysis (PCO). PCO is normally used to ordinate linear data (such as environmental data – water quality, or genetic distance data, etc.). Ordinations are not used to test hypotheses but to visually compare spatial data in order to inform hypothesis testing (e.g., *a priori* groupings using permutational PERMANOVA).

Ordinations attempt to set ‘into order’ samples with multiple parameters (e.g., a sample of water with *n* associated chemical variables). Samples are compared mathematically to determine their level of similarity (two samples with identical parameters would be 100% similar). Once a similarity value is determined (accounting for all measured variables), it can be plotted on a graph, so two samples 100% similar would be at the same point on the graph and then increasingly further away if they were less similar. The ordination attempts to show the samples spaced according to their similarity to each other, in two or more dimensions.

9. RESULTS AND DISCUSSION

Sampling of the floating islands was limited to June/July and December 2019 as these were periods when water levels within the dam were low enough to ensure that the dam was not directly connected to the lake. Additionally, these times were when the solar pump was fully operational.

Examination of the physico-chemical data collected (temperature, dissolved oxygen, ORP, conductivity, pH and alkalinity) in a PCO (Figure 3) shows strong separation between the groundwater collected and the other sites. No differences are obvious between surface (top) and bottom samples. Further other than a separation based on warmer temperatures and higher pH in December compared to June/July there are no obvious differences between sites.

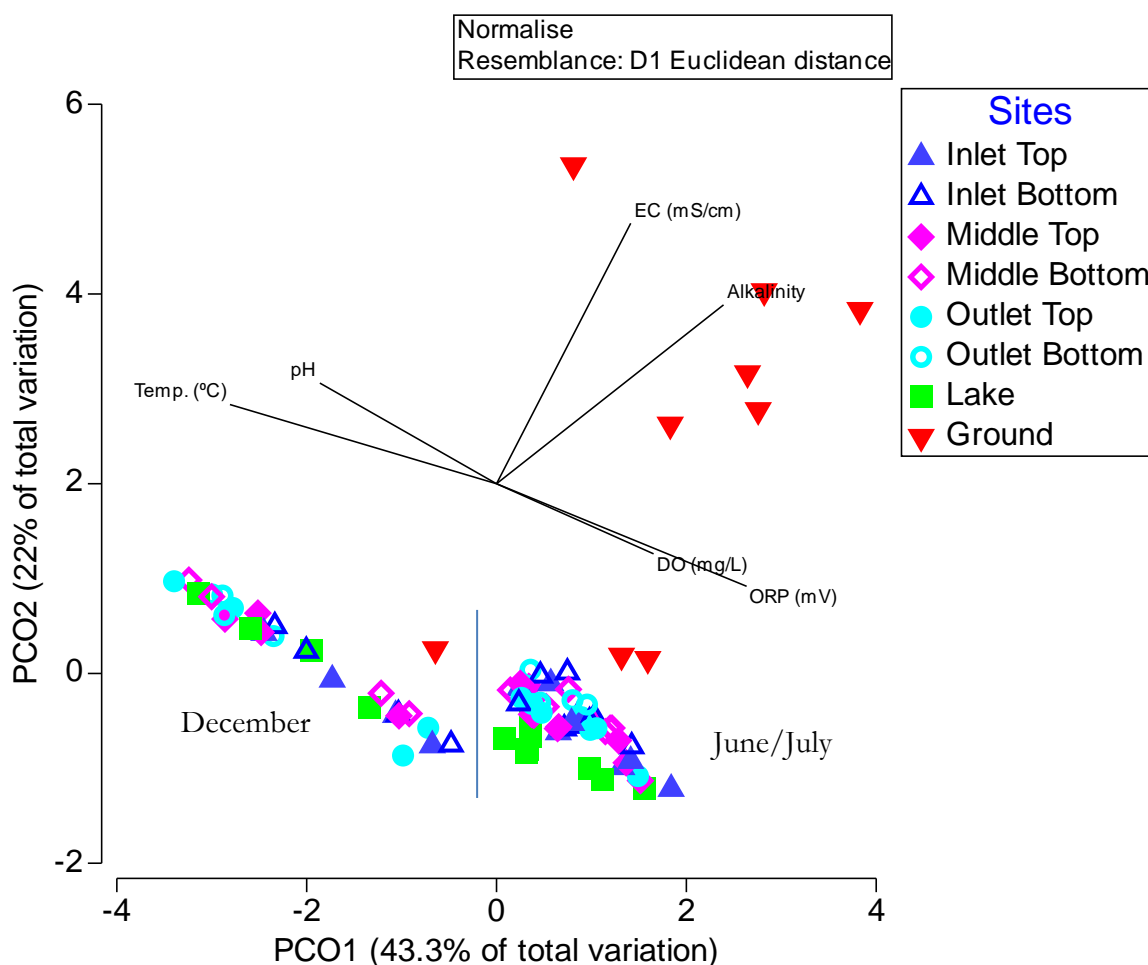
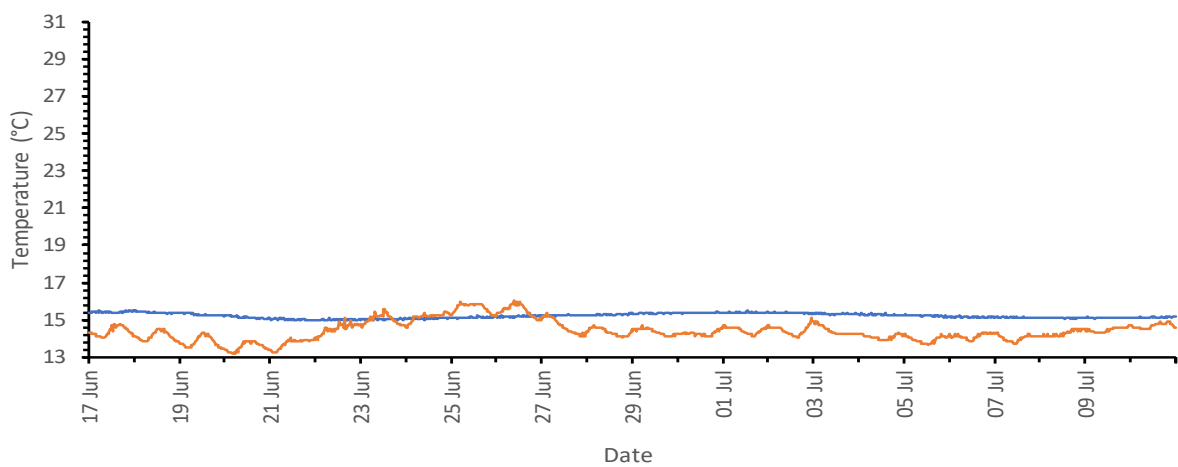


Figure 3. Principal coordinates analysis (PCO) of physico-chemical data collected at the floating island dam monitoring sites in December and June/July 2019. Vectors show correlations with the ordination space in a positive direction.

The floating island dam was thermally stratified from the 13th of December 2019, with daily stratification between 9th and 12th of December (Figure 4). Between June and July 2019, there was no stratification – although the surface was occasionally cooler than the bottom water this has probably more to do with sensor being not deep enough and became exposed to the air. Stratification results in the physical separation of surface and bottom waters in the dam due to density changes in water caused by the temperature difference (warmer water is less dense than cooler water). The roots of the plants on the floating islands would probably not penetrate the bottom waters. Therefore, stratification would potentially create a thin surface layer for treatment with high contact between the water and plant roots, with a deeper storage area below for nutrients coming from biofilms and dead plant materials deposited at the sediment. Samples from the bottom were therefore analysed throughout December and on the 21/6/2019.

a) Sampling Time 1 (June to July 2019)



b) Sampling Time 2 (December 2019)

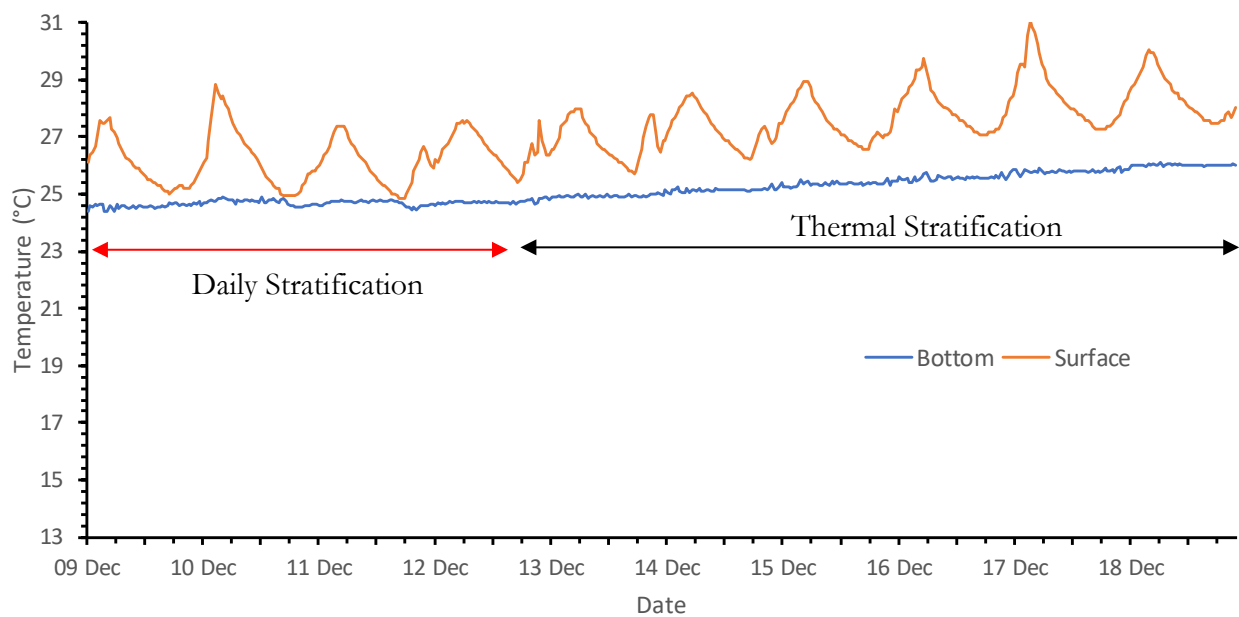


Figure 4. Temperature at the surface and bottom of the floating island dam during the two sampling periods.

Focusing on the top and bottom samples firstly using the combined nutrient and metal data, these are shown in a PCO (without groundwater or lake sites) in Figure 5. A oneway PERMANOVA comparing top and bottom samples for nutrient and metal data found no significant difference ($F_{s0.99}$; $P=0.38$) between them, therefore bottom samples will not consider further. Stratification was absent in June and had just become established in December which may account for the lack of difference seen.

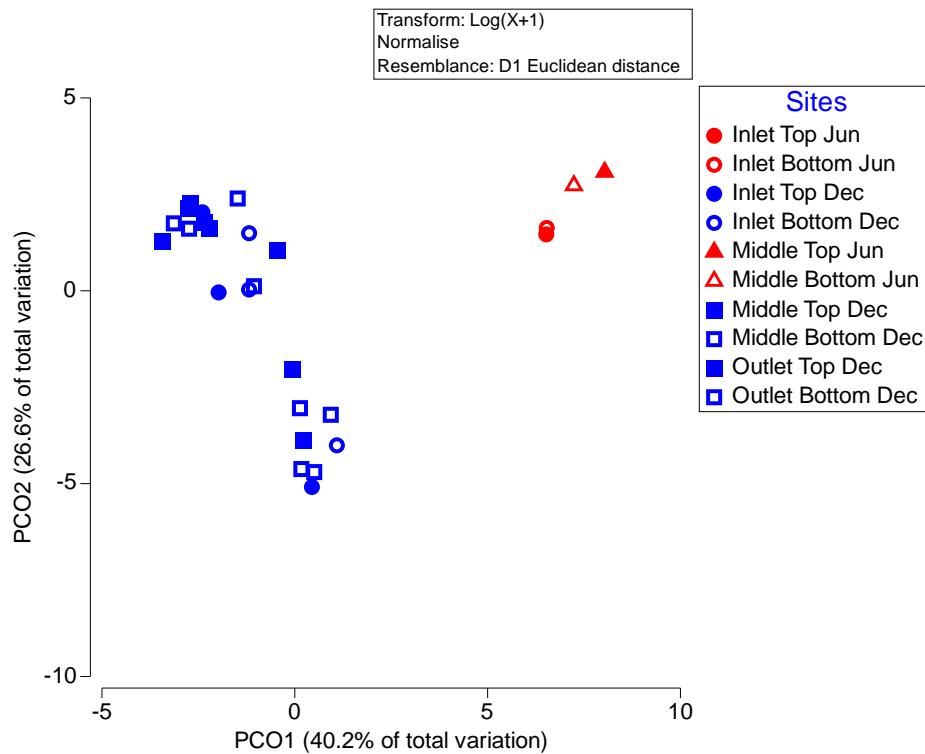


Figure 5. Principal coordinate analysis (PCO) of metals and nutrients data in top and bottom samples collected in June and December 2019.

Next we examined the surface (top) metal and nutrient data for differences between sites which would indicate possible treatment by the islands (Figure 6). There was a significant difference ($F_{s5.67}$; $P<0.001$) between sites (top only), however pairwise comparisons revealed only groundwater samples were significantly ($P<0.05$) to other sites. The lack of difference between sites (excluding groundwater) states that overall the water quality in the lake were not significantly different to the waters at any stage of the treatment process i.e the floating islands do not generally alter water quality. The differences seen in groundwater suggest that barriers between the floating island dam and the lake and solar pond were effective at preventing significant water movement between them – in fact it was very difficult to collect enough water for analysis. The middle site groundwater (not identified in the figures) was much closer to the other sites in terms of physico-chemical, metal and nutrients than the other groundwater sites – suggesting that this edge of the dam was connected to the groundwater. High levels of water in the dam relative to the lake due to pumping would probably ensure that water from the dam was being lost to groundwater rather than the groundwater being added to the dam (which could reduce removal rates).

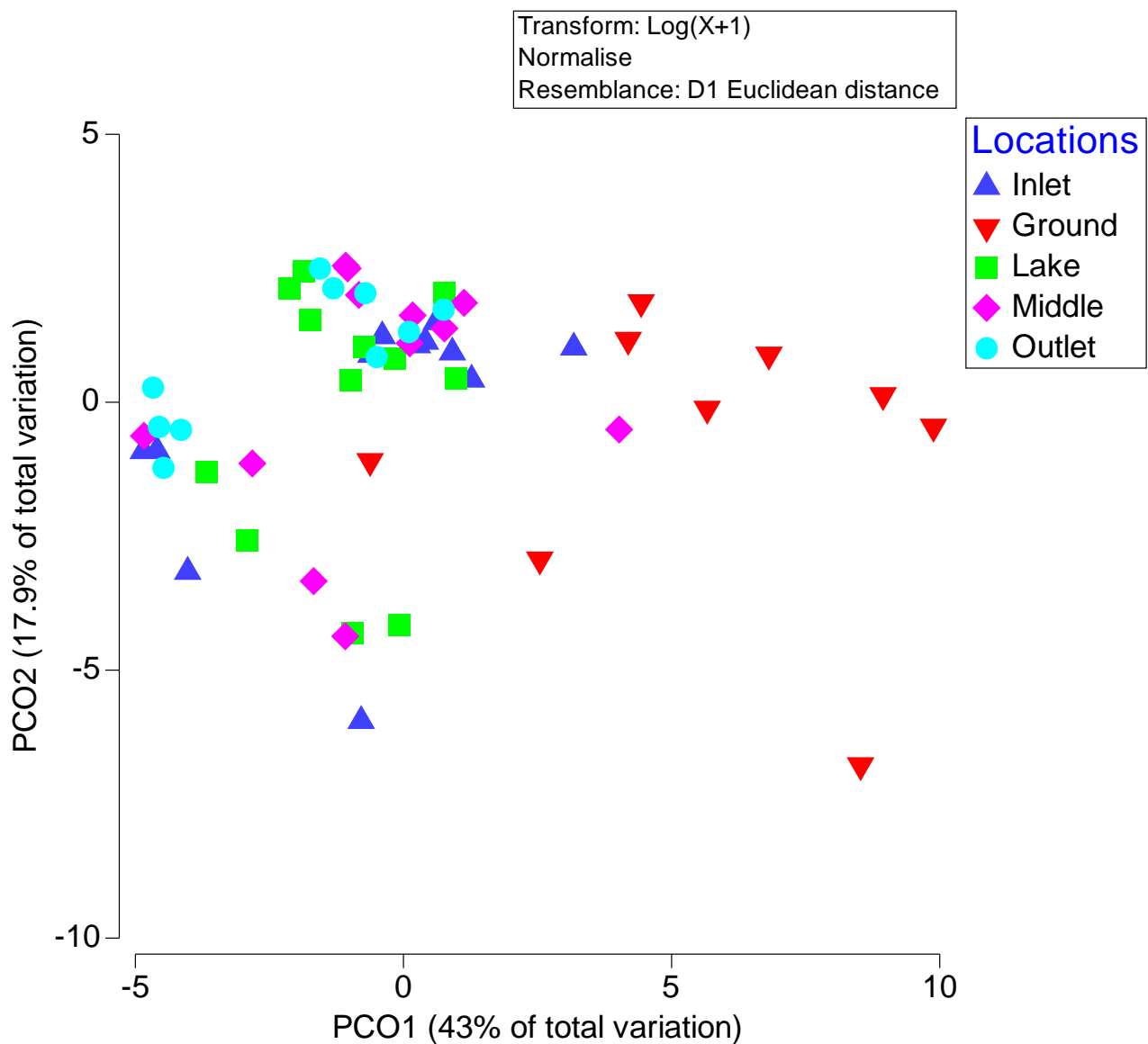


Figure 6. Principal coordinate analysis (PCO) of metals and nutrients data in top samples collected in June/July and December 2019 from all sites sampled.

It was speculated that large rainfall events could have impacted on the efficiency of the floating islands for metal or nutrient removal. There was no rainfall during the December sampling and as shown in Figure 7 for the June/July sampling. Despite no rainfall in December, there was no difference across the sites in nutrients or metals suggesting that rainfall did not have an impact on the functioning of the system.

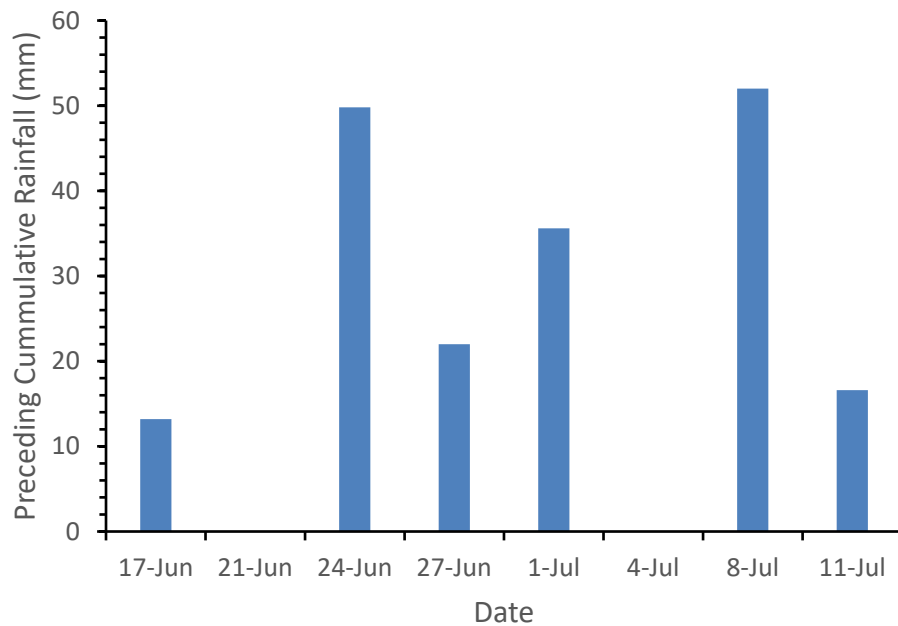
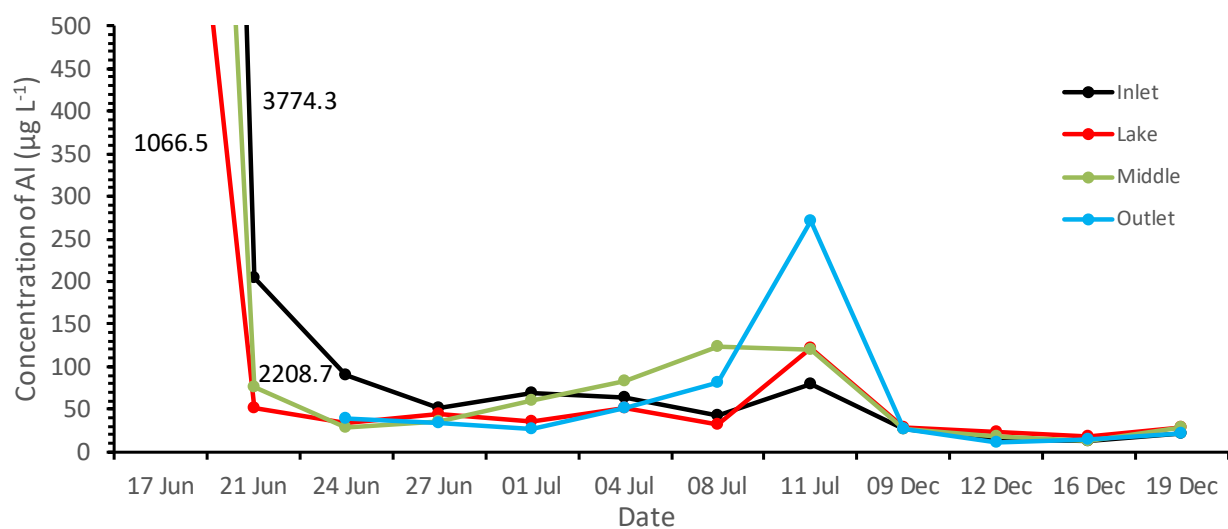


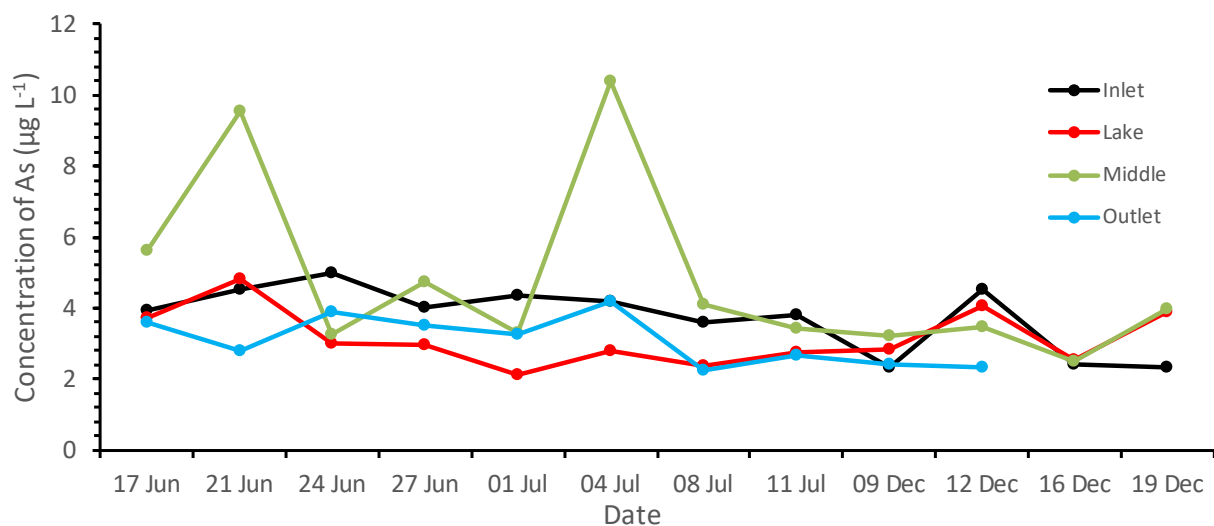
Figure 7. Rainfall recorded for Wanneroo (Bureau of Meteorology) accumulated between sampling times or 3 days before the first sampling occasion. There was no rainfall during December sampling.

Although there were no overall changes in water quality across the floating island system, this may have masked changes in individual metals or nutrients. In Figure 8, individual trace metals are shown over time and between sites. In December 2019 samples, there is a slight suggestion of As, Cd, Co, Cr, Cu, Pb, Ni, Se and U that outlet concentrations are lower and less variable than those of the other sites which may be indicative of removal by the floating plants.

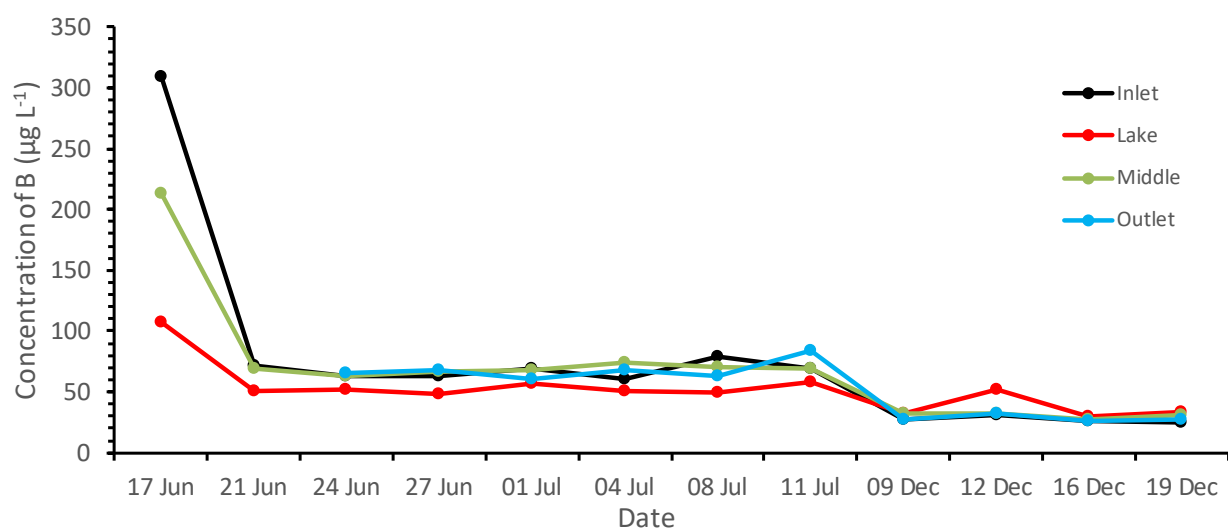
a) Aluminium



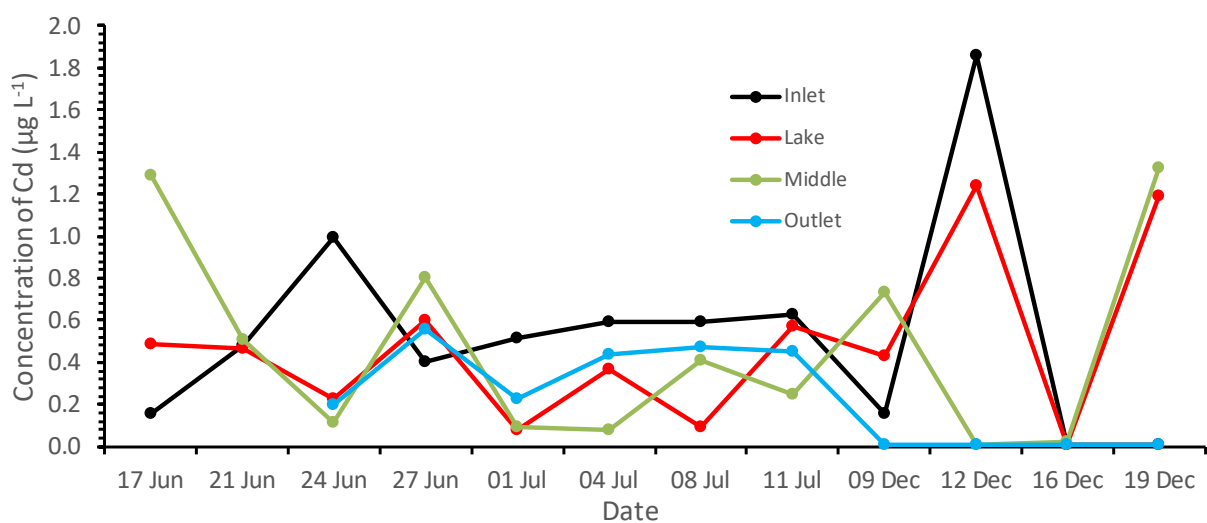
b) Arsenic



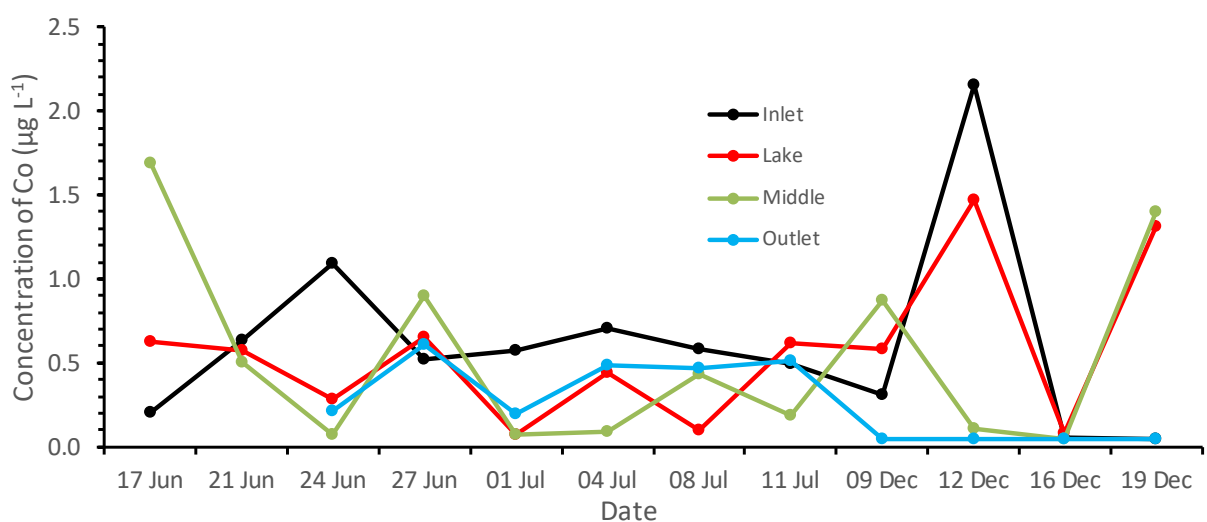
c) Boron



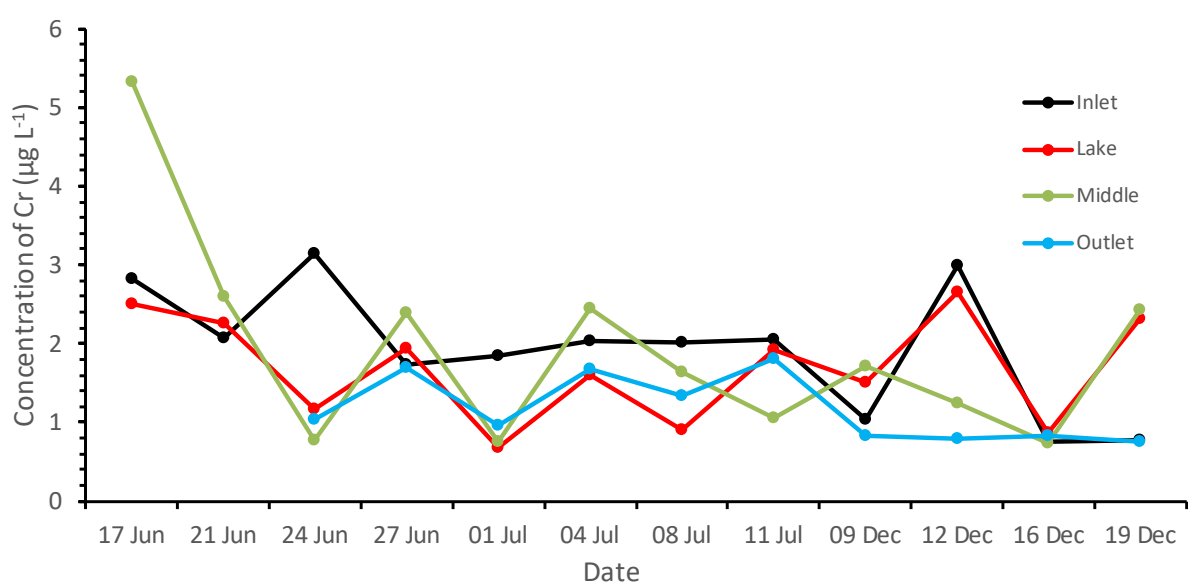
d) Cadmium



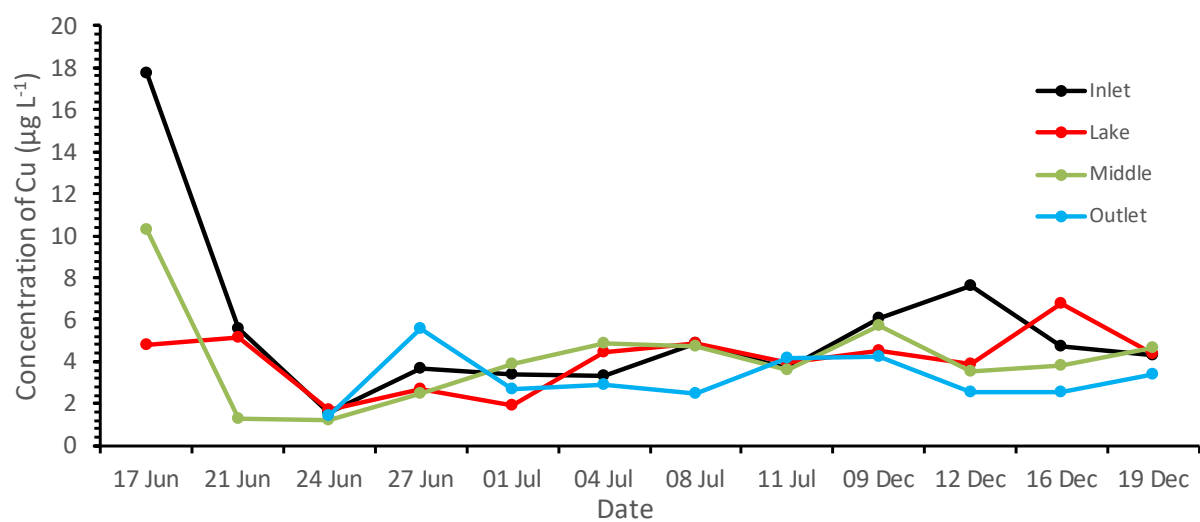
e) Cobalt



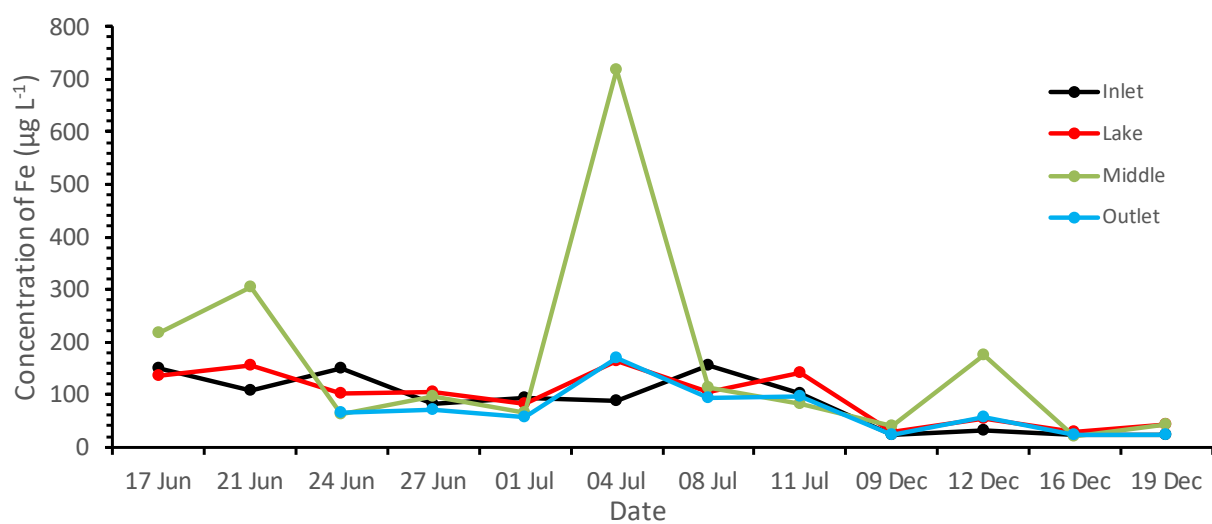
f) Chromium



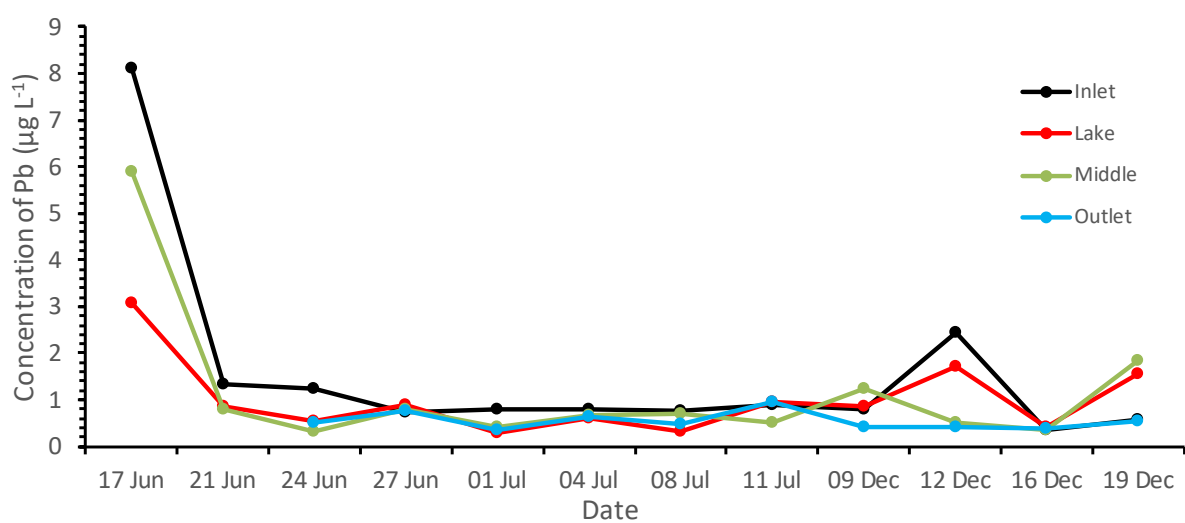
g) Copper



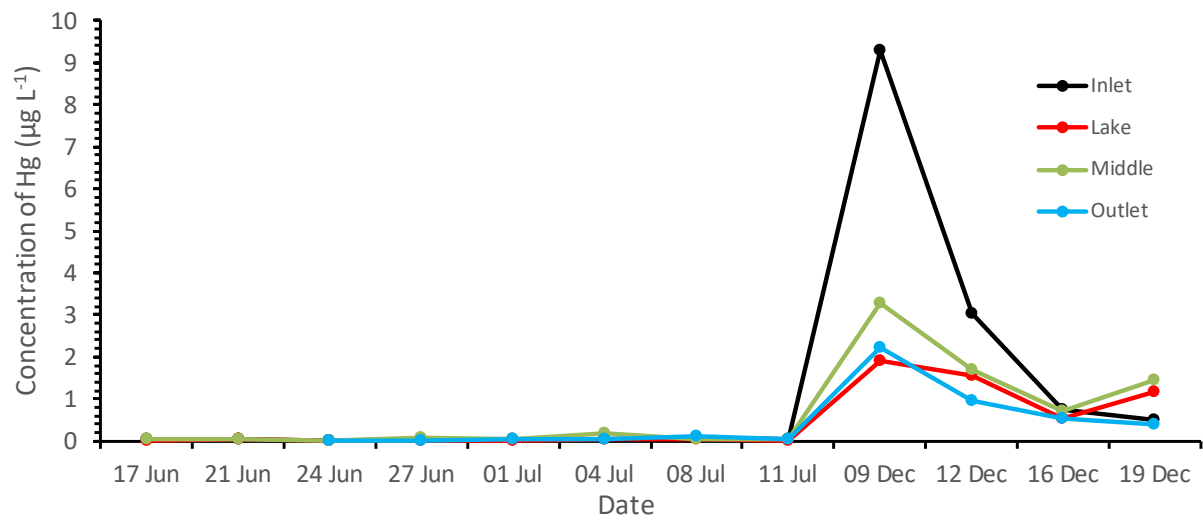
h) Iron



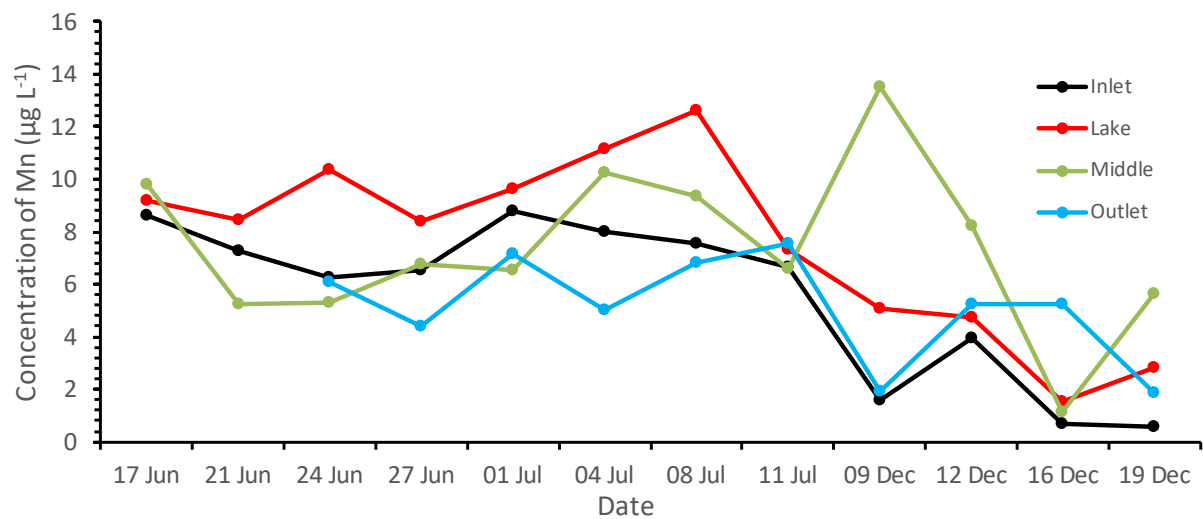
i) Lead



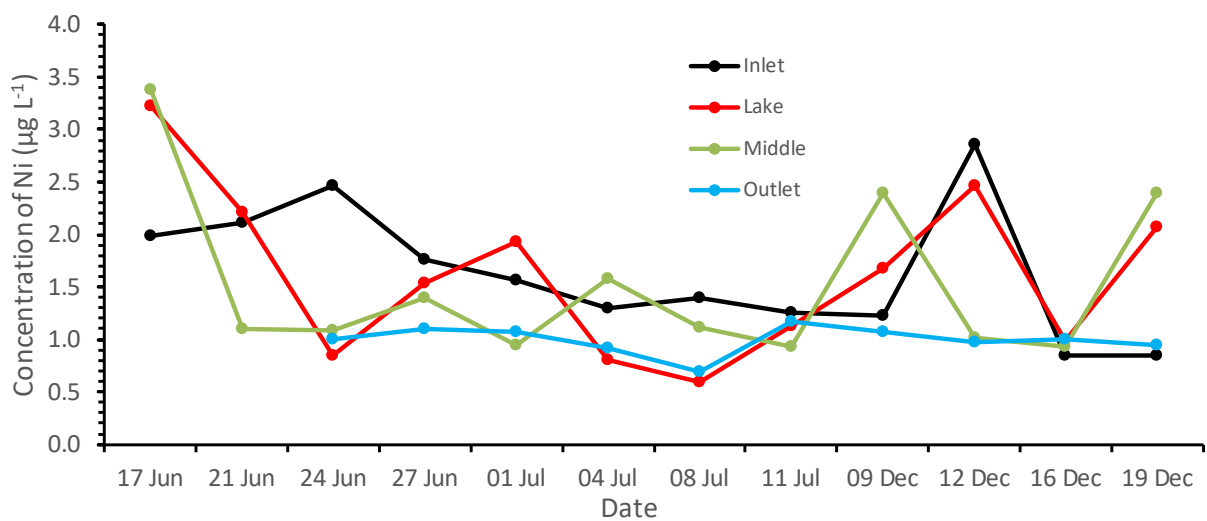
j) Mercury



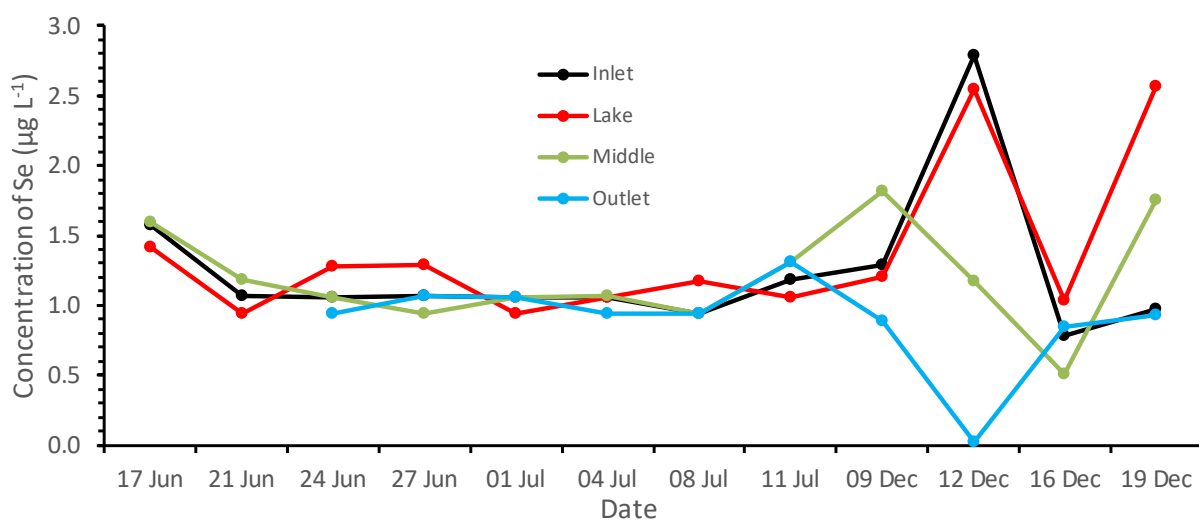
k) Manganese



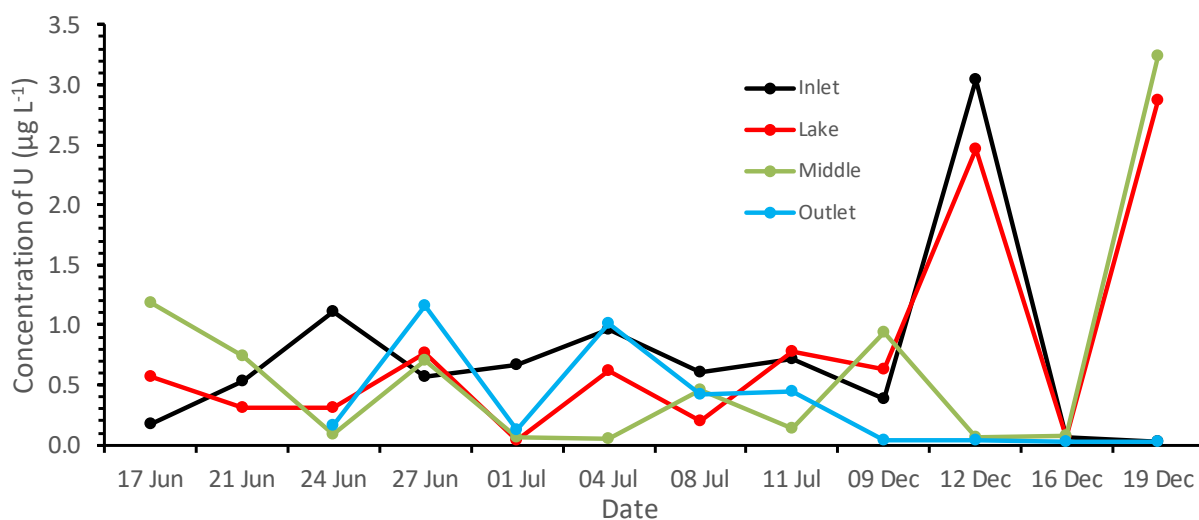
l) Nickel



m) Selenium



n) Uranium



o) Zinc

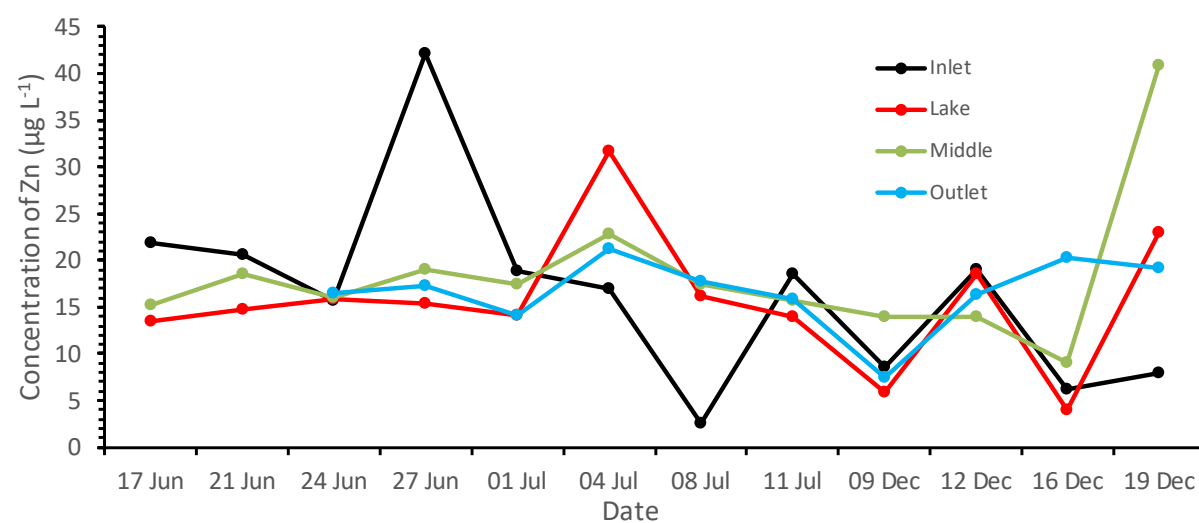


Figure 8. Trace metal concentrations at surface sampling sites across the floating islands at Lake Goollelal, across the sampling times (shown as categories rather than time).

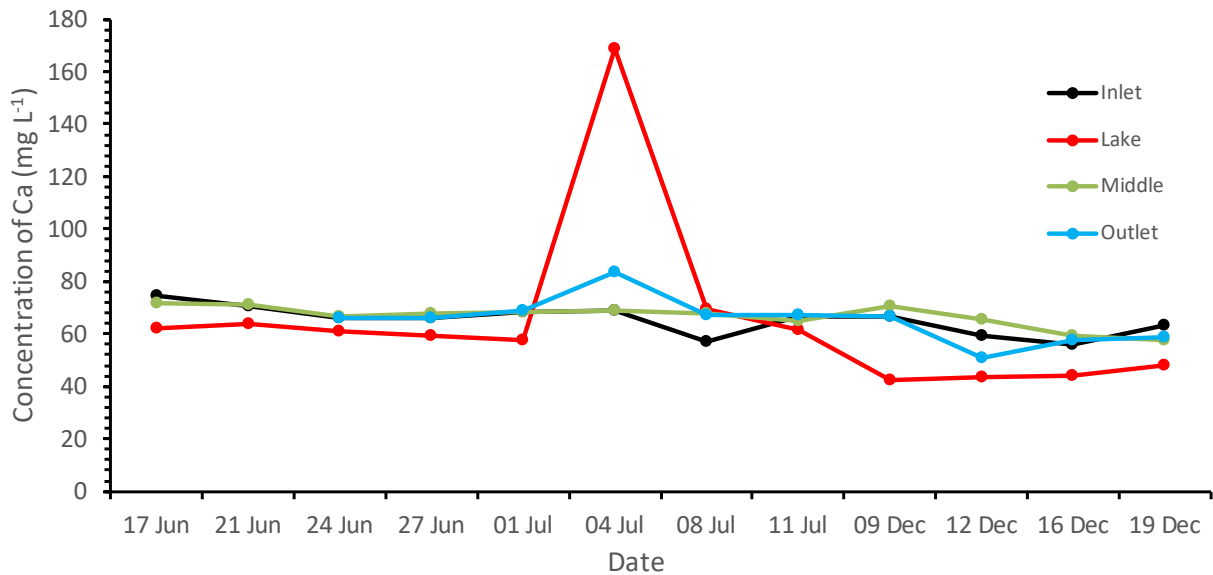
The lake site was originally chosen to reflect the water flowing out of the floating island dam to demonstrate any potential treatment that might occur between the outlet and lake. While the floating islands were being sampled, Lake Goollelal was also being sampled as part of the regular Yellagonga monitoring program. Generally, for most metals and nutrients at most times the lake concentrations were higher than that of the monitoring site (Table 1). As the lake site was not significantly different to the floating island sites, this suggests that the solar pond from where the water is drawn is slightly more contaminated than the rest of the lake.

Table 1. Comparison of metals and nutrients measured at the lake site for this study and samples taken as part of the Yellagonga monitoring at South Lake Goollelal at the closest time possible.

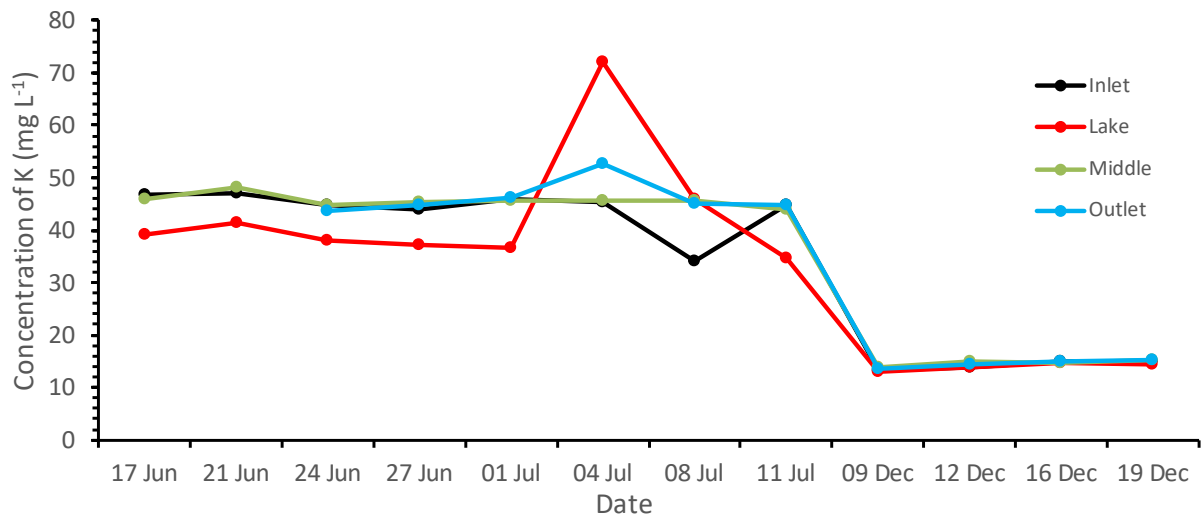
Analyte	Units	21/6/19		23/7/19		11/7/1		19/12/19	
		Monitoring	Lake	Monitoring	Lake	Monitoring	Lake	Monitoring	Lake
Al	µg L ⁻¹	100	51.8	44	121.5	14.7	28.6		
As	µg L ⁻¹	2.3	4.82	1.9	2.76	1.94	3.90		
B	µg L ⁻¹	47	50.7	36	58.6	57.3	34.0		
Cd	µg L ⁻¹	<0.01	0.46	<0.01	0.57	<0.01	1.19		
Co	µg L ⁻¹	0.08	0.57	0.06	0.61	0.07	1.32		
Cr	µg L ⁻¹	0.8	2.25	0.7	1.93	0.52	2.31		
Cu	µg L ⁻¹	1.9	5.13	2.4	3.96	6.48	4.41		
Fe	µg L ⁻¹	71	155	85	140	11.8	42.0		
Hg	µg L ⁻¹	0.5	0.02	0.9	0.01	14.23	1.16		
Mn	µg L ⁻¹	1.9	8.43	2.3	7.32	0.62	2.81		
Ni	µg L ⁻¹	0.8	2.21	0.6	1.12	0.60	2.07		
Pb	µg L ⁻¹	0.9	0.85	0.3	0.95	0.37	1.56		
Se	µg L ⁻¹	<0.05	0.94	<0.05	1.06	1.89	2.56		
U	µg L ⁻¹	0.1	0.31	<0.02	0.78	0.07	2.87		
Zn	µg L ⁻¹	2.9	14.81	3.3	13.89	<0.25	22.97		
Ca	mg L ⁻¹	52	64	72	62	44	48		
K	mg L ⁻¹	14	41	12	35	36	14		
Mg	mg L ⁻¹	34	147	28	121	140	37		
Na	mg L ⁻¹	125	18	100	15	12	166		
NH ₄ -N	µg L ⁻¹	<3	19	<3	24	24	10		
NO _x -N	µg L ⁻¹	<2	11	5	14	5	4		
Total N	µg L ⁻¹	746	1490	389	990	904	898		
FRP-P	µg L ⁻¹	4	3	5	4	4	7		
Total P	µg L ⁻¹	50	<20	29	<20	<20	<20		
Cl ⁻	mg L ⁻¹	84	167	104	121	159	149		
SO ₄ ²⁻	mg L ⁻¹	57	81	63	83	111	108		
DOC	mg L ⁻¹	10.0	13.7	13.2	9.4	13.1	12.7		

Common cations and anions show little variation across the sites, although this would be expected as plants generally do not uptake these ions (Figure 9). The major ions do show shifts in abundance between sampling times, with sodium increasing in December, and potassium and magnesium decreasing in concentration.

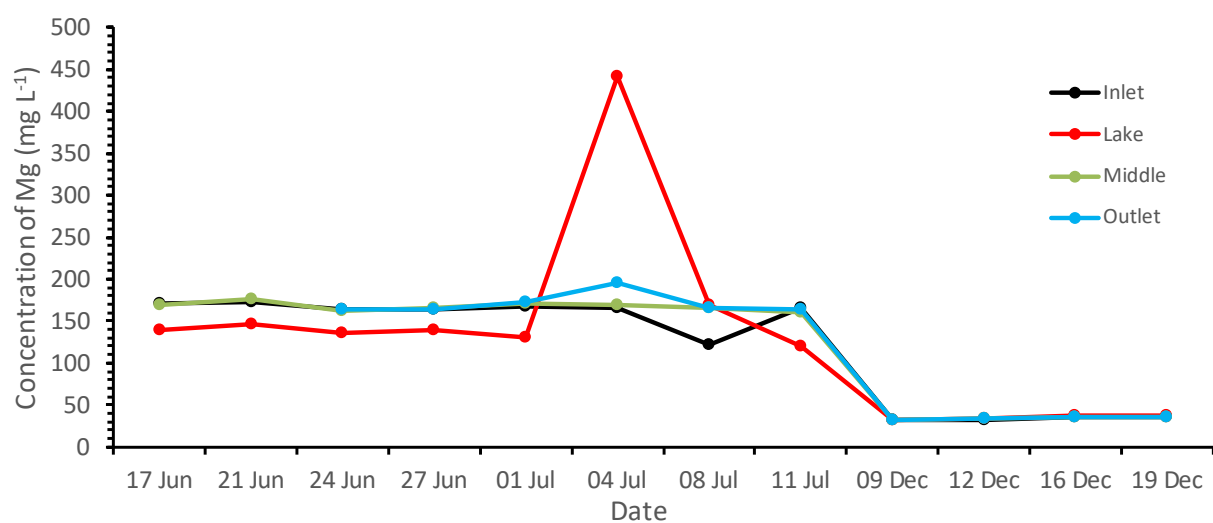
a) Calcium



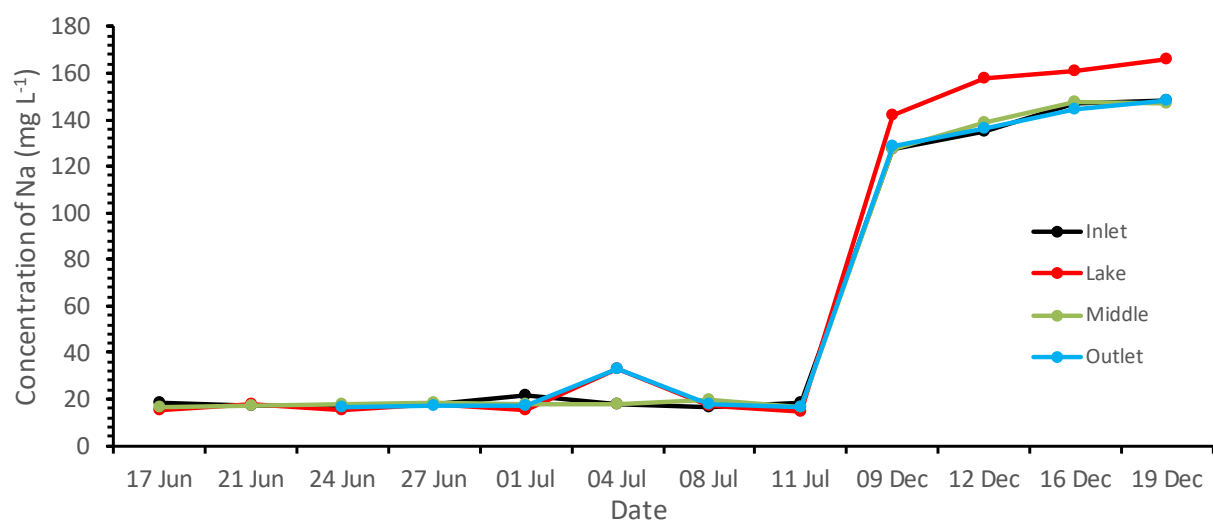
b) Potassium



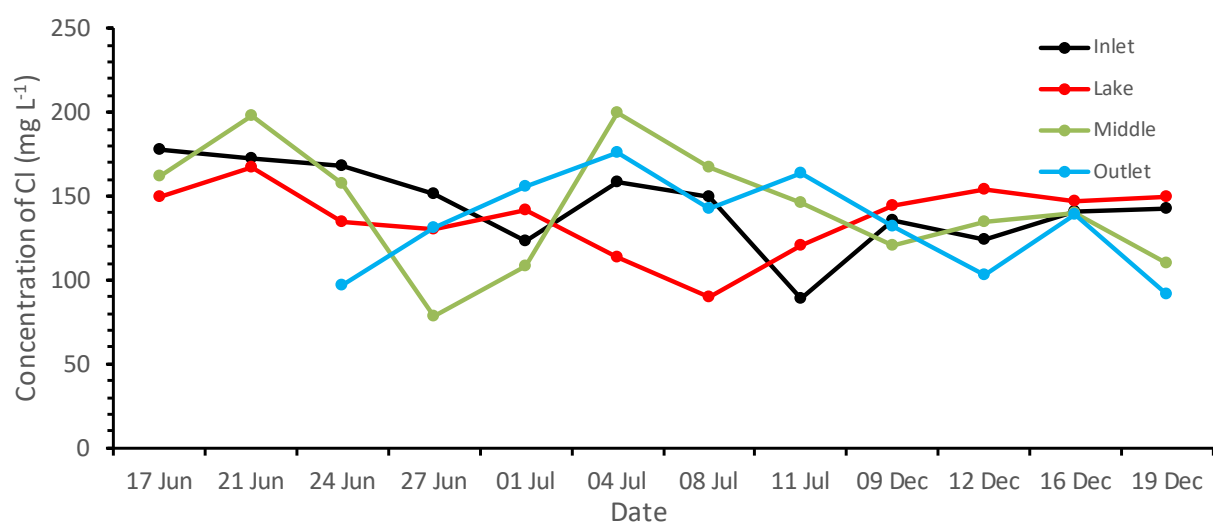
c) Magnesium



d) Sodium



e) Chloride



f) Sulphate

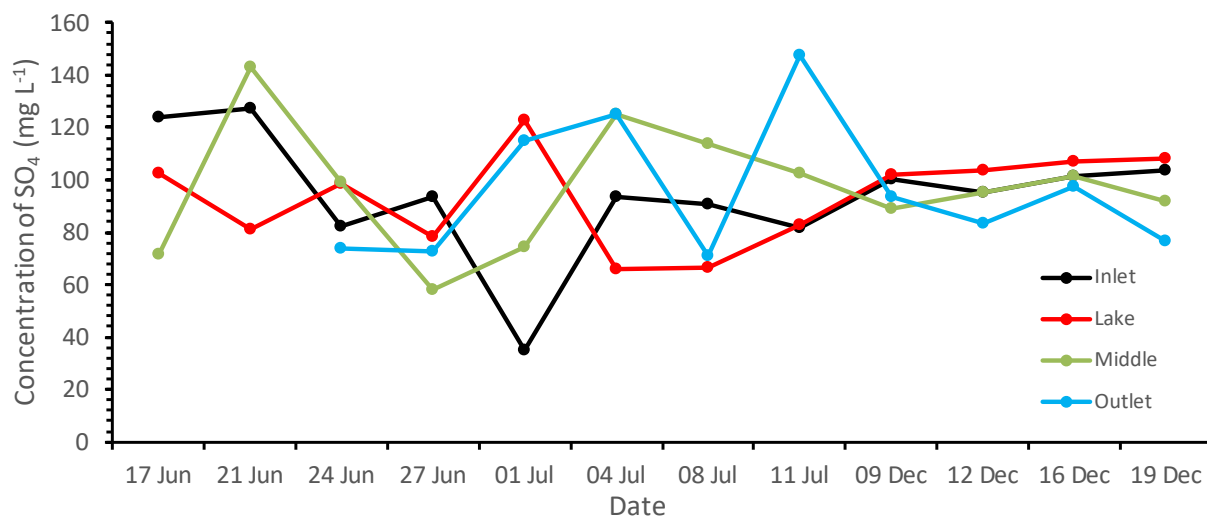
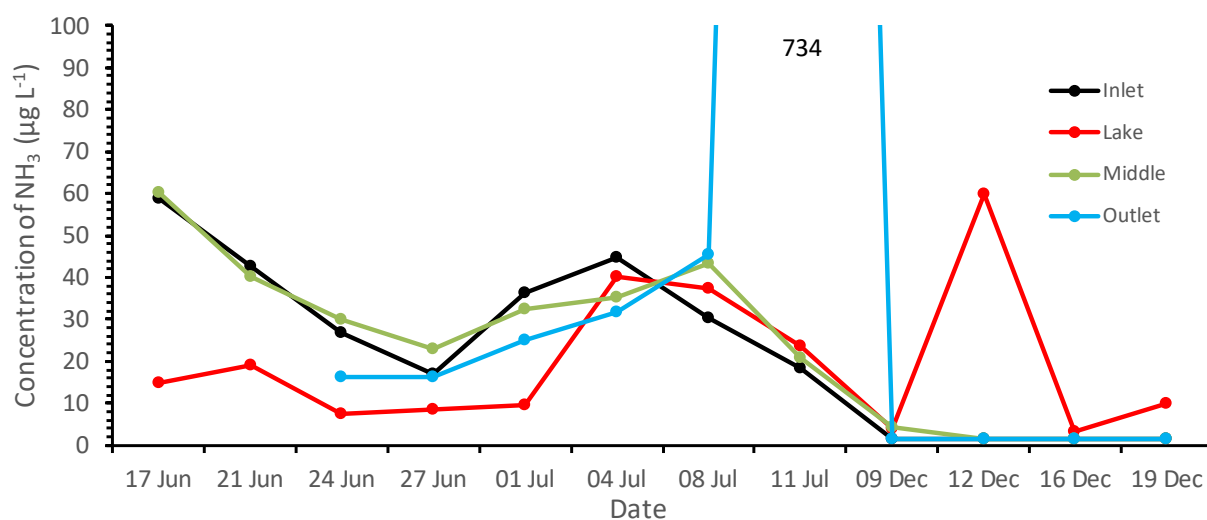
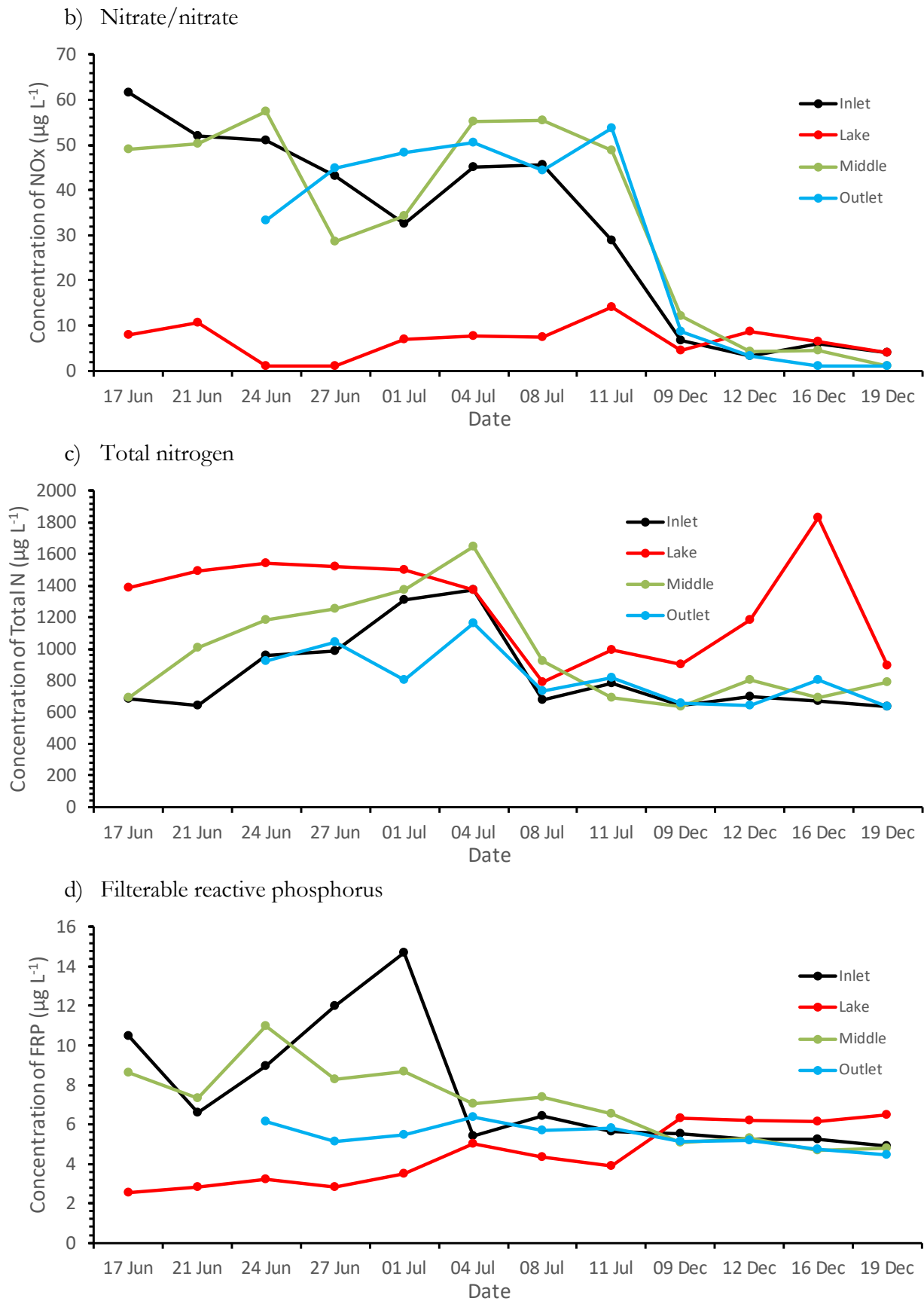


Figure 9. Common cation and anion concentrations at surface sampling sites across the floating islands at Lake Goollelal, across the sampling times (shown as categories rather than time).

Close examination of the trends in nutrients (Figure 10) does not reveal any trends or instances that suggest nutrients are being removed by the floating islands.

a) Ammonia





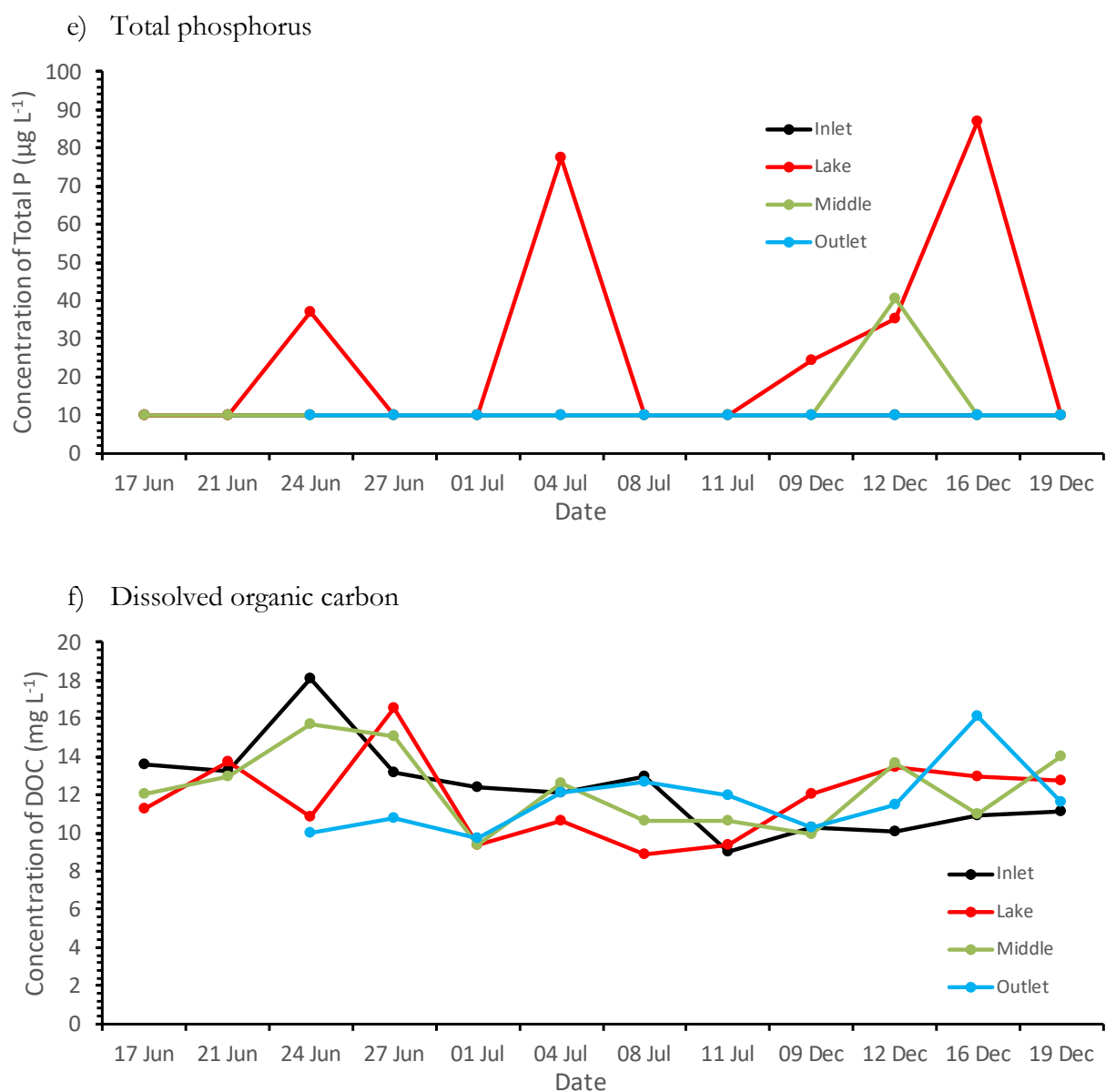
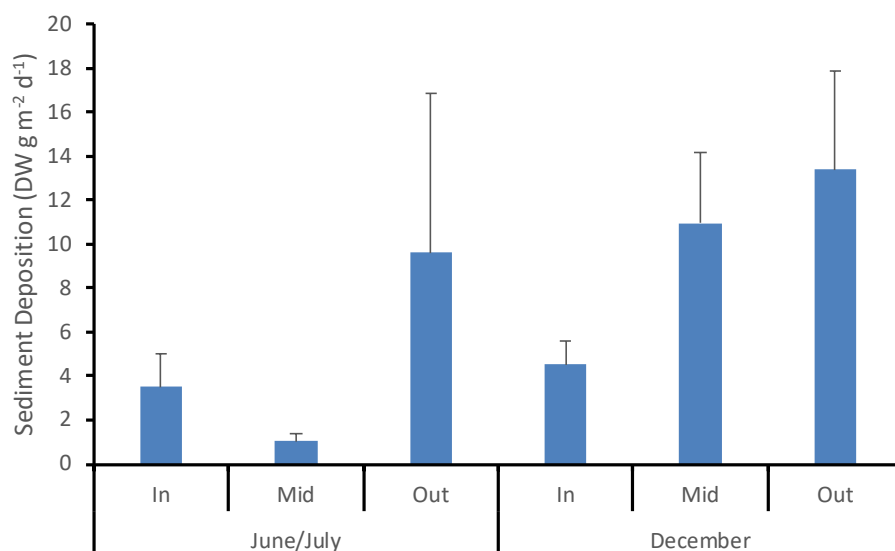


Figure 10. Nutrient concentrations at surface sampling sites across the floating islands at Lake Goolllelal, across the sampling times (shown as categories rather than time).

Floating islands are believed to achieve long term effectiveness for nutrient removal through biofilms and dead plant material accumulating beneath them, transferring stored nutrients to the sediment. To assess the rate of deposition we used sediment traps in both sampling occasions. Sedimentation data was highly variable, but it appeared to increase slightly across the dam (inlet to outlet) and the bulk of the material being deposited was organic (Figure 11). These sedimentation results therefore support the deposition of material from the floating islands – it is unknown what nutrients were contained within this deposited material.

a) Sediment deposition



b) Organic matter

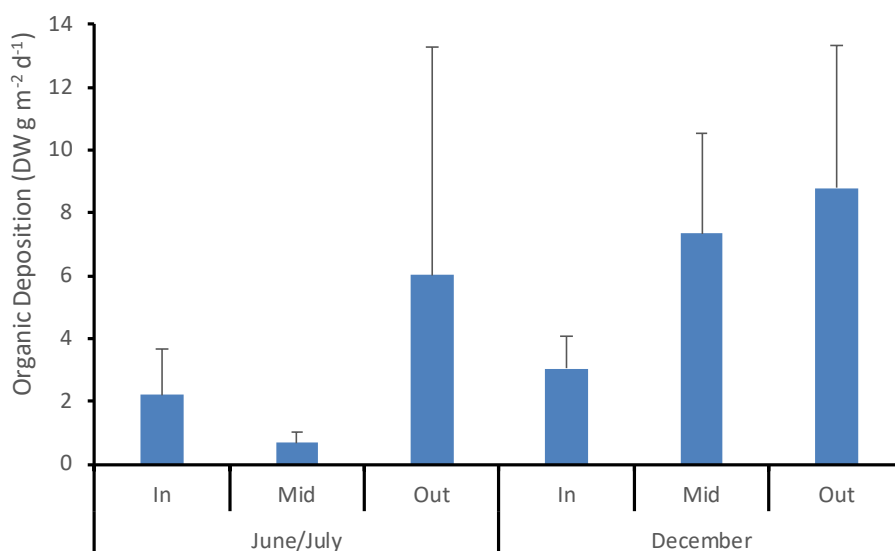


Figure 11. Rate of deposition of sediment as a) dry weight and b) organic matter in the floating islands experiment in June/July and December 2019 across the inlet, middle and outlet sites.

The design of the floating islands trial is unique in that it moves the treatment system out of the lake and into a controlled environment which can be manipulated to maximise its efficiency. Obviously increasing the quality of plants and islands would potentially improve performance with just 5% of the dam covered. Further, while no evidence could be found regarding the islands effectiveness at removing nutrients or metals, this may be due to the relatively small size of the islands and the low concentrations within the system.

Regular monitoring of Lake Goollelal as part of the Yellagonga surface and groundwater monitoring program shows the lake has low concentrations of all dissolved nutrient, with occasional spikes in total nutrients. There are however indications of increasing concentrations of total P in incoming groundwater. The low nutrient concentrations at present do not suggest that there is currently a need for the floating islands solution. The approach of using floating islands in this manner may have value at other more contaminated sites, if removal efficiencies can be demonstrated.

10. CONCLUSIONS

The physical arrangement of the floating islands at Lake Goollelal, utilising a dam off the main lake and solar power to pump water through the system is a useful innovation. More islands and more plants would increase the chance of producing a detectable change in water quality across the systems. The system if it was able to treat 60,000 L per day (rounded up from the December flow rate) would take approximately 25 years to treat the entire volume of the lake if it was 1 m deep. Therefore, for the system to have any meaningful impact on lake nutrient or metal concentrations it would need to substantially improve removal efficiency and the volume treated. The high hydraulic residence time of 86 days in December suggests that there is scope for substantially increasing flow rates and still allowing time for treatment. This research project was unable to detect any measurable improvement in water quality due to the system. Furthermore, it is not apparent that there is a need for this system at Lake Goollelal as nutrient concentrations presently in the lake are not problematic.

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