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Phytoremediation of Stormwater by Floating Treatment Wetland

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Abstract: Floating treatment wetland (FTW) is a promising technology for nutrient and metal removal from stormwater. Plant is the key component of an FTW, facilitating pollutant removal through plant uptake and microbial actions. A careful selection of plant species is essential for an efficient FTW. This paper reviews available literature focusing on the role of plants in FTWs to identify research gaps and provide future research directions. From field-scale research, it was identified that *Baumea articulata*, *Phragmites australis*, *Chrysopogon zizanoidses* and *Carex appressa* were high-performing plants for nitrogen and phosphorus removal. It was found that the presence of microbial community largely depends upon the plant species. Microbial species and abundance are also limited by environmental factors such as pH, dissolved oxygen and nutrient concentration. Multi-species plantation is widely adopted in field-scale FTWs, but its effectiveness is not proven even though it has the potential for enhanced treatment under the right condition. Development of plant harvesting strategies for permanent removal of pollutants from the FTW system was found to depend on the season and nutrient distribution in plant tissue. This review paper provides critical insights into plant selection, role of microbes, multi-species plantation and harvesting strategies for permanent removal of pollutants from an FTW system.

1 INTRODUCTION

Stormwater pollution is one of the key sources of pollution to the receiving waterbodies such as rivers, lakes, and estuaries (Alam *et al.*, 2018). Agricultural lands where fertilisers are applied, contribute nutrients, such as nitrogen and phosphorus to the stormwater (Spangler *et al.*, 2019). Urban runoff typically contains heavy metals, such as copper, zinc, lead, nickel, cadmium, etc. and hydrocarbons such as oil and grease (Alam *et al.*, 2017). An excessive influx of nutrients (nitrogen, phosphorus) triggers algal bloom causing dissolved oxygen (DO) depletion at the end of the algae life cycle due to dead algae decomposition (Jones *et al.*, 2017). Metal influx causes toxicity to the aquatic animals and harms the aquatic ecosystem (Kayhanian *et al.*, 2008). As such, treatment of stormwater is paramount to protect aquatic habitats. Floating treatment wetland (FTW), also known as constructed floating wetland (CFW) or floating treatment island (FTI), is recently gaining worldwide popularity for its effectiveness, low cost and convenience in retrofitting FTW in existing stormwater ponds (Bi *et al.*, 2019; Headley *et al.*, 2012). In an FTW system, water-tolerant plant species are floated on the water with their soil-removed roots extending into the water column and the upper part (leaves) being in the air (Pavlineri *et al.*, 2017). In other words, FTW employs phytoremediation to purify polluted water. Direct plant uptake of nutrients and metals plays a major role in pollutant removal from stormwater (Keizer-Vlek *et al.*, 2014; Tanner *et al.*, 2011). The root matrix provides a large surface area for microbial growth and biofilm production (Winston *et al.*, 2013). Microbial endophytes and microbes attached to the roots matrix convert toxic forms of pollutants into less toxic forms (e.g., ammonia nitrogen to nitrate nitrogen) and removes pollutants (e.g., denitrification) (Zhang *et al.*, 2016). Microbes help converting pollutants into

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more readily bioavailable form to the plants (Shahid *et al.*, 2020a). The root matrix also acts as a physical filter and traps sediment and sediment-bound pollutants from stormwater (Borne *et al.*, 2013). FTWs offer advantages that traditional constructed wetlands (CWs) cannot afford. For example, traditional CWs have little flexibility on the depth of water flow and extra flow need to be diverted away from it to protect the plants. In contrast, FTW can handle variable depth without any damage as it floats on the water. FTW also removes the additional land requirements as opposed to CWs, making FTW a very cheap solution (Schwammberger *et al.*, 2019). The maintenance requirement is also very low for FTW. All these advantages are shooting the popularity of FTW high across the world. Field-scale and pilot-scale FTWs have been installed across the globe including USA, Australia, China, India, Brazil, New Zealand, Italy, Mexico and Singapore for stormwater, river water and wastewater treatment (Benvenuti *et al.*, 2018; Billore *et al.*, 2009; Borne *et al.*, 2013; Chua *et al.*, 2012; De Stefani *et al.*, 2011; Ma *et al.*, 2021; Maxwell *et al.*, 2020; Nichols *et al.*, 2016; Olguín *et al.*, 2017). Microcosm and mesocosm studies were conducted to improve its treatment performance. Many of the published articles focused on the plant performance of pollutant removal. For instance, Luca *et al.* (2019) investigated *Typha domingensis* for nitrogen and phosphorus removal. White and Cousins (2013) utilized *Canna flacida* and *Juncus effusus* for nutrient removal from agricultural runoff. Ladislas *et al.* (2013) experimented Cd, Ni and Zn removal by *Juncus effusus* and *Carex riparia.* Selection of plant species play a key role in achieving high treatment efficiency since plant physiology determines the need for nutrients and thus nutrient uptake. Despite the existence of numerous research articles on various plant performance, not much information is available on future research direction and developing a guideline to select high performing plant species, maintenance and utilization of different plant species to optimize pollutant removal. As such, this review paper aims to review currently available information and provide direction to future research and layout the foundation on the development of guidelines on using plant species in FTW.

2 PLANT BIO-ACCUMULATION OF POLLUTANTS

Comparison of plant bio-accumulation of pollutants (nutrients and heavy metals) within the plant tissue for plants used in FTWs is a difficult task due to variation in reporting. There were three main approaches to reporting bio-accumulation in plant tissue: (1) gm of pollutants per unit area of FTW (Schwammberger *et al.*, 2020) (2) gm of pollutants per unit dry weight of plants (Ladislas *et al.*, 2015) (3) gm of pollutants per plant (Wang *et al.*, 2014). This variability in reporting, especially when other crucial information, e.g., plant density, total number of plants and total biomass of plants are absent, makes it harder to compare plant performance. Furthermore, the use of plants for treating different types of water induces additional errors for comparison. As such, we present bio-accumulation of pollutants from field-scale studies only and in mg per gm dry weight (Table 1).

It is important to note that just measuring the pollutant concentration within plant tissue is not so accurate in comparing plant performance. This is because a species can have a high concentration within its tissue, but if it fails to produce enough biomass so that total accumulation is less, it may lead to an inefficient treatment by the FTW system compared to a species that can produce a high amount of biomass even concentration within plant tissue is low. The importance of this factor was also highlighted by Vymazal (2016). For example, by only observing the N concentration in *Alisma subcordatum* (24.1 mg/gm) and *Carex stricta* (11 mg/gm) in Table 1, one may conclude that the latter is an inferior plant compared to the former one, which would be a wrong conclusion. By observing the dry weight of the two plants, it can be understood that due to high biomass production by *Carex stricta* (221 gm), it will outweigh the total N removal by *Alisma subcordatum* per plant, which has only 1.29 gm of dry biomass. From Table 1, it seems that *Baumea articulata* is the highest performing plant out of the 16 unique plants. This high accumulation and plant growth could be fuelled by high nutrient concentration (9 mg/L N and 5 mg/L P). It can be observed that N accumulation in *Carex appressa* used by Huth *et al.* (2021) and Schwammberger *et al.* (2020) were 26 mg/gm and 10.57 mg/gm, respectively, marking a stark difference. P concentration of the same plant was 3.3 mg/gm and 1.01 mg/gm by the two studies, respectively. This difference in nutrient accumulation in the same plant species occurred due to their exposure concentration mainly. N and P concentration in Schwammberger *et al.* (2020) study was 1.8 and 0.08 mg/L, respectively, compared to 9 mg/L N and 5 mg/L P in the Huth *et al.* (2021) study. N concentration in *Juncus effusus* by Tharp *et al.* (2019) and Winston *et al.* (2013) were both around 15 mg/gm. In both of the studies, urban runoff was the source of nutrients and thus nutrient concentrations were similar.

Baumea articulata was the top performing plant in terms of total N and P accumulation per plant, followed by *Phragmites australis*, *Chrysopogon zizaninides* and *Carex appressa*, all of which are characterized by high nutrient concentration accumulation capacity and biomass production.

Lai *et al.* (2011) investigated 35 wetland plants in microcosm constructed wetlands and identified unique characteristics of plants that have a higher potential to uptake nutrients. It was found that plants having fibrous root matrix (individual root diameter. D < 1 mm) can uptake a higher amount of nutrients (N and P) into their tissue compared to thick root plants (D > 1mm). Information regarding the root characteristics of any of the plants in Table 1 were not reported in the respective literature.

Table 1: Pollutant bio-accumulation in plant tissue from field-scale studies

Reference	**Plant**	**Maximum Bio-accumulation (mg/g)**	**Dry biomass per plant (gm)**	**Maximum root length (m)**	**Water type**
Huth *et al.* (2021)	*Baumea articulata*	N-25,P-3.5	920	-	Sewage
	Phragmites australis	N-20, P-3.2	393	-	
	Carex appressa	N-26, P-3.3	98	-	
	Chrysopogon zizaninides	N-22.5, P-3.3	209	-	
Schwammberger *et al.* (2020)	*Carex appressa*	N-10.57, P-1.01, K-11.45, Ca-3.08	227	2.1	Urban runoff
Tharp *et al.* (2019)	*Juncus effusus*	P-2.1	9	0.18	Suburban runoff
	Schoenoplectus tabernaemontani	P-3.5	7	0.23	
	Carex comosa	P-4.8	38	0.42	
	Pontederia cordata	P-5.72	3	0.14	
McAndrew *et al.* (2016)	*Alisma subcordatum*	N-24.1	1.29	-	Urban runoff
	Carex stricta	N-18.2	4.31	-	
	Iris versicolor	N-16.2	2.7	-	
	Juncus effusus	N-14.6	4.47	-	
	Pontederia cordata	N-20.4	2.24	-	
Ladislas *et al.* (2015)	*Juncus effusus*	Cd- <0.0001, Ni-0.04, Zn- 0.093	12	-	Highway runoff
	Carex riparia	Cd- <0.0001, Ni-0.063, Zn-0.094	56	-	
Borne *et al.* (2014)	*Carex virgata*	P-1.79	82.4	-	Highway runoff
Winston *et al.* (2013)	*Juncus effuses*	N-15, P-1.5, K-11	45	-	Urban runoff
	Carex stricta	N-11, P- 0.7, K-9	221	0.75	
	Spartina pectinate	N-11.5, P- 1, K-7.5	66	-	
	Hibiscus moscheutos	N-16, P-1.1, K-6	74	-	
	Pontederia cordata	N-14, 0.9, K-30	58	-	

3 ROLE OF MICROBES ATTACHED WITH ROOT MATRIX

Microbial communities play an important role in the phytoremediation mechanisms (Bissegger *et al.*, 2014), but it is not a well-understood phenomenon and one of the least explored aspects of FTW (Faulwetter *et al.*, 2009). Microbes are known to break down complex compounds into simple nutrients readily available to plants (Shahid *et al.*, 2020a). After investigating three plants, e.g., *Iris pseudacorus*, *Thalia dealbata* and *Typha orientalis*, Zhang *et al.* (2015) concluded that plant species play a vital role in the abundance of ammonia-oxidizing micro-organisms.

Zhang *et al.* (2018) studied the response of the functional genes available in the root zone and floating bed of FTW system. Among the functional genes, anammox, *amoA*, *narG*, *nirK*, *nirS* and *nosZ* were identified from the quantitative polymerase chain reaction (qPCR) analysis. It was observed that the presence of aerobic ammonia oxidation gene (*amoA*) increased with the increase of NH_3-N concentration in the water. Presence of annamox was much higher than *amoA* due to low DO concentration in the water. It was also found that denitrifying genes (*narG*, *nirK*, *nirS*, *nosZ*) were less in the root zone than in the floating bed due to the micro-environment created by oxygen released by the root in the rhizosphere. It was concluded that plant uptake of nitrogen and phosphorus contributed less than the microbial removal in N and P removal. In contrast, Keizer-Vlek *et al.* (2014) demonstrated that plant uptake explained 74% N and 60% P removal in their respective study. The remaining removal could be attributed to microbial activities, which implies that plant uptake was the major source of nutrient removal. Water environmental conditions such as nutrient concentration, temperature, DO and pH have a significant impact on pollutant removal by microbial activities (Shahid *et al.*, 2020a), which was also iterated by Wu *et al.* (2016). It is possible that the differences in the studies by Zhang *et al.* (2018) and Keizer-Vlek *et al.* (2014) were due to water environmental conditions. Bacteria augmented FTW successfully removed oil, organic and inorganic compounds from crude oil contaminated water, as demonstrated by Rehman *et al.* (2018). Metal removal was also reported to be accelerated in bacterial assisted FTW to treat river water (Shahid *et al.*, 2020b). Different other studies also demonstrated that microbial presence depends on the plant species, environmental factors such as DO, pH and nutrient availability and the correlation between loss of nutrient species and responsible microbial gene copy numbers as outlined in Table 2 (Faulwetter *et al.*, 2011; Wei *et al.*, 2011; Yi *et al.*, 2014; C.-B. Zhang *et al.*, 2014; Zhang *et al.*, 2016).

Future research can focus on resolving the issue with the contribution of microbes attached with root matrix in pollutant removal. Most of the microbial studies are laboratory-scale. As such, field-scale studies are necessary to understand their true contribution. Furthermore, the feasibility of bacteria inoculation in field-scale FTWs and its effectiveness can be explored for higher treatment efficiency.

4 MULTI-SPECIES PLANTATION

Many field-scale FTW studies adopted mono species plantation. However, there are abundant examples of multi-species plantation as well. For instance, Ladislas *et al.* (2015) used *Carex riparia* and *Juncus effuses* at a 50:50 proportion in a stormwater pond receiving highway runoff in France. *Pontederia sagittata* and *Cyperus papyrus* were planted at a 20:80 ratio in a eutrophic urban pond in Mexico (Olguín *et al.*, 2017). Numerous other studies also reported the use of multi-species plantations using up to 18 different species at different proportions. (Huth *et al.*, 2021; Vázquez-Burney *et al.*, 2015; Wang *et al.*, 2015; Winston *et al.*, 2013). However, none of the field studies have tested how multi-species plantation affects treatment efficiency. Only a few studies have reported investigating the effect of multi-species plantation in microcosm and mesocosm experiments (Garcia Chance *et al.*, 2020; Han *et al.*, 2018). Multi-species plantations affect treatment efficiency either by enhancing or decreasing the overall efficiency. Enhanced treatment efficiency is obtained when the plants have a synergistic effect, i.e., the overall efficiency is higher than the sum of individual species contributions (Chance *et al.*, 2020). Conversely, when the overall efficiency is less than the sum of individual contributions, it is known as an antagonistic effect. An additive effect occurs when the overall efficiency equals the individual contributions. Chance *et al.* (2020) investigated multi-species plantation by *Iris ensata*, *Canna ×generalis*, *Agrostis alba*, *Carex stricta* and *Panicum virgatum* in different combinations and found an additive effect for nitrogen and phosphorus removal. It implies multi-species plantation was neither of any benefit nor having any negative effect. Han *et al.* (2018) studied Ca, Mg and K removal by a combination of *Oenanthe javanica*, *Rumex japonicas*, *Phalaris arundinacea* and *Reineckia carnea* and concluded that plant diversity had no significant effect on treatment efficiency. However, it was also noted that multi-species plantations altered the plant uptake of heavy metals. It was also stated that the selection of the right plant species with the right combinations might enhance treatment efficiency. Geng *et al.* (2017) investigated multi-species plantation by experimenting 15 combinations of

Oenanthe hookeri, *Rumex japonicas*, *Phalaris arundinacea* and *Reineckia carnea*, including bi, tri and tetra species combinations for P removal from wastewater. It was observed that bi and tri species combinations that included *O. hookeri* removed the highest amount of P. However, this result was not statistically significant. It was concluded that species richness has an overall positive impact on P removal given that the most important species is present in the combination. It has been demonstrated in case of CWs that multi-species plantation positively influences treatment efficiency (Huang *et al.*, 2019; Zhu *et al.*, 2017). It is reasonable to assume that multi-species plantation will also benefit FTW systems. But the problem that needs to be solved is the right kind of species with the right combination. As such, future research can concentrate on finding out the synergistic effect between plant species to facilitate informed selection of multi-species combination rather than mere arbitrary selection for FTW applications.

Table 2: Features and findings of studies on microbes attached with root matrix of FTWs

Reference	**Plant**	**Water quality parameters**	**Molecular Methods applied**	**Identified Bacteria/Gene**	**Key Findings**
Zhang *et al.* (2016)	*Vallisneria natans, Potamogeton malaianus, Ceratophyllum demersum, Elodea nuttallii,*	NO_3-N, DO	qPCR analysis	narG, napA, nirS, nirK, norB and nosZ	Denitrifying genes are positively correlated with nitrate concentration but negatively correlated with DO.
Zhang *et al.* (2018)	*Canna indica*		qPCR analysis	amoA, anammox, narG, nirK, nirS and nosZ	narG and nirK were the most abundant genes among the nitrogen functional genes
Wu *et al.* (2016)	*Canna indica, Iris pseudacorus*	COD, NH_3-N, TN, TP	PCR-DGGE analysis	β-Proteobacteria, α-Proteobacteria	Bacterial abundance changes with temperature, pollutant concentration and plant growth.
Faulwetter *et al.* (2011)	*Unplanted floating bed*	COD, NH_3-N, NO_3-N, TN	PCR-DGGE analysis	amoA, nirS, nirK	Water depth is vital for denitrifying communities, aeration did not impact nitrifying and denitrifying communities after establishment period.
Yi *et al.* (2014)	*Eichhornia crassipes*	NH_3-N, NO_3-N	PCR-DGGE and qPCR analysis	nirK, nirS and nosZ	Nitrogen loss was significantly correlated with denitrifying gene copy numbers.
Zhang *et al.* (2015)	*Iris pseudacorus, Thalia dealbata, Typha orientalis*	NH_3-N, NO_3-N, TN, TP	qPCR analysis	amoA	Plant type affected the copy number of nitrifying communities
Wei *et al.* (2011)	*Eichhornia crassipes, Pistia stratiotes, Ipomoea aquatic*	-	qPCR analysis	amoA	Ammonia Oxidizing Bacteria (AOB) amoA gene copies were more abundant than Ammonia Oxidizing Archaea (AOA) amoA gene copies.

qPCR = quantitative polymerase chain reaction, PCR-DGGE = polymerase chain reaction - denaturing gradient gel electrophoresis, COD = chemical oxygen demand, TN = total nitrogen, TP = total phosphorus

5 PLANT HARVESTING

Literature on developing harvesting strategies of FTW plants for the permanent removal of pollutants from the system is scarce. Developing a harvesting strategy requires analyzing plant tissue samples throughout the year to understand the peak pollutant accumulation season of the plant species in use and pollutant distribution in the roots and shoots (Ge *et al.*, 2016; White *et al.*, 2013). It also requires observation of plant senescing period when accumulated pollutants may return back to the water column due to nutrient relocation from shoots to roots (Ruiz *et al.*, 2010). Plant senescing may be driven by environmental factors such as temperature and season (Masters *et al.*, 2012). Ge *et al.* (2016) recommended that *Thalia dealbata* and *Canna indica* shoots should be harvested during late October and early November in Jiaxing city, China, based on the peak nutrient accumulation season. For *Lythrum salicaria*, harvesting was recommended during September. Wang *et al.* (2014) recommended whole plant harvesting of *Pontederia cordata* during September in Virginia, USA. However, it was also noted that whole plant harvesting is more aggressive and sometimes may pose difficulty, especially when plant roots are entangled with the floating bed. Shoot harvesting of *Schoenoplectus tabernaemontani* was found suitable during October. Chua *et al.* (2012) harvested *Typha angustifolia* and *Chrysopogon zizanioides* multiple times in a single year in Singapore and found that the plants could mature again within 80 – 100 days. Multiple harvesting did not pose any performance issue to the plant species. However, it was reported that harvesting shoots prior to its peak season may reduce nutrient removal capacity in subsequent years (Nakamura *et al.*, 1997). Wang *et al.* (2014) suggested that any adverse effects from multiple harvesting of plant leaves need to be investigated. The study conducted by Xu *et al.* (2017) in Jinan, China observed maximum nutrient accumulation in *Iris pseudacorus* and *Thalia dealbata* in September. The authors recommended only shoot harvesting due to its low cost and operational simplicity.

It is to be noted that peak nutrient accumulation within plant tissue and senescing events are driven by seasonal changes. Since, seasons typically vary from one geographic location to another, the harvesting period of the same plant species will be different in different geographic location unless there is no variation in seasons between the concerned regions. As such, investigation at a local level is required for optimum results. It is important to note that harvesting only plant roots is not feasible as it can pose threats to the survival of plants. Therefore, development of harvesting strategies should focus mainly on the shoot harvesting. Plants that can translocate a significant amount of nutrients from their roots to shoots will be more effective in the permanent removal of nutrients from the system due to simplicity of plant shoot harvesting. As such, future research should endeavor identifying these kinds of plants and their capacity to store nutrients. Plants that can produce a higher amount of shoots will have an advantage in storing a higher amount of nutrients.

The harvested plant biomass enriched with N and P can be composted and used as fertilisers in the agricultural land and gardens. However, caution must be taken if the plants have accumulated a significant amount of heavy metal, especially cadmium and lead within its tissue as that would have toxic heavy metals entering into the food chain.

6 CONCLUSIONS

We reviewed the literature on the role of plants in FTW systems and identified some key research gaps. We also discussed how these gaps should be addressed in future research. The following are the key conclusions drawn based on the arguments made throughout the paper.

- The main role in removing pollutants in an FTW system is played by the plants. Other components like microbial removal are largely controlled by plant species, i.e., microbial removal is passively supported by the plant. In some cases, microbial removal may have a significant role to play, but it is not a well-understood removal pathway. Plant bio-accumulation of nutrients and plant growth is influenced by environmental factors such as nutrient concentration in water. Generally, plants capable of producing a higher amount of biomass will tend to remove a higher amount of total nutrient and metals from the system. As such, plant biomass production should be factored in when comparing different plants instead of just measuring pollutant concentration in plant tissue.
- The presence of microbial communities in the plant root matrix largely depends on the plant species. Different plant species tend to create different micro-environment due to plant secretion of exudates, organic acid and oxygen release, which controls the type and abundance

of microbial communities. Bacteria inoculation has proven to enhance treatment efficiency, but studies are limited. As such, further investigations are required to truly understand the overall benefit of different types of bacteria inoculation and their effectiveness in field-scale FTWs.

- Multi-species plantation is widely practiced in FTW systems, but little attention is given on the careful selection of plant species to attain a synergistic effect. Thus, it is highly likely that the true potential of multi-species plantation is not utilized and in some cases, may even have negative outcomes due to antagonistic effects. Therefore, scientific investigation on multi-species plantation practice is of high importance.
- Despite a plethora of literature on FTW phytoremediation studies, little attention is paid to developing harvesting strategies for the permanent removal of nutrients from the system. Maintenance negligence is highly likely to undermine the effort to improve water quality by an FTW. Furthermore, harvesting strategies should be developed under local conditions as studies from other geographic regions may not be applicable anywhere else due to climatic variations, even if the same plant species is used.

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REFERENCES

Alam, M. Z., Anwar, A. F., Sarker, D. C., Heitz, A., & Rothleitner, C. (2017). Characterising stormwater gross pollutants captured in catch basin inserts. *Science of the Total Environment*, *586*, 76-86.

Alam, M. Z., Anwar, A. H. M. F., & Heitz, A. (2018). Stormwater solids removal characteristics of a catch basin insert using geotextile. *Science of The Total Environment*, *618*, 1054–1063.

Benvenuti, T., Hamerski, F., Giacobbo, A., Bernardes, A. M., Zoppas-Ferreira, J., & Rodrigues, M. A. S. (2018). Constructed floating wetland for the treatment of domestic sewage: A real-scale study. *Journal of Environmental Chemical Engineering*, *6*(5), 5706–5711.

Bi, R., Zhou, C., Jia, Y., Wang, S., Li, P., Reichwaldt, E. S., & Liu, W. (2019). Giving waterbodies the treatment they need: A critical review of the application of constructed floating wetlands. *Journal of Environmental Management*, *238*, 484–498.

Billore, S. K., & Sharma, J. K. (2009). Treatment performance of artificial floating reed beds in an experimental mesocosm to improve the water quality of river Kshipra. *Water Science and Technology*, *60*(11), 2851–2859.

Bissegger, S., Rodriguez, M., Brisson, J., & Weber, K. P. (2014). Catabolic profiles of microbial communities in relation to plant identity and diversity in free-floating plant treatment wetland mesocosms. *Ecological Engineering*, *67*, 190–197.

Borne, K. E., Fassman-Beck, E. A., & Tanner, C. C. (2014). Floating treatment wetland influences on the fate of metals in road runoff retention ponds. *Water Research*, *48*, 430–442.

Borne, K. E., Fassman, E. A., & Tanner, C. C. (2013). Floating treatment wetland retrofit to improve stormwater pond performance for suspended solids, copper and zinc. *Ecological Engineering*, *54*, 173–182.

Chua, L. H. C., Tan, S. B. K., Sim, C. H., & Goyal, M. K. (2012). Treatment of baseflow from an urban catchment by a floating wetland system. *Ecological Engineering*, *49*, 170–180.

De Stefani, G., Tocchetto, D., Salvato, M., & Borin, M. (2011). Performance of a floating treatment wetland for in-stream water amelioration in NE Italy. *Hydrobiologia*, *674*(1), 157–167.

Faulwetter, J. L., Burr, M. D., Cunningham, A. B., Stewart, F. M., Camper, A. K., Stein, O. R. (2011). Floating treatment wetlands for domestic wastewater treatment. *Water science and technology*. *64*(10), 2089–2095.

Faulwetter, J. L., Gagnon, V., Sundberg, C., Chazarenc, F., Burr, M. D., Brisson, J., Camper, A. K., & Stein, O. R. (2009). Microbial processes influencing performance of treatment wetlands: a review. *Ecological Engineering*, *35*(6), 987–1004.

Garcia Chance, L. M., Majsztrik, J. C., Bridges, W. C., Willis, S. A., Albano, J. P., & White, S. A. (2020). Comparative nutrient remediation by monoculture and mixed species plantings within floating treatment wetlands.

Environmental Science & Technology, 54(14), 8710–8718.

Ge, Z., Feng, C., Wang, X., Zhang, J. (2016). Seasonal applicability of three vegetation constructed floating treatment wetlands for nutrient removal and harvesting strategy in urban stormwater retention ponds. *Biodeterioration & Biodegradation, 112,* 80–87.

Geng, Y., Han, W., Yu, C., Jiang, Q., Wu, J., Chang, J., & Ge, Y. (2017). Effect of plant diversity on phosphorus removal in hydroponic microcosms simulating floating constructed wetlands. *Ecological Engineering*. *107*, 110–119.

Han, W., Ge, Y., Ren, Y., Luo, B., Du, Y., Chang, J., & Wu, J. (2018). Removal of metals and their pools in plant in response to plant diversity in microcosms of floating constructed wetlands. *Ecological Engineering, 113,* 65–73.

Headley, T. R., & Tanner, C. C. (2012). Constructed wetlands with floating emergent macrophytes: an innovative stormwater treatment technology. *Critical Reviews in Environmental Science and Technology*, *42*(21), 2261–2310.

Huang, X., Ye, G., Yi, N., Lu, L., Zhang, L., Yang, L., Xiao, L., & Liu, J. (2019). Effect of plant physiological characteristics on the removal of conventional and emerging pollutants from aquaculture wastewater by constructed wetlands. *Ecological Engineering*, *135*, 45–53.

Huth, I., Walker, C., Kulkarni, R., & Lucke, T. (2021). Using Constructed Floating Wetlands to Remove Nutrients from a Waste Stabilization Pond. *Water, 13*(13), 1746.

Jones, T. G., Willis, N., Gough, R., & Freeman, C. (2017). An experimental use of floating treatment wetlands (FTWs) to reduce phytoplankton growth in freshwaters. *Ecological Engineering*, *99*, 316–323.

Kayhanian, M., Stransky, C., Bay, S., Lau, S.-L., & Stenstrom, M. K. (2008). Toxicity of urban highway runoff with respect to storm duration. *Science of the Total Environment*, *389*(2–3), 386–406.

Keizer-Vlek, H. E., Verdonschot, P. F. M., Verdonschot, R. C. M., & Dekkers, D. (2014). The contribution of plant uptake to nutrient removal by floating treatment wetlands. *Ecological Engineering*, *73*, 684–690.

Ladislas, S., Gerente, C., Chazarenc, F., Brisson, J., & Andres, Y. (2015). Floating treatment wetlands for heavy metal removal in highway stormwater ponds. *Ecological Engineering*, *80*, 85–91.

Lai, W.-L., Wang, S.-Q., Peng, C.-L., & Chen, Z.-H. (2011). Root features related to plant growth and nutrient removal of 35 wetland plants. *Water Research*, *45*(13), 3941–3950.

Ma, C., Qiao, Y., Bin, L., & Yao, Y. (2021). Performance of hybrid-constructed floating treatment wetlands in purifying urban river water: A field study. *Ecological Engineering*, *171*, 106372.

Masters, B. (2012). The ability of vegetated floating Islands to improve water quality in natural and constructed wetlands: a review. *Water Practice and Technology*, *7*(1).

Maxwell, B., Winter, D., & Birgand, F. (2020). Floating treatment wetland retrofit in a stormwater wet pond provides limited water quality improvements. *Ecological Engineering*, *149*, 105784.

McAndrew, B., Ahn, C., & Spooner, J. (2016). Nitrogen and sediment capture of a floating treatment wetland on an urban stormwater retention pond—the case of the rain project. *Sustainability*, *8*(10), 972.

Nakamura, K., & Shimatani, Y. (1997). Water purification and environmental enhancement by artificial floating island. *Proceedings of Asia Waterqual in Korea. IANQ*, 888–895.

Nichols, P., Lucke, T., Drapper, D., & Walker, C. (2016). Performance evaluation of a floating treatment wetland in an urban catchment. *Water*, *8*(6), 244.

Olguín, E. J., Sánchez-Galván, G., Melo, F. J., Hernández, V. J., & González-Portela, R. E. (2017). Long-term assessment at field scale of Floating Treatment Wetlands for improvement of water quality and provision of ecosystem services in a eutrophic urban pond. *Science of the Total Environment*, *584*, 561–571.

Pavlineri, N., Skoulikidis, N. T., & Tsihrintzis, V. A. (2017). Constructed floating wetlands: a review of research, design, operation and management aspects, and data meta-analysis. *Chemical Engineering Journal*, *308,* 1120–1132.

Rehman, K., Imran, A., Amin, I., & Afzal, M. (2018). Inoculation with bacteria in floating treatment wetlands positively modulates the phytoremediation of oil field wastewater. *Journal of Hazardous Materials*, *349,* 242–251.

Ruiz, M., & Velasco, J. (2010). Nutrient bioaccumulation in Phragmites australis: management tool for reduction of pollution in the Mar Menor. *Water, Air, and Soil Pollution*, *205*(1), 173–185.

Schwammberger, P. F., Lucke, T., Walker, C., &

Trueman, S. J. (2019). Nutrient uptake by constructed floating wetland plants during the construction phase of an urban residential development. *Science of The Total Environment*, *677*, 390–403.

Schwammberger, P. F., Yule, C. M., & Tindale, N. W. (2020). Rapid plant responses following relocation of a constructed floating wetland from a construction site into an urban stormwater retention pond. *Science of The Total Environment*, *699*, 134372.

Shahid, M. J., AL-surhanee, A. A., Kouadri, F., Ali, S., Nawaz, N., Afzal, M., Rizwan, M., Ali, B., & Soliman, M. H. (2020a). Role of microorganisms in the remediation of wastewater in floating treatment wetlands: a review. *Sustainability*, *12*(14), 5559.

Shahid, M. J., Ali, S., Shabir, G., Siddique, M., Rizwan, M., Seleiman, M. F., & Afzal, M. (2020b). Comparing the performance of four macrophytes in bacterial assisted floating treatment wetlands for the removal of trace metals (Fe, Mn, Ni, Pb, and Cr) from polluted river water. *Chemosphere*, *243*, 125353.

Spangler, J. T., Sample, D. J., Fox, L. J., Owen Jr, J. S., & White, S. A. (2019). Floating treatment wetland aided nutrient removal from agricultural runoff using two wetland species. *Ecological Engineering*, *127,* 468-479.

Tanner, C. C., & Headley, T. R. (2011). Components of floating emergent macrophyte treatment wetlands influencing removal of stormwater pollutants. *Ecological Engineering*, *37*(3), 474–486.

Tharp, R., Westhelle, K., & Hurley, S. (2019). Macrophyte performance in floating treatment wetlands on a suburban stormwater pond: Implications for cold climate conditions. *Ecological Engineering*, *136*, 152–159.

Vázquez-Burney, R., Bays, J., Messer, R., & Harris, J. (2015). Floating wetland islands as a method of nitrogen mass reduction: results of a 1 year test. *Water Science and Technology*, *72*(5), 704–710.

Vymazal, J. (2016). Concentration is not enough to evaluate accumulation of heavy metals and nutrients in plants. *Science of the Total Environment*, *544*, 495–498.

Wang, C.-Y., & Sample, D. J. (2014). Assessment of the nutrient removal effectiveness of floating treatment wetlands applied to urban retention ponds. *Journal of Environmental Management*, *137*, 23–35.

Wang, C. Y., Sample, D. J., & Bell, C. (2014). Vegetation effects on floating treatment wetland nutrient removal and harvesting strategies in urban stormwater ponds. *Science of the Total Environment*, *499*, 384-393.

Wang, C.-Y., Sample, D. J., Day, S. D., & Grizzard, T. J. (2015). Floating treatment wetland nutrient removal through vegetation harvest and observations from a field study. *Ecological Engineering*, *78*, 15–26.

Wei, B., Yu, X., Zhang, S., & Gu, L. (2011). Comparison of the community structures of ammonia-oxidizing bacteria and archaea in rhizoplanes of floating aquatic macrophytes. *Microbiological research*, *166*(6), 468–474.

White, S. A., & Cousins, M. M. (2013). Floating treatment wetland aided remediation of nitrogen and phosphorus from simulated stormwater runoff. *Ecological Engineering*, *61*, 207–215.

Winston, R. J., Hunt, W. F., Kennedy, S. G., Merriman, L. S., Chandler, J., & Brown, D. (2013). Evaluation of floating treatment wetlands as retrofits to existing stormwater retention ponds. *Ecological Engineering*, *54*, 254–265.

Wu, Q., Hu, Y., Li, S., Peng, S., & Zhao, H. (2016). Microbial mechanisms of using enhanced ecological floating beds for eutrophic water improvement. *Bioresource Technology*, *211*, 451–456. https://doi.org/10.1016/j.biortech.2016.03.113

Xu, B., Wang, X., Liu, J., Wu, J., Zhao, Y., & Cao, W. (2017). Improving urban stormwater runoff quality by nutrient removal through floating treatment wetlands and vegetation harvest. *Scientific Reports*, *7*(1), 7000.

Yi, N., Gao, Y., Long, X. hua, Zhang, Z. yong, Guo, J. yao, Shao, H. bo, Zhang, Z. hua, & Yan, S. hua. (2014). Eichhornia crassipes cleans wetlands by enhancing the nitrogen removal and modulating denitrifying bacteria community. *Clean - Soil, Air, Water*, *42*(5), 664–673. https://doi.org/10.1002/clen.201300211

Zhang, C.-B., Liu, W.-L., Pan, X.-C., Guan, M., Liu, S.-Y., Ge, Y., & Chang, J. (2014). Comparison of effects of plant and biofilm bacterial community parameters on removal performances of pollutants in floating island systems. *Ecological Engineering*, *73*, 58–63.

Zhang, J., Liu, B., Zhou, X., Chu, J., Li, Y., & Wang, M. (2015). Effects of emergent aquatic plants on abundance and community structure of ammonia-oxidising microorganisms. *Ecological Engineering*, *81*, 504–513.

Zhang, L., Sun, Z., Xie, J., Wu, J., & Cheng, S. (2018). Nutrient removal, biomass accumulation and nitrogen-transformation functional gene response to different nitrogen forms in enhanced floating treatment wetlands. *Ecological Engineering*, *112*, 21–25.

Zhang, S., Pang, S., Wang, P., Wang, C., Guo, C., Addo, F. G., & Li, Y. %J S. reports. (2016). Responses of bacterial community structure and denitrifying bacteria in biofilm to submerged macrophytes and nitrate. *Scientific Reports*, *6*, 36178.

Zhu, S., Huang, X., Ho, S.-H., Wang, L., & Yang, J. (2017). Effect of plant species compositions on performance of lab-scale constructed wetland through investigating photosynthesis and microbial communities. *Bioresource Technology*, *229*, 196–203.