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Literature Review: Pollutant Removal Efficacy of Floating Treatment Wetlands Across Water Bodies

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by

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ABSTRACT

Wetland numbers are declining worldwide and there is a need to replace the water filtration services they provide. One emerging option is floating treatment wetlands (FTW). FTW are a floating mat that serves as a habitat for aquatic plants whose roots are suspended in the water and that remove both organic and inorganic pollutants like nutrients (nitrogen and phosphorus), potentially toxic metals, and suspended solids. A literature search was performed to examine the efficacy of FTW pollutant removal. Specifically, I inspected 1) how effective FTW are at removing a range of nutrients; 2) what types of plants are most effective in FTWs; and 3) does FTW's efficacy differ across water body types (eutrophic water, sewage and domestic water, stormwater runoffs, and industrial wastewaters). Given the potential of FTW, I expected that in all cases, there will be a reduction in all observed criteria. After all the research on FTW, it had a range of effect on nutrient removal efficacy. However, there was no noticeable plant species in a given water body type, except for the plants, *Juncus* and *Pontederia*, which were found in eutrophic water, sewage and domestic waters, and stormwater runoffs. Some things to consider for future research to explore were species specific impacts, seasonality and inoculates.

Keywords: floating treatment wetland, FTW, removal rates, removal efficacy, pollutant removal

INTRODUCTION

The loss of wetland habitat is problematic, as these declines result in the loss of ecosystem services, such as water filtration. Wetlands improve water quality through the removal of pollutants (DEC, 2020). However, wetlands numbers have been declining worldwide, with a loss of 35% of natural wetland sites (in both marine, costal, and inland) between 1970 and 2015 (Larson, 2018; Ramsar Convention, 2018). As wetlands decrease in number, efforts must be taken to replace the water filtration services they provided. One emerging new option is floating treatment wetlands (FTW) (Lubnow, 2014; Sanicola et al., 2019; IISD, 2017).

FTW are buoyant rafts or mats hosting naturally occurring hydrophytic macrophytes (large plants that live in or near water) (EPA, 2016). The FTW are anchored to the bottom of the water body and float on the surface (Figure 1; Lubnow, 2014). The macrophytes living on FTW remove both organic and inorganic pollutants like nutrients, potentially toxic metals, and suspended solids (Colares et al., 2020; Stewart et al., 2008; Shahid et al., 2018). Over time, the roots become covered in biofilms, a slimy green layer created by microbes that live under the mat and on plant roots (IISD, 2017). The biofilms reduce water flow rates, allowing the settling of sediments and burial of suspended sediments (aka sediment trapping) (DEC, 2020; IISD, 2017; Short & Inman, 2019). The macrophytes used in the construction of FTW are native to the regions they are deployed, thus ensuring suitability to local climatic conditions (Shahid et al., 2020).

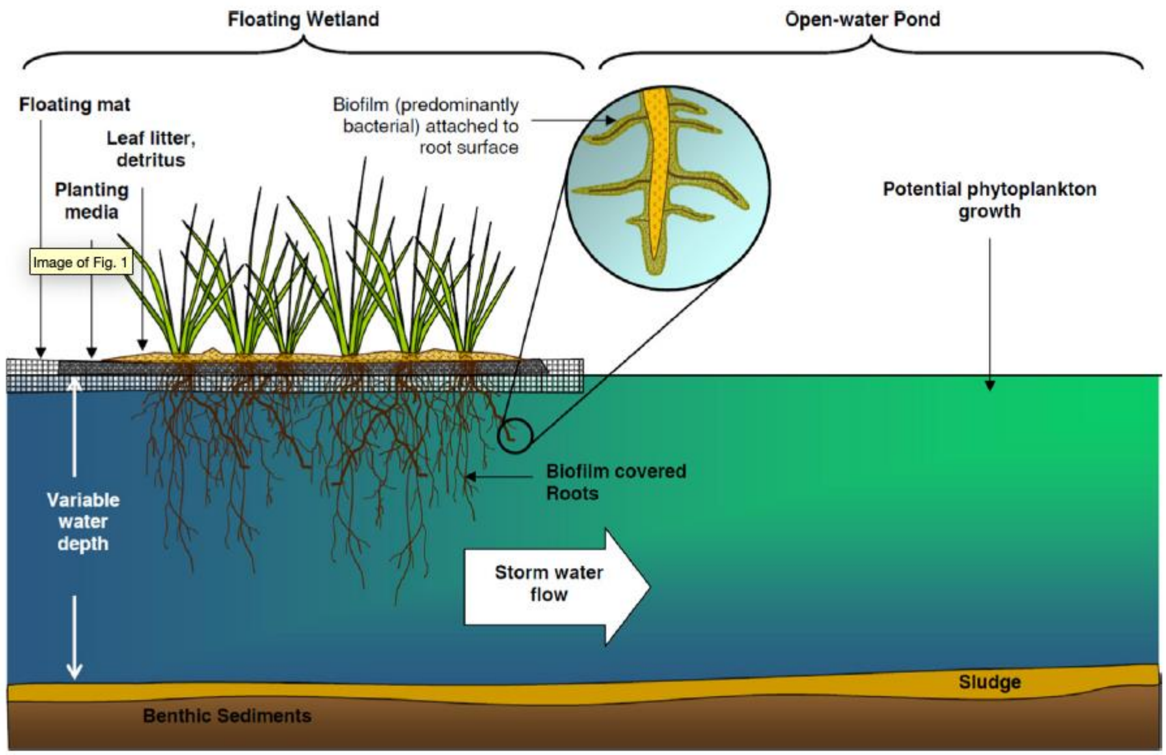

Figure 1. Schematic view of a typical floating treatment wetlands (FTW) and framework of nutrient/heavy metals uptake interaction (Yeh et al. 2015).

Compared to FTW, traditional water filtration options such as mechanical treatment plants or wetland restorations can be costly and have undesirable environmental impacts. For example, the cost of designing, building, installing, and starting a water treatment plant can cost between \$45,000 to tens of millions of U.S. dollars, not including ongoing maintenance costs (Samco, 2017). Restoring wetlands, another viable alternative, also carries high financial costs, although it should be noted that restoration provides additional services a FTW may not provide (water storage, erosion control, etc.). Restoration efforts for the Prairie Pothole Region (PPR) cost between \$200 to over \$3,300 per acre (Hansen, 2015). In contrast, FTW costs between one to twenty-four dollars per square foot, making it a low-cost benefit to manufacture, install, and maintain (Sample et al., 2013).

Additionally, FTW have a smaller environmental footprint compared to current alternatives (Sanicola et al., 2019). For example, a 250 ft^2 FTW is equivalent to one acre of natural wetland (Lubnow, 2014). FTW also serve as habitat for a variety of birdlife (Sanicola et al., 2019) and smaller organisms such as fish and insects (McAndrew, 2016). FTW are also highly versatile with diverse designs for use in both fresh and saline wetlands (Sanicola et al., 2019). In a study by Sanicola et al. (2019), FTW that were placed into a saline environment developed a dense network of fibrous roots that increased in mass as salinity levels increased during a 12-week study period.

Restoring and constructing wetlands are another option for replacing the actions of lost wetlands (Comin et al., 2014). Even though wetland restoration and construction are probably more ideal, however, there are a lot of challenges. The FTW's biological processes can be more effective because the roots are freely suspended in the water column allowing direct contact between contaminants and the root-associated microbial communities (Shahid et al., 2018). Additionally, restoring wetlands can be difficult because watershed, land, and water use differ between regions and societies (Comin et al., 2014). The addition of FTW don't require highly impactful installation, such as the digging/moving of earth required in wetland restoration and construction (Shahid et al., 2018). Finally, the ability to install FTW on existing water bodies eliminates the space requirements associated with wetland construction (Headley & Tanner, 2007).

Despite the potential of FTW as a sustainable option to replace wetlands, further investigation is needed to fully understand and maximize their contaminant removal efficacy. In order to assess the actual efficacy of FTW concerning water quality, I performed a literature review exploring the various applications of FTW. The goal of the review is to determine 1) how effective are FTW at removing a range of nutrients; 2) what types of plants are most effective in FTW; and 3) does FTW efficacy differ across water body types (eutrophic water, sewage and domestic water, stormwater runoffs, and industrial wastewaters). Given the potential of FTW, I expected that there will be a reduction in nutrient concentrations across all circumstances.

METHODOLOGY

A literature review was done to provide insight on the main topic—the efficacy of floating treatment wetlands (FTW) in contaminant removal. Sources were found using the search engines of Google Scholar, PDX (Portland State University) database, Web of Science, and Science Direct. In addition, sources were found by using references from the listed research articles (Table 1-3). Searches were performed using the following keywords: floating islands, floating treatment wetlands, and floating wetland water quality control; and word roots were used on each type of freshwater type. This online search was limited to 2000 through 2020 since FTW are a recent development and no references exist prior to 2000. Some articles covered the deployment of FTW in more than one water body. In these circumstances, each water body was counted as a separate case study (a case study consisting of FTW deployed in unique water body).

Case studies were organized using Microsoft Excel. For inclusion in this review, a case study had to meet the following criteria. First, a FTW had to be installed in a location where one did not previously exist. Secondly, the study had to include information on changes in the concentration of at least one of the following pollutants: total nitrogen (TN), ammonium (NH_4) and ammonia (NH_3), nitrate- and nitrite-nitrogen (NO_x-N), phosphate (PO_4) and total phosphorus (TP) after the installment of the FTW. These pollutants were chosen because they lead to a decline in water quality and aquatic ecosystem (Bi et al., 2019). Water body type (eutrophic water, sewage and domestic water, stormwater runoffs, and industrial wastewaters) and plants used in the FTW were recorded. It should be noted that plant information was not included in one study (Faulwetter et al., 2011).

RESULT

In total, twenty-one papers and twenty-four case studies were found. Of these, eight case studies looked at eutrophic waters, eight at sewage and domestic waters, five at storm water runoffs, and three at industrial wastewaters. Overall, all case studies showed a reduction in at least one contaminant after floating treatment wetlands (FTW) installment.

Of the water body types examined, the most information available was for the eutrophic water bodies (Table 1). The eight case studies observed removal rates in five contaminants: total nitrogen (TN), ammonium (NH_4), nitrate- and nitrite-nitrogen (NO_x-N), phosphate (PO_4), and total phosphorus (TP). The overall removal rates were TN ranged from 16.2 to 92.9% (n = 6), NH_4 ranged from 3 to 59.4% (n = 6), NO_x-N ranged from 24.6 to 82.4 % (n = 5), PO_4 ranged from 2 to 67% (n = 2), and TP ranged from 16.1 to 91.6% (n = 5).

Table 1. List of removal efficiency in eutrophic waters.

Case Study	Publication	TN	NH_4	NO_x-N	PO_4	TP
1	Li et al., 2010	52.7%	33.7%	-	-	54.5%
2	Zhao et al., 2012a	36.9%	44.8%	25.6 – 53.2%	-	43.3%
3	Zhao et al., 2012a	16.2%	18.4%	12.8 – 25.8%	-	17%
4	Zhao et al., 2012b	50.3%	59.4%	82.4%	-	-
5	Bu and Xu, 2013	25.4 – 48.4%	-	-	-	16.1 – 42.1%
6	Ogluín et al., 2017	-	3 – 29%	37 – 63%	2 – 43%	-
7	Ogluín et al., 2017	-	5 – 35%	38 – 63%	27 – 67%	-
8	Yajun et al., 2019	43.9 – 92.9%	-	-	-	74.4 – 91.6%

Note: * indicates only specify as nitrogen, therefore, falls under TN
Note: NOx-N was recorded for NO3 and NO2
Note: - indicates the information was unavailable in that particular case study

The second most information available out of the water body types was sewage and domestic waters. The eight case studies observed removal rates in six contaminants: TN, NH_4, ammonia (NH_3), NO_x-N, PO_4, and TP (Table 2). The overall removal rates were TN ranged from 25 to almost 100% (n=8), NH_4 ranged from 16.7 to 99.4% (n=2), ammonia (NH_3 ranged from 38 to 43.2% (n=2), NO_x-N ranged from 34.6 to 99.9% (n=3), PO_4 ranged from 10 to 71% (n=3), and TP ranged from 37 to 74.4% (n=3).

Table 2. List of removal efficiency in sewage and domestic waters.

Case Study	Publication	TN	NH_4	NH_3	NO_x-N	PO_4	TP
1	Faulwetter et al., 2011	50%	-	-	90%	-	-
2	Ijaz et al., 2015	56.2%	-	-	-	-	-
3	Lu et al., 2015	66 ~ 100%	-	43.2%	82.3 – 99.8%	64 – 71%	66.2 – 74.4%
4	Ijaz et al., 2016	35 - 50% *	-	-	-	20 – 30%	39% **
5	Prajapati et al., 2017	40% *	40 – 70%	-	-	10 – 23%	-
6	Benvenuti et al., 2018	25 – 80%*	-	38%	-	-	37%
7	Shahid et al. 2019	25 – 47%	-	-	-	-	-
8	Barco and Borin, 2020	44.1 – 95.8%	16.7 – 99.4%	-	34.6 – 99.9%	-	-

Note: * indicates only specify as nitrogen, therefore, falls under TN
Note: NOx-N was recorded for NO3 and NO2
Note: - indicates the information was unavailable in that particular case study

The second least amount of available information of water body type was stormwater runoffs. The five case studies observed removal rates in five contaminants: TN, NH_3, NO_x-N, PO_4, and TP (Table 3). The overall removal rates were TN ranged from 11 to 83.5% (n=5) and TP ranged from 0 to 75.0% (n=5). The other removal rates were NH_3 (n=1), NO_x-N (n=1), and PO_4 (n=1) which was found in one study.

Table 3. List of removal efficiency in stormwater runoffs.

Case Study	Publication	TN	NH3	NO_x-N	PO_4	TP
1	Chang et al., 2013	15.7%	51.1%	20.6%	79%	47.7%
2	White and Cousins, 2013	58.0 – 83.5% *	-	-	-	45.5 – 75.0%**
3	Winston et al., 2013	48%	-	-	-	39%
4	Winston et al., 2013	88%	-	-	-	88%
5	Garcia Chance et al., 2019	11 – 57.3%	-	-	-	0 – 41.7%

Note: * indicates only specify as nitrogen, therefore, falls under TN
Note: - suggests the information was unavailable in that particular case study
Note: NOx-N was recorded for NO3 and NO2

Lastly, the least information available of the water body type was industrial wastewaters. The three case studies observed removal rates in three contaminants: TN, PO_4, and TP (Table 4). The overall removal rates were TN ranged from 35 to 98.22% (n=3), PO_4 ranged from 20 to 30% (n=1) and TP ranged from 39 to 91.74% (n=3).

Table 4. List of removal efficiency in industrial wastewaters.

Case Study	Publication	TN	PO4	TP
1	Tara et al., 2019	60%	-	-
2	Li et al. 2012	63.05 – 98.22%	-	50.43 – 91.74%
3	Ijaz et al., 2016	35 – 50% *	20 - 30%	39% **

Note: * indicates only specify as nitrogen, therefore, falls under TN
Note: ** only identify as phosphorus, therefore, falls under TP
Note: - suggests the information was unavailable in that particular case study

There were no obvious trends in the plant types used in the FTW (Tables 5-8). Only a handful of plants were utilized in more than one case studies. In addition, only *Juncus* and *Pontederia* were used in more than one water bod types.

Table 5. List of the plant used in eutrophic waters.

Plant species	Number of case study included	List of Case Study
Accords calamus	2	Bu and Xu, 2013; Zhao et al., 2012b
Calla palustris	1	Zhao et al., 2012a
Canna indica	2	Zhao et al., 2012a; Bu and Xu, 2013
Cyperus alternifolius	1	Bu and Xu, 2013
Cyperus papyrus	1	Olguin et al., 2018
Eichhirnia crasslpes	1	Zhao et al., 2012a
Hydrocotyle dubia	1	Zhao et al., 2012a
Hydrocotyle verticillate	1	Zhao et al., 2012a
Ipomoea aquatica	1	Li et al., 2010
Jussiaea reppens	1	Zhao et al., 2012a
Miscanthus sinensis anderss	1	Zhao et al., 2012b
Myriophyllum aquaticum	1	Zhao et al., 2012a
Pisitia stratiotes	1	Zhao et al., 2012a
Pontederia cordata	1	Zhao et al., 2012a
Pontederia sagittate	1	Olguin et al., 2017
Suaeda salsa	1	Yajun et al., 2019
Thalia dealbata	1	Zhao et al., 2012b
Triarrhena lutarioriparia	1	Zhao et al., 2012b
Vetiveria zizanioides	2	Zhao et al., 2012b; Bu and Xu, 2016
Zizania caduciflora	1	Zhao et al., 2012b

Table 6. List of the plant used in sewage and domestic waters.

Plant species	Number of case study included	List of Case Study
Azolla filiculoides	1	Prajapati et al., 2017
Brachia mutica	2	Shahid et al. 2020; Ijaz et al., 2015
Eleocharis dulcis	1	Lu et al., 2015
Iris pseudacorus L.	1	Barco & Borin, 2020
Juncus effuses L.	1	Lu et al., 2015
Lactuca sativa	1	Prajapati et al., 2017
Lemna minor	1	Prajapati et al., 2017
Phragmites australis	2	Shahid et al. 2019; Prajapati et al., 2017
Phragmites australis (Cav.) Trin. Ex Steud.	1	Barco & Borin, 2020
Pistia stratiotes	1	Prajapati et al., 2017
Typha domingensis Pers.	2	Ijaz et al., 2016; Benvenuti et al., 2018
Typha latifolia L.	1	Barco & Borin, 2020
Typha orientalis Persl.	1	Lu et al., 2015

Table 7. List of the plant used in stormwater runoffs.

Plant species	Number of case study included	List of Case Study
Andropogon gerardii	1	Winston et al., 2013
Canna flaccida	1	White and Cousins, 2013
Carex stricta	1	Winston et al., 2013
Hibiscus moscheutos	1	Winston et al., 2013
Juncus effusus L.	4	Winston et al., 2013; White and Cousins, 2013; Chang et al., 2013; Garcia Chance et al., 2019
Pontederia cordata	3	Winston et al., 2013; White and Cousins, 2013; Chang et al., 2013

Table 8. List of the plant used in industrial wastewaters.

Plant species	Number of case study included	List of Case Study
Geophila herbacea O Kumtze	1	Li et al., 2012
Lolium perenne L.	1	Li et al., 2012
Lolium perenne Topone	1	Li et al., 2012
Phragmites australis	1	Tara et al. 2019
Typha domingensis	1	Ijaz et al., 2016

DISCUSSION

This review examined the efficacy of floating treatment wetlands (FTW), what plants were predominately used, and how effectively FTW removed contaminants across different water body types. FTW were found to effectively remove contaminants in all circumstances. In the eutrophic waters, FTW had the highest removal efficacy on the levels of the interested pollutants (Table 1). The case studies on eutrophic waters didn't only just report total nitrogen (TN), it reported nitrite- and nitrate-nitrogen compounds and ammonium, whereas in the sewage and domestic were only interested in TN, phosphate (PO_4), and total phosphorus (TP) as it lacked ammonium (NH_4) and ammonia (NH_3) examination (Table 2). As for the case studies on stormwater runoffs, there was almost nothing on nitrogen compounds (NO_x-N) (Table 3); and industrial wastewater, low reports on PO_4 (Table 4).

While not universal, some researchers examined the specific removal efficacies of plants in FTW on each water body. For example, *Accords calamus* had a high TN removal rate of

43.5% (Bu and Xu, 2013) and of 79.1% (Zhao et al., 2012b) for the eutrophic waters. In the sewage and domestic water, the removal rates of TN and TP were 56.2% and 61% for *T. domingensis* Pers. (Ijaz et al. 2016). In the stormwater runoff, *P. cordata* had high TN and TP removal rates of 57% and 41.7%, and in the industrial wastewaters, all the plants from the case study, Li et al. (2012), had a TN removal range of 69.5 – 59.1%.

A somewhat surprising trend was the lack of consistency of plants used in FTW for a given water body types (some exceptions did exist; for instance *Juncus* and *Pontederia*, in eutrophic, sewage and domestic waters, and stormwater runoffs) (Table 5, 6, & 7). There were no apparent main plant species listed in the other three water bodies which may be due to accessibility or not being native in that area, or the case study was more focused on the removal efficacy on the FTW bed. The dominant plants of *Juncus* and *Pontederia* were reported to have high TP and TN removal rates (Winston et al., 2013; White & Cousins, 2013; Chang et al., 2013; Garcia Chance et al., 2019). Furthermore, these plants were only examined in one specific location with stormwater runoffs, and it was unclear whether these plants could work in other areas.

Some things that should be noted about FTW's removal efficacy were seasonality and adding inoculates to the plant that helped promote removal efforts. For example, Zhao et al. (2012a) and Ogluín et al. (2017) showed that seasonality had an impact on nutrient removal. Zhao et al. (2012a) demonstrated the plants removed more nutrients in the warmer season, while Olguin et al. (2017) showed the plants removed more in the colder season. Adding bacterial inoculate to the plants in the FTW had an increase of 10 – 20% of removal efficacy (Ijaz et al., 2016; Tara et al., 2019). Bacterial inoculate was known to enhance removal capacity since its processes can transform and decompose organic matter and heavy metals (Shahid et al., 2019; Ijaz et al., 2016; Ijaz et al., 2015).

The comparison of FTW across the water body types showed it worked in all water bodies since there was a wide range of removal efforts. However, there should be more experiments done in industrial wastewater since only three case studies were observed. Inspection of specific species, seasonality and inoculants would also be worth investigating. The reason for investing in seasonality was due to the inconsistency of different time periods where Zhao et al. (2012a) covered year pattern while Ogluín et al. (2017) covered month patterns. This would be necessary, not in when the plants were present, but more in terms of FTW efficacy and functionality.

CONCLUSION

Largely from this paper, floating treatment wetlands (FTW) did have an effect on nutrient removal efficacy. There was no noticeable plant species in a given water body type, except for the plants, *Juncus* and *Pontederia*, which were found in eutrophic water, sewage and domestic waters, and stormwater runoffs. Some things to consider for future research to explore were specific species, seasonality and inoculates. As for the differences of removal efficacy of FTW across water bodies, all water body types were affected, even though there was a limited amount of existing case study in industrial wastewaters. With that in mind, FTW does work even with the need for required further study on their efficacy, they are a useful tool to help improve water quality in water control management.

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