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Nutrient Removal from Stormwater using Australian Native Plants in Constructed Floating Wetland

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Abstract. Stormwater pollution causes excessive nutrient influx to rivers and lakes, which can trigger algal bloom and subsequent damages to the freshwater ecosystem. Constructed Floating Wetland (CFW), a cost-effective technology, uses aquatic plants in a hydroponic system to strip nutrients from stormwater through plant uptake. In this study, performance of two native Australian plants such as *Eleocharis acuta* (*EA*) and *Baumea preissi* (*BP*) in removing nutrients (NH_3-N, NO_3-N, and PO_4-P) was investigated. Experiments were conducted outdoor in microcosm (20L) buckets, including an unplanted control bucket. About 65% and 96% of Total Inorganic Nitrogen (NH_3-N + NO_3-N) was removed in 14 days by *EA* and *BP*, respectively. Both plants could remove up to 40% of PO_4-P in the same duration. A significant difference ($p<0.05$) between control and planted buckets was detected in ANOVA analysis. First-order kinetic rates (k) for both plants revealed that *BP* (k=0.341, 0.099 and 0.044 per day) has higher kinetic rates than *EA* (0.174, 0.021 and 0.039 per day) for all nutrients (NH_3-N, NO_3-N and PO_4-P), respectively. Elevated level of Dissolved Oxygen (DO) was observed in *EA* planted bucket, raising interest for further research. This study proved the suitability of CFW system to treat stormwater using Australian native plants.

Keywords: *stormwater*, *treatment*, *floating wetland*, *aquatic plants*, *nutrients*.

1. Introduction

Stormwater carries nutrient and metals to the rivers and lakes impacting the aquatic ecosystems throughout the world including Australia (Alam et al., 2018; Beck and Birch, 2012). It is one of the major sources of pollutants for surface waters in many countries (Barbosa et al., 2012). An estimated 3 billion m^3 of stormwater is generated in Australia from its urban areas alone (ECRC-Australia, 2015). To treat this huge amount of stormwater, cheap and eco-friendly solutions are required. Constructed Floating Wetland (CFW) system is an emerging Best Management Practice (BMP) (Schwammberger et al., 2020) and is increasingly used throughout the world including Australia for stormwater treatment (Nichols et al., 2016; Walker et al., 2017). In a CFW system, aquatic plants are floated on the water with the help of floating bed and the roots of the plants goes directly into the water column from where they uptake pollutants such as nitrogen, phosphorus and dissolved metals (Bi et al., 2019).

One of the vital aspects of CFW treatment efficiency is plant selection (Shahid et al., 2018) and it is essential to select native plants where CFW system will be employed for stormwater treatment. It has been reported that non-native species may adapt to a different locality or different weather conditions, but nutrient removal efficiency will be reduced (Pavlineri et al., 2017). Moreover, exotic species can be invasive and can damage the native ecosystem. Hence, use of local water-tolerant species in a CFW system is highly recommended (Wang and Sample, 2014). Unfortunately, despite the increasing use of CFW systems in Australia, only one native plant, *Carex appressa* has been investigated for nutrient removal performance in CFW systems (Nichols et al., 2016; Schwammberger et al., 2019, 2020; Walker et al., 2017). Another study investigated six other native plants but not for nutrient removal; rather their salinity tolerance was studied (Sanicola et al., 2019). Hence, there is a need to investigate the nutrient removal performance of Australian native plants in CFW systems to achieve higher treatment efficiency and provide a range of choices to the end-users to remove their target pollutants.

Therefore, the objective of this study is to investigate nutrients (Ammonia Nitrogen: NH_3-N, Nitrate Nitrogen: NO_3-N and Phosphate Phosphorus: PO_4-P) removal performance of two Australian native species (*Eleocharis acuta - EA* and *Baumea preissi - BP*) for using in CFW system for stormwater treatment.

2. Materials and Methods

Two native plants (*Eleocharis acuta - EA* and *Baumea preissi - BP*) were selected for this study discussing with the local nursery (Natural Area Nursery in Perth, Western Australia) and two local companies (Ecocraft Environmental, https://www.ecocraft.net.au/ and FIA Technology, www.fiatechnology.com.au) who supply and install floating bed in CFW systems in Western Australia. To the best of our knowledge, there is no published article till 2020 regarding the nutrient removal performance of these two plants in a CFW system. Two plants from each species weighing around 45 gm fresh weight were acclimatized outdoor for two weeks. Typical acclimatization period in other studies varied between 1 and 8.5 weeks (Urakawa et al., 2017; Zhang et al., 2016). After the acclimatization period (2 weeks), when some physical growth of the plants was noticeable, the plants were moved to the experimental buckets. Three microcosm buckets of 20 L capacity were filled up to 18L with synthetic stormwater and placed outdoor for experiments. The synthetic stormwater was prepared using Ammonium Chloride (NH_4Cl), Potassium Nitrate (KNO_3) and Potassium dihydrogen Phosphate (KH_2PO_4) respectively. In two of the buckets, one *Eleocharis acuta* and one *Baumea preissi* were floated with styrofoam and supporting cups. The remaining bucket was the control bucket without any plant. Another set of three buckets with same configuration was placed to duplicate the results of the experiment. Evapotranspiration losses from the buckets were filled up by adding the lost amount of water daily to keep the water level constant. The plants were exposed to a concentration of 6.27 mg/L of NH_3-N, 7.06 mg/L of NO_3-N and 3.22 mg/L of PO_4-P, which are the concentrations found in a stormwater receiving wetland named Neil McDougall park lake in the City of South Perth, Western Australia and is considered as a highly polluted lake.

The microcosm experiment was continued until 14 days. Sampling was performed at days 0, 1, 2, 3, 4, 6, 9, 11 and 14. Around 10 mL of samples were extracted from three sides of the bucket at 10 cm and 25 cm depth yielding a total sample volume of 60 mL. During this time, pH, electrical conductivity and Dissolved Oxygen (DO) were also monitored. The samples were measured for nutrients using Aquakem Analyzer 200 (Thermofisher Scientific). The data of the buckets with the same plant species or no species were averaged for further analysis. Percentage removal of the nutrients by each species and control experiment was calculated. The data were analyzed for normality and Levene's homogeneity of variances before conducting One-way ANOVA analysis to detect differences between the control and planted buckets. Since both the normality and homogeneity assumptions were violated, two robust tests of equality of means such as Brown-Forsythe and Welch tests were performed to confirm the results of ANOVA. Games-Howell post-hoc analysis was conducted to detect differences between species as variances between groups were not equal. Finally, first-order kinetic rates of the plant species were determined for different parameters using the following equation (Kadlec and Wallace, 2008; Kumar and Zhao, 2011):

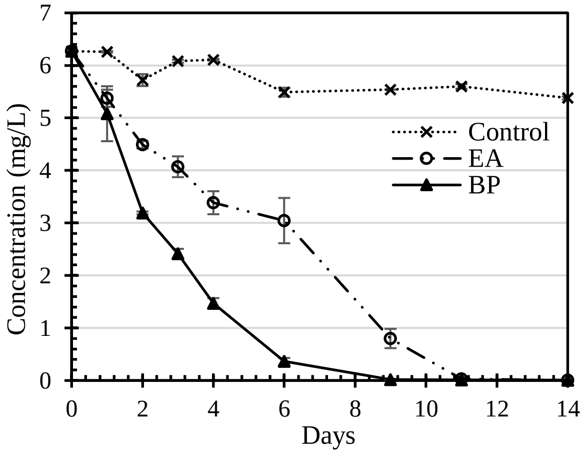
$$C = C_0 e^{-kt}$$

where C_0 is the initial concentration, t is time (days), C is the concentration (mg/L) at time t, k is the first-order kinetic or removal rate (per day).

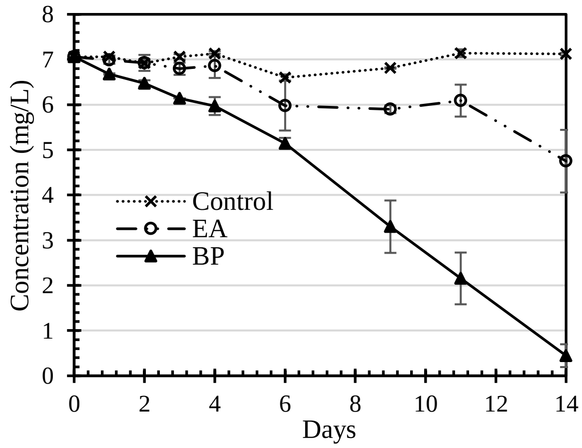
The errors of data fitting were calculated in terms of Root Mean Square Error (RMSE), R^2 and Nash-Sutcliffe Efficiency (NSE).

3. Results and Discussion

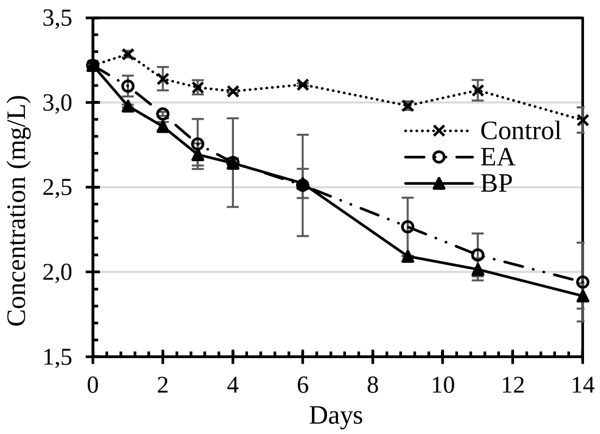
Figure 1 shows the reduction of concentration for NH_3-N, NO_3-N and PO_4-P over the 14 day experimental duration. Significant reduction of nutrient concentration by the plants compared to that of the control buckets (unplanted) is clearly visible from the figure. Figure 2 depicts the percentage removal of the nutrients at the end of 14 days. Both the plants achieved greater than 99% removal of NH_3-N after 14 days. *Baumea preissi* (*BP*) removed bulk of NH_3-N in 9 days, whereas it took 11 days for *Eleocharis acuta* (EA) to achieve similar removal. Only 14% NH_3-N removal was observed in the control bucket due to microbial presence. Ammonia volatilization also likely played a role in ammonia loss as the average pH was 7.75 in the control bucket. Almost 94% of NO_3-N was removed by *BP* after 14 days, whereas *EA* was able to remove only 33%. There was an increase of NO_3-N concentration by nearly 1% in the control bucket due to the conversion of the NH_3-N into NO_3-N. Concentration of NO_2 were measured but it was always below 0.001 mg/L and in many days below detection limit and as such ignored in the calculation. Nearly 96% of Total Inorganic Nitrogen (TIN) considered as Total Nitrogen (TN) for this study calculated as the summation of NH_3-N and NO_3-N were removed by *BP* compared to the 64.3% and 6.2% removal by *EA* and the control bucket. PO_4-P removal by both the plants were around 40% with *BP* doing slightly better (42.3%) than *EA* (39.7%). Only 10% PO_4-P was removed in the control bucket.



(a)



(b)



(c)

Figure 1: Nutrient Concentration Reduction over time by *EA*, *BP* and Control buckets. (a) NH_3-N (b) NO_3-N and (c) PO_4-P. Error bars in Standard Deviation.

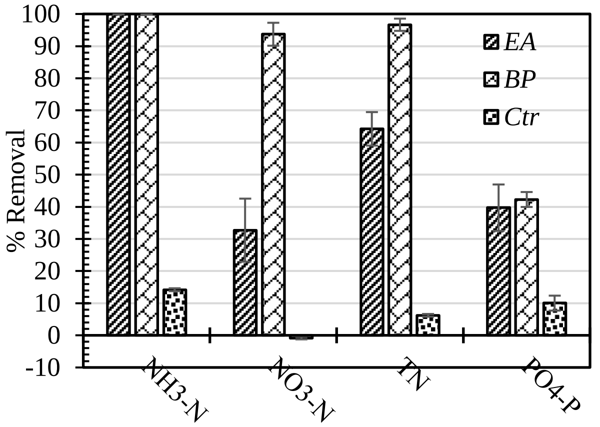


Figure 2: Percentage removal of Nutrients at 14 days. Error bars in Standard Deviation.

Nutrient removal performance of both plants were comparable with the results found in the literatures for different other plants in different regions. The TN removal between 4 – 92% for a hydraulic retention time (HRT) of 1 – 35 days were reported by a review study, which compiled the findings from studies conducted in the USA, China, Singapore, India, Turkey, Thailand, Netherlands, Italy Belgium, Uganda and New Zealand (Pavlineri et al., 2017). The same study reported a range of 13–90% TP removal in the reviewed articles. However, if similar HRT of this study (14 days) is considered, the highest reported removal of TP will come down to 58%, which implies that the other plants in other regions also have limited capability in removing TP compared to TN as found in this study. *Carex appressa* (*CA*), which is a native Australian plant was reported to remove 17% TN and 52% TP in a field study in Queensland, Australia (Nichols et al., 2016; Walker et al., 2017). Another field study in Queensland, Australia reported 15% TN and 17% TP removal by *CA* (Schwammberger et al., 2019). It is to be noted that direct comparison removal efficiency results of microcosm versus field studies may not be meaningful. Therefore, this study recommends plant tissue analysis of *EA* and *BP* grown in actual wetland to compare the nutrient accumulation in the plant tissue with that of *CA*. Plant tissue analysis is also important for developing harvesting strategy to permanently remove nutrients from the stormwater pond.

Table 1 highlights the significance of difference by different treatments through ANOVA, Brown-Forsythe and Welch tests. All three tests confirm that there is a significant difference ($p < 0.05$) between treatments. Games-Howell post-hoc analysis revealed that the mean concentrations of NH_3-N in both the planted buckets were significantly different from the control bucket, but the treatment between the plant species was not significantly different. For NO_3-N, there was no significant difference between *EA* and control bucket but *BP* was significantly different. For PO_4-P, both the plants (*EA* and *BP*) had significant difference with the control bucket, but no significant difference was detected between the plants.

Table 1: Comparison of mean concentration

Parameters		NH_3-N	NO_3-N	PO_4-P
Mean concentration (mg/L)	*EA*	3.05 ^{b}	6.37 ^{a}	2.61 ^{b}
	BP	2.09 ^{b}	4.48 ^{b}	2.54 ^{b}
	Ctr	5.83 ^{a}	6.99 ^{a}	3.10 ^{a}
Significance (p value)	ANOVA	0.001	0.003	0.009
	Brown-Forsythe	0.000	0.009	0.003
	Welch	0.002	0.01	0.012

*Concentrations (parameter wise) with same letters are not significantly different

Table 2 presents the results of kinetic analysis through first-order kinetic rate and data fitting errors. Kinetic rates of BP (0.341, 0.099 and 0.044) were higher than the kinetic rates of EA (0.174, 0.021 and 0.039) for all the three parameters (NH_3-N, NO_3-N and PO_4-P), respectively. On the other hand, kinetic rates of the control bucket were well below the rates of both plants, which further confirms the ability of nutrient removal by the plants. Since, NO_3-N concentration was increasing in the control bucket, the data did not fit in the first-order kinetic equation and the rate is zero. A negative value of Nash-Sutcliff Efficiency (NSE) confirms that the data could not be fitted in the equation. First order kinetics does not appear to be a good fit for BP for NO_3-N, which can be explained by NH_3-N depletion. Around 76% of NH_3-N was removed by day 4 and a rapid NO_3-N removal was observed after day 4 in the BP planted bucket.

Table 2: Kinetic rates and errors of data fitting

Treatment	**Kinetic Rate (per day)**			**RMSE (mg/L)**			**R^2**			**NSE**		
	NH_3-N	**NO_3-N**	**PO_4-P**	**NH_3-N**	**NO_3-N**	**PO_4-P**	**NH_3-N**	**NO_3-N**	**PO_4-P**	**NH_3-N**	**NO_3-N**	**PO_4-P**
EA	0.174	0.021	0.039	0.752	0.251	0.011	0.959	0.858	0.987	0.946	0.84	0.98
BP	0.341	0.099	0.044	0.241	3.423	0.020	0.989	0.769	0.982	0.984	0.76	0.96
Ctr	0.012	0.000	0.007	0.109	0.095	0.009	0.701	0.001	0.741	0.667	-0.11	0.75

RMSE = Root Mean Square Error, NSE = Nash-Sutcliffe Efficiency

We hypothesize that *BP* is a nitrogen hungry species and to satisfy the requirement of nitrogen, it started rapid uptake of NO_3-N once NH_3-N concentration depleted by day 4, which impacted the concentration curve. First-order kinetic rates of TN of five different plants were reported to be within the range of 0.09 – 0.73 per day (Chang et al., 2012; Chua et al., 2012). Kinetic rates for TP were not found to be reported in the literature.

Average DO concentration of *EA* was 10.8 mg/L, whereas for *BP*, it was 9.0 mg/L. It is well-established that many plants release oxygen through their roots in the hydroponic system (Bi et al., 2019; Shahid et al., 2018). We hypothesize that *EA* released oxygen, which resulted in a higher DO level in *EA* planted bucket. Further research on the oxygen release by *EA* is recommended to use it as an oxygenator plant.

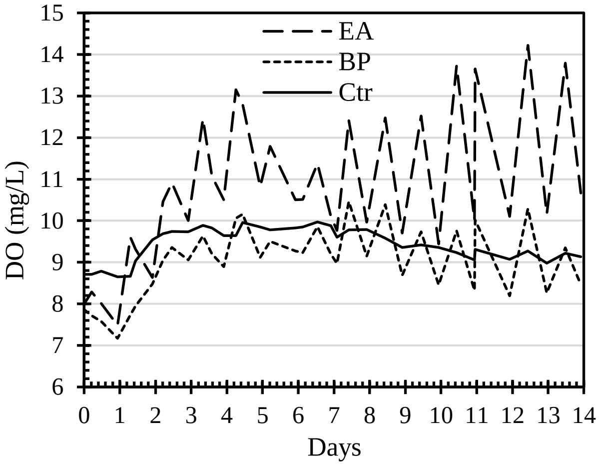


Figure 3: Variation of DO Concentration

4. Conclusions

Performance of nutrient removal from stormwater by two native Australian plants investigated in this study shows their suitability of using them in CFW system. It was found that both plants were able to improve water quality significantly with *BP* performing better than *EA* in terms of Nitrogen removal. The TN removal of 65% and 96% was achieved in 14 days by *EA* and *BP* respectively. About 40% of TP was removed by both plants in the same duration. Kinetic rates of *BP* were found to be higher than that of *EA* for all the parameters. But *EA* was found superior to *BP* in increasing DO level of water. Thus EA may be considered as a potential oxygenator plant but it needs further research. A harvesting strategy for CFW system needs to be developed and further research on plant tissue analysis is recommended to determine the nutrient accumulation in the roots and shoots of the plants.

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