

Biodiversity associated to floating wetland islands

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Abstract.

Floating wetland islands (FWI) are nature-based solutions that can be applied in different water bodies, such lakes, ponds and rivers, considering a wide range of purposes. They have been considered for eutrophication abatement, wastewater treatment and ecosystem rehabilitation. They are of great value since their efficiency relies on bioremediation processes and thus very versatile in terms of water depuration but also on biodiversity promotion.

These systems comprise a floating platform, selected plants and an anchoring system. Depending on their configuration, they will attract and harbor different organisms such macrofauna and microorganisms, that will use the platform as shelter, habitat, stepping stone, nursery, food source among other benefits. The plant species are of particular interest since they are the living interface between the platform and the water body and they must be selected according to criteria that will enable their successful establishment having in consideration the biotic factors.

The present paper intends to give an overview of the role of FWI towards their associated biodiversity and what has been identified in literature as the main groups that can be found and related operational conditions. This approach can support future decisions concerning the FWI implementation conditions and components towards biodiversity enhancement.

Keywords: Microbial communities, Macrophytes, Macrofauna, Macroinvertebrates, Nature-based solutions, Plant diversity

1 Introduction

The conservation and sustainable use of the marine and terrestrial environment is supported by the primary biodiversity Goals (SDG 14 and 15) although, the 17 SDGs ultimately depend on healthy ecosystems and biodiversity. Concerning nature-based solutions (NBS), biodiversity has firstly a functional role, which underpins ecosystem functions and processes thus delivering ecosystem services and supporting conservation objectives (WWAP, 2018). Nature-based solutions “are inspired and supported by nature and use, or mimic, natural processes to contribute to the improved management of water. An NBS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems.” (WWAP, 2018, pp2).

The use of constructed wetlands as NBS for bioremediation has been widely used, considering wastewater treatment, management and ecosystems rehabilitation (Calheiros et al, 2020a). Although, when the target is a water body, such river, lake, pond, the floating wetland islands (FWI) is usually the most adequate approach. There are several reviews that detail the systems applications and configurations (e.g., Arivukkarasu et al, in press; Colares et al, 2020; Pavlineri et al, 2017). Floating wetlands islands are also known as Treatment Floating Wetlands, Floating Islands or vegetated floating mats, and they deliver a wide range of ecosystem services, having the advantage that no additional surface land is required and can operate *in situ*. These systems comprise a floating platform, plants species and an anchoring system. In relation to the floating platform, in order to ensure the buoyancy, it can be made of different materials such polyethylene, polypropylene, polyurethane or polyvinyl alcohol foam (Karstens et al, 2021) or cork (Calheiros et al, 2020b). The plant species considered may vary widely depending on the environment (e.g., saline, freshwater) that the FWI will be implemented, being important to select them based on established criteria (Arivukkarasu and Sathyanathan, 2022; Calheiros et al, 2022; Wang and Sample, 2014). The promotion of the biodiversity is one of the ecosystem services delivered by these systems and can be enhanced by adding other features to the platform in order support for example nursery purposes, habitat, shelter, etc. A huge interest is rising concerning the species that these systems can harbor at the macro and micro level.

The aim of this paper is to deliver an overview of the FWI role towards biodiverse promotion. In that sense it will be explored their associated biodiversity and what has been identified in literature as the main groups that can be found and related operational conditions. This approach is of outmost importance to support future decisions concerning the FWI implementation conditions and components towards biodiversity enhancement.

2 Biodiversity behind Floating Wetland Islands

In addition to the FWI’s main purpose of treating water, these systems can also deliver numerous ecosystem services, including the improvement of biodiversity. The wide

range of plant species used to vegetate the platforms will boost the biodiversity of the surrounding ecosystem. Starting with the increment of the diversity of plant species in the FWI itself. A study performed by Wang et al. (2015) showed that plant diversity increased from three (initially planted) to seven species after 1 year of the FWI implementation. The biofilm attached to the surface of roots and rhizomes and to the floating mat also comprises diverse bacterial, fungi, and algae communities. Moreover, FWI contribute to increase the diversity of several macroinvertebrates communities, namely insects, snails, and molluscs, while they create habitats for several animals, namely fishes, amphibians, and birds (Karstens et al., 2021).

2.1 Plant selection and establishment

Floating wetland islands consist in a buoyant structure floating on the surface of water that supports emergent vegetation. The roots of plants are completely emerged in the water, while the upper parts remain and grow above the water level (Arivukkarasu and Sathyanathan, in press; Benvenuti et al., 2018; Pavilineri et al., 2017). The main natural components of FWI are the macrophytes which have extensive root systems enabling the absorption of nutrients and contaminants from water (Arivukkarasu and Sathyanathan, in press). Macrophytes can be classified according to the water level as emergent, floating, and submerged (Thampatti et al., 2020). A plethora of plant species have been used for water treatment by FWI, however the selection of macrophytes is a crucial step and should rely on several criteria as they will impact the performance of the system, as well as the surrounding ecosystem.

Wang and Sample (2014) defined some criteria to select plants for FWI implementation:

- Native and non-invasive plants species
- Terrestrial and perennial plant species
- Emergent wetland plants able to adapt and thrive in hydroponic conditions
- Plants with aerenchyma for higher oxygen diffusion from aerial parts to below-ground organs (roots and rhizomes)
 - Plant species with aesthetic attributes
 - Plants with high nutrient uptake capacity

In addition, Arivukkarasu and Sathyanathan (in press) reported that the selection of macrophytes should be based on following criteria:

- Saplings should be readily available
- Good adaptation to climatic conditions throughout the year
- Ease vegetative reproduction
- Good resistance to insects and plant diseases
- High growth rate and fast biomass production throughout the year
- High root development and anchoring well in the growth medium
- Provision of oxygen to the belowground organs even under anoxic conditions

Further on, Calheiros et al (2020b) used the following criteria for plant selection: (1) native to the country; (2) potential to survive in hydroponic mode with tolerance to variable salinity levels; (3) presence in the region of the experimental site; (4) perennial species and (5) possibility to form a polyculture. Shaïd et al. (2018) highlighted that the tolerance of plants to salinity, metals, organic compounds should also be considering.

The species mostly used in artificially created FWI belonged to genera *Canna*, *Carex*, *Typha*, *Phragmites*, *Juncus*, and *Cyperus* (Headley and Tanner, 2012; Rheman et al., 2019). According to the meta-analysis performed by Pavlineri et al. (2017), *Canna* is a widely adapted plant species that is commonly used in FWI systems operating in several locations and climate zones in the world. Similarly, several species of *Typha* and *Cyperus* genera have also been broadly tested in FWI. For instance, the macrophyte *Typha domingensis* Pers. was successfully used in a FWI to treat raw sewage in a municipal sewage treatment plant (Benvenuti et al., 2018). However, many other plant species can be used, including terrestrial plant species such as *Brachiaria mutica* and *Salix babylonica*. These species are a good solution to increase the rate of removal of nutrients and contaminants from water as they possess extensive root systems (Ijaz et al. 2015; Zhu et al., 2011).

Queiroz et al. (2020) evaluated the use of the macrophytes *Eichhornia crassipes*, *Eichhornia paniculate*, *Polygonum ferrugineum* and *Borreria scabiosoides* for the treatment of dairy wastewater using FWI. The aquatic macrophytes *E. crassipes* and *E. paniculate* were the species that better performed showing higher organic load removal efficiency and biomass growth. Calheiros et al. (2020b) reported the successful installation of an *in-situ* FWI in a seawater port marina, comprising a polyculture of species able to withstand high salt levels - *Sarcocornia perennis*, *Juncus maritimus*, *Phragmites australis*, *Halimione portulacoides*, *Spartina maritima*, *Limonium vulgare*.

Ornamental plants can also be used in FWI contributing to improve the aesthetic landscape (Barco and Borim, 2020; Zarin et al., 2018), which could be of particular interest in urban areas. Moreover, ornamental plants will attract further wildlife, including insects pollinators. These plants must thrive and growth well in aquatic environment and at same time show ornamental features. Several strategies can be applied when using ornamental plants in FWI, namely the use of plants with a colorful flowering, mixtures of species with different colored flowers, and species with aesthetic foliage characteristics (Barco and Borim, 2020). The suitability of 11 wetland species with ornamental features: *Canna indica* L., *Pontederia cordata* L., *Thalia dealbata* Fraser ex Roscoe, *Acorus calamus* L., *Juncus effusus* L., *Iris laevigata* L., *Mentha aquatica* L., *Oenanthe javanica* (Blume) DC., *Caltha palustris* L., *Sparganium erectum* L. and *Zantedeschia aetiopica* (L.) Srengel was evaluated. Results showed that *C. indica*, *P. cordata* and *T. dealbata* were the species that better performed regarding the vigor and colonization of the floating maps, survival, and nitrogen uptake (Barco and Borim, 2020) (Figure 1). According to Liu et al. (2016) the ornamental emergent macrophytes, *Lythrum salicaria* Linn. and *Iris wilsonii*, were efficient in removing total nitrogen and phosphorous from the wastewater. Urakawa et al. (2017) also used *Canna flaccida* and *Juncus effusus* roots in a FWI established in a manmade stormwater pond.



Figure 1. Examples of ornamental plant species used in floating wetland islands. (a) *Canna indica*, (b) *Canna flaccida*, (c) *Zantedeschia aethiopica*.

2.2 Microorganisms associated to floating wetland islands

The roots of plants growing in the FWI, and the mat platform harbor a variety of microorganisms (Lubnow, 2014; Lucke et al., 2019), which may be involved in the removal of total nitrogen and $\text{NH}_4\text{-N}$ from water by several processes, such as nitrification, denitrification, and anaerobic ammonium oxidation (Tao et al., 2009). Indeed, according to Sun et al. (2009) the removal efficiency of nitrogen was fostered by the addition of immobilized denitrifying bacteria to the floating bed. In addition, microorganisms also play an important role on the degradation of pollutants, including metals and organic compounds (Liu et al., 2019), especially whether associated to the roots of plants in FWI (Demarco et al., 2023; Li et al., 2012; Rehman et al., 2019). Recent studies reported the inoculation of specific microorganisms in FWI systems as a successful strategy to increase the efficiency of pollutant removal from water (Shahid et al., 2020). For instance, Nawaz et al. (2020) demonstrated that the bacterial inoculation of a FWI composed of *P. australis* increased the removal of dyes from textile wastewater. Likewise, the inoculation of two aquatic plants with bacterial strains showing pollutant-degrading ability and growth-promoting traits fostered textile dye degradation (Tusied et al., 2020).

Despite the importance of microorganisms in nutrient and/or pollutant removal, little is known about the microbial communities associated to FWI plant roots (Urakawa et al., 2017). Preliminary studies are being carried out by Calheiros et al. (2022) that is studying the integration of a FWI pilot in a freshwater pond assessing its biodiversity (Figure 2), namely the culturable bacterial communities associated to the floating platform biofilm and to the plant rhizosphere.



Figure 2. (a) Floating wetland island in a freshwater pond, (b) biofilm sampling for microbial communities analysis.

Urakawa et al. (2017) evaluated the microbial communities colonizing *C. flaccida* and *J. effusus* roots, as well as the biofilms of plant pots and floating mat foam, in a FWI implemented in a manmade stormwater pond. Results showed that FWI's plant root microbiomes were dominated by *Anabaena*, *Rhizobium*, and *Rhodobacter* genera. In addition, microbial communities of the FWI plant roots were quite different from the those found in the biofilm, being more related to the communities thriving in the surrounding water samples. Similar results were obtained by Calheiros et al. (2020b) in a FWI installed in a seawater port marine. The structure of the microbial communities retrieved from biofilm adhering the planting media and the submerged platform was distinct from the communities associated to the surrounding water.

2.3 Aquatic and terrestrial associated fauna

Floating wetlands islands have real potential to provide habitats for aquatic and terrestrial fauna (Kartens et al., 2022). Aquatic and terrestrial species usually use the available area as shelter and refuge to escape predator pressure (Kartens et al., 2022). FWI are also used by the fauna as a food source (Preshant and Billore, 2020). The roots of plants in FWI are usually able to retain particulate matter that serve as food source for the macroinvertebrates (Preshant and Billore, 2020). Aquatic and terrestrial associated species mainly include, annelids (mainly oligochaete worms and leeches), molluscs (mainly aquatic gastropods and freshwater mussels), arachnids (mainly spiders and water mites), crustaceans (mainly shrimps and crabs), insects (mainly dragonflies, bugs, water scorpions, water boatmen, beetles, caddisflies, midges), amphibians (American bullfrogs, gray treefrogs, crawfish frogs, southern leopard frogs), reptiles (Common snapping turtles, eastern painted turtles, red-eared slider turtles, northern water snakes), fishes (mainly eels, cyprinids, gobies, rosy bitterlings, topmouth gudgeons, black basses) and birds (mainly mallards, red-winged blackbirds, twice gulls, grey herons, Canada geese, sparrows) (Table 1).

FWI can provide critical habitat also for many migratory fishes and invertebrate species important to commercial and recreational fisheries (Deegan et al., 2002; Moody et al., 2013). Indeed, Huang et al. (2017) reported that stereoscopic artificial floating

wetlands vegetated with *P. australis* proved to be efficient fish aggregation devices in estuarine and coastal habitats. Recent studies have also observed that large numbers of juvenile European eel (*Anguilla anguilla*) are associated with the dense roots structures of FWI plants (Cicero-Fernandez, 2022; Kartens et al., 2022). In this case, the FWI serve as a refuge to avoid predators; normally, eels seek out dark, structurally rich areas during the day (Kartens et al., 2021). This is of particular importance as the population of the European eel has declined in several places in recent years, and the species is nowadays considered critically endangered (Pike et al., 2020).

According to Kartens et al. (2022), the FWI can serve as a steppingstone to improve habitat connectivity of several species, such as the diadromous fish species. There are several bird species that are attracted to FWI and use the structure as an enhancement of available habitat (Yeh et al., 2015). Shealer et al. (2006) observed that during periods of flooding birds preferred FWI over natural sites. They have also observed that bird eggs that were laid in FWI were significantly larger than those laid at natural sites, suggesting that FWI were occupied by better quality birds. According to Hancock (2000), the availability of FWI have probably increased the Black-throated Diver (*Gavia artica*) population in Scotland by an average of 44% (from 7% to 130%, varies by site). The FWI appears to have been used by birds as an additional benefit contributing to landscape aesthetics and also habitat enhancement.

Table 1. Main species and groups observed in association with the Floating wetlands islands (FWI).

Species	Main use of the floating wetland	Period of study	System	Reference
Annelida (2 species), Mollusca (2 species), Crustacean (<i>Macrobrachium niponense</i>), Arachnida (<i>Aranae</i> sp.), Insects (Terrestrial, 4 groups; Aquatic, 4 groups), Fishes (6 species)	Favorable habitat, safe nesting habitat, area for feeding	3 years	Shoreline of a lake	Nakamura et al., 1997
Annelida (Freshwater leech), Mollusca (<i>Physella acuta</i>), Arachnida (<i>Dolomedes triton</i>), Insects (Aquatic, 4 species; Terrestrial, 5 species), Fishes (<i>Cyprinus carpio</i>), Reptiles (4 species), Birds (5 species),	Foraging, breeding, nursing, resting	5 months	Pond	Wang et al., 2015
Crustaceans (Crabs, 8 species; Shrimps, 5 species), Fishes (13 species)	Used to compensate habitat degradation, improve fish and crustacean	Few days during 4 months	Reservoir	Huang et al., 2017

	recruitment and increase refuge capacity			
Mollusca (Gastropods, 2 species), Arachnida (2 species), Insects (3 species), Reptiles (4 species), Birds (3 species)	Habitat creation	2 years	Ponds	Strosnider et al., 2017
Annelida (Polychaeta), Crustaceans (<i>Chthamalus</i> sp.; <i>Palaemon</i> sp.), Bivalvia (<i>Mytilus</i> sp.), Fishes (<i>Mugil</i> sp.)	Feeding	16 months	Next to a pier of a Marina	Calheiros et al., 2020b
Mollusca (7 species), Insects (11 species)	Shelter and food availability	Not available	River	Prashant & Billore, 2020
Insects (<i>Nepa</i> sp.), Crustaceans (2 species), Mollusca (<i>Gastropoda</i> <i>indet.</i>), Fishes (<i>Anguilla anguilla</i>), Amphibians (<i>Rana esculenta</i>), Reptiles (<i>Natrix natrix</i>), Birds (5 species)	Foraging, shelter and refuge	4 months	Shallow lagoon	Kartens et al., 2021

Crustaceans (2 species), Fishes (<i>Anguilla anguilla</i>)	Functional habitat, nursery and refuge	2 years	Floating dock in the tidal lagoon	Cicero-Fernandez et al., 2022
Cnidaria (<i>Hydra</i> sp.), Annelida (Oligochaetes), Mollusca (3 species), Arachnida (<i>Hydracarina</i> sp.), Insects (5 species)	Diverse habitats for the different stages of macroinvertebrates	Seasonal (Autumn 2018, Winter 2019, Spring 2019, Summer 2019)	Bays in the downstream part of a reservoir	Salmon et al., 2022

Overall, FWI seem to improve ecosystem conditions and lead to more diverse fauna (invertebrates, fishes, amphibians, reptiles, and birds) communities. In particular, FWI provide shelter when they provide more interstitial spaces favorable to the colonization of macroinvertebrates; heterogeneous habitats that contributes to attract diverse and abundant fauna; stable and constantly accessible habitats for fauna regardless of the water level, as they are floating structures; and they also serve as a relevant food source for some species.

3 Conclusion

Floating wetland islands are very interesting NBS to consider when a water body needs of intervention being for water management and treatment or ecosystem rehabilitation or aesthetic integration. They are very versatile and adaptative in terms of their configuration and components. Enhancement of biodiversity is an asset associated to these systems above and below water surface. Biodiversity can thus be promoted when choosing the adequate materials, especially the plant species, that are the most visible component being the living interface. A wide range of biodiversity has already been identified to be associated to FWI, such, macroinvertebrates, vertebrates and microorganisms. Nevertheless, there is still the need for further research on the ecosystem's services accounting related to biodiversity, especially species association to different environments (marine, freshwater, wastewater) and their response to different biotic and abiotic profiles.

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