Artificial Floating Island System as a Sustainable Solution for Addressing Nutrient Pollution and Harmful Algal Blooms (HABs) in Ohio

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Abstract

Nutrient pollution is considered one of America's most widespread, costly, and challenging environmental problems. Artificial Floating Islands (AFIs), a phytoremediation technology, has been proven as an efficient, environmental-friendly, and cost-effective strategy to address this issue. However, most previous studies of AFIs were done in controlled conditions at mesocosm experiments. In addition, limited information exists on the use of AFIs as a nutrient remediation/prevention strategy in Ohio. This study aims to fill these gaps. We are currently undertaking a combination of mesocosm and natural experiment to assess the nutrient-removal efficiency of AFI systems in the Milliron Research Wetlands (at the Ohio State University Mansfield campus), and establish a performance baseline for two native aquatic plant species, Carex comosa and Eleocharis palustris. In this study, 18 AFIs, 6 planted with Carex comosa, 6 with Eleocharis palustris, and 6 have no plants, were deployed in a section of the Milliron Research Wetlands. Physical and chemical parameters are being monitored bi-weekly. The AFI systems are constructed using PVC pipes to provide buoyance, EVA foam mats as platforms, and nylon nets to cover the system. Each AFI unit has nine luffa sponges, inserted in the foam mat, to hold aquatic plant seedlings, keep the moisture of roots, and enlarge the surface area for bacterial biofilm development. Since nutrient removal from the wetland is affected by numerous natural processes, a mesocosm experiment was set up to assist the quantification of nutrient removal due specifically to the presence of AFIs. The mesocosm experiment mimics the natural experiment at the wetland and contain 12 equal-size tanks containing water pumped directly from the wetland, 3 of which have AFIs with Carex comosa, 3 have Eleocharis palustris, 3 have no plants, and 3 contain just water from the wetland. Physical and chemical measurements (as well as sample collections) are performed weekly in the tanks. Water in the tanks are exchanged bi-weekly. Preliminary results show that the AFI systems quickly developed large root systems and extensive bacterial biofilms. The effects of the associations between plant biomass, biofilm development, and changing chemical and physical conditions will be investigated as the experiment progresses.

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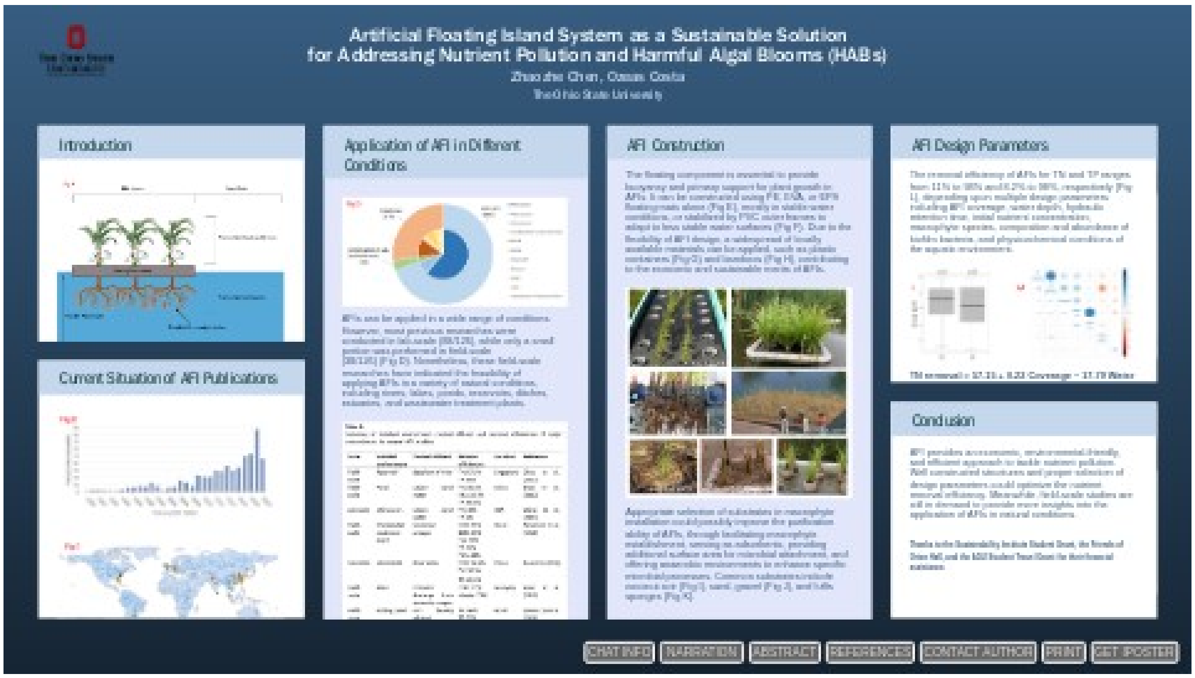

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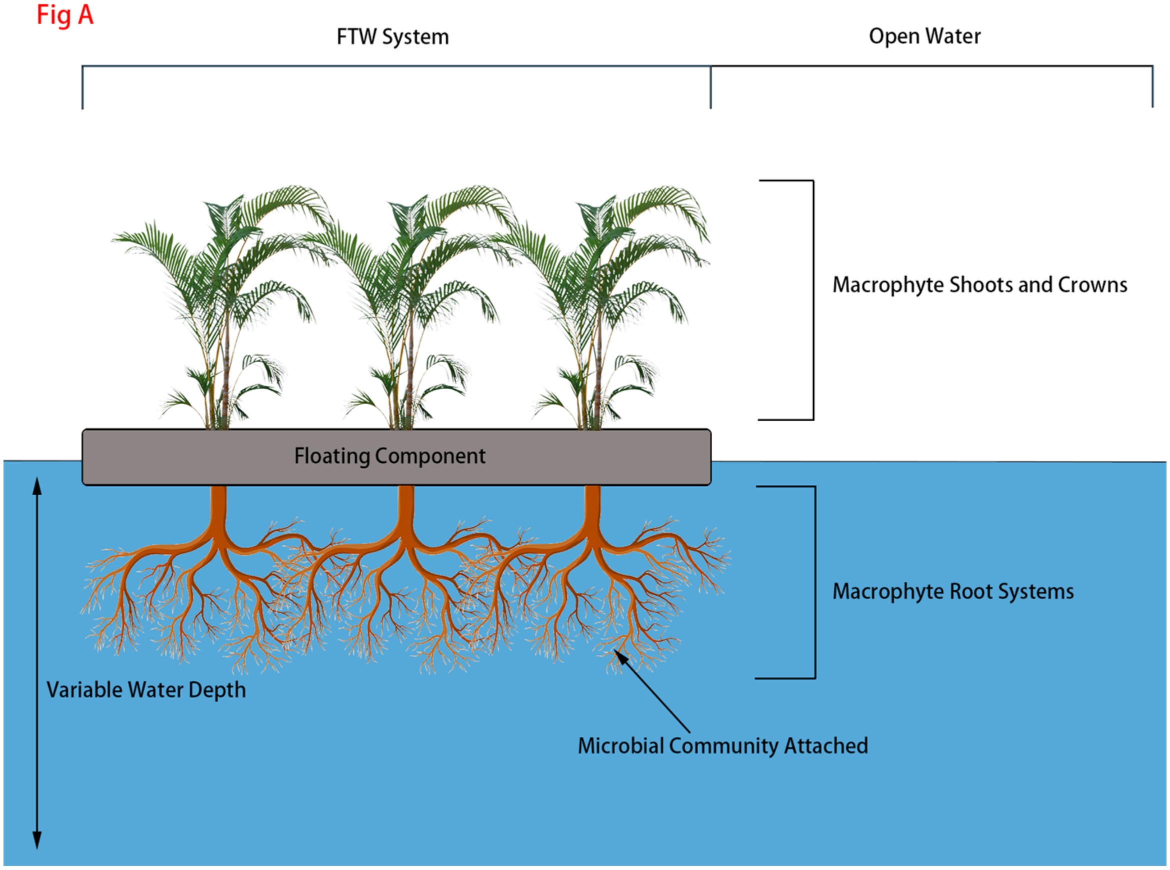
INTRODUCTION

Fig A



Artificial Floating Island (AFI) is composed of three main components, emergent macrophyte crowns and shoots growing above the water level, floating components providing buoyancy for the system, and extensive underwater root systems associated with microbial communities (Fig A). AFIs remove nutrients in the water through three major approaches, direct uptake by macrophytes, sedimentation or entrapment of suspended solids by root systems, and assimilation or conversion by microbial communities attaching to root systems.

CURRENT SITUATION OF AFI PUBLICATIONS

Fig B

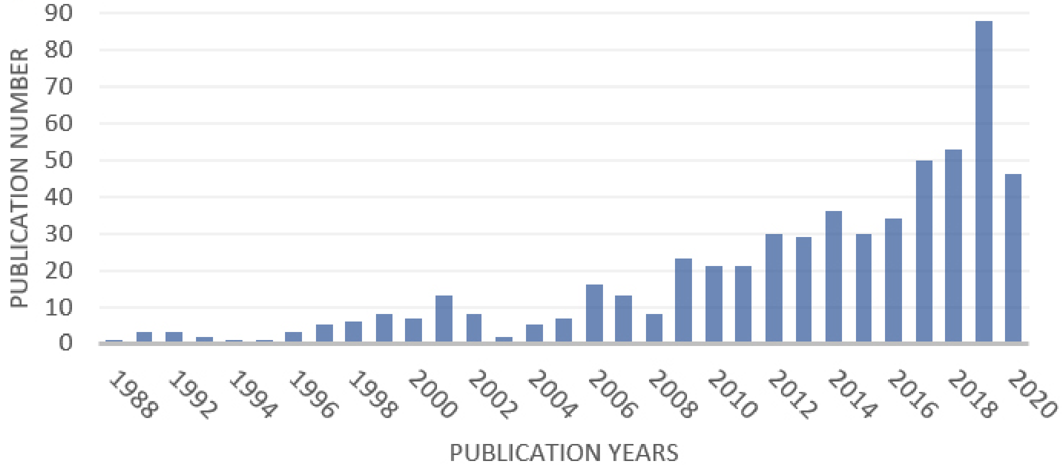
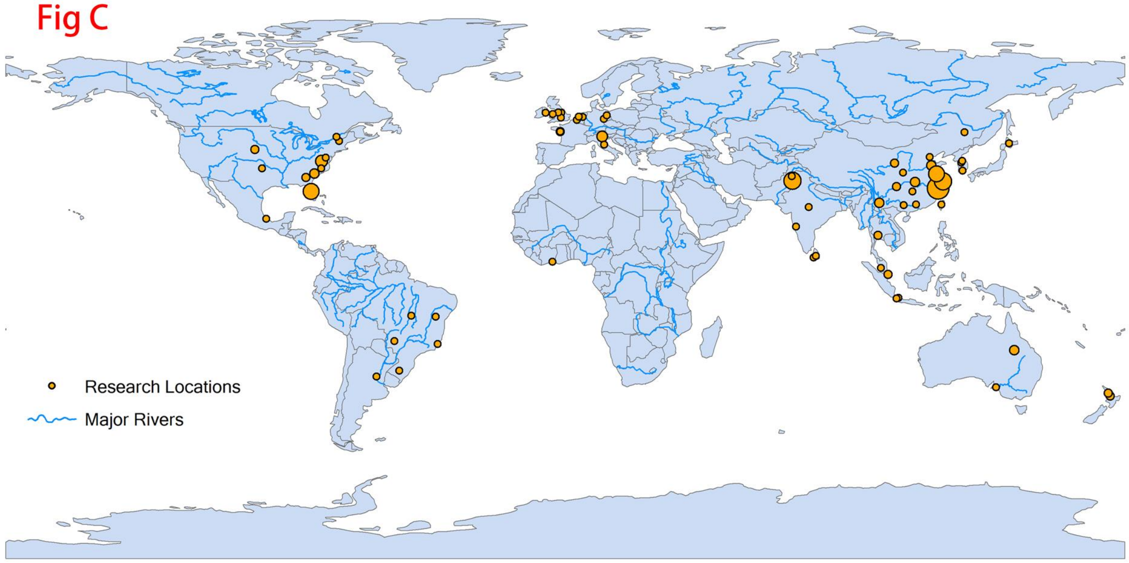


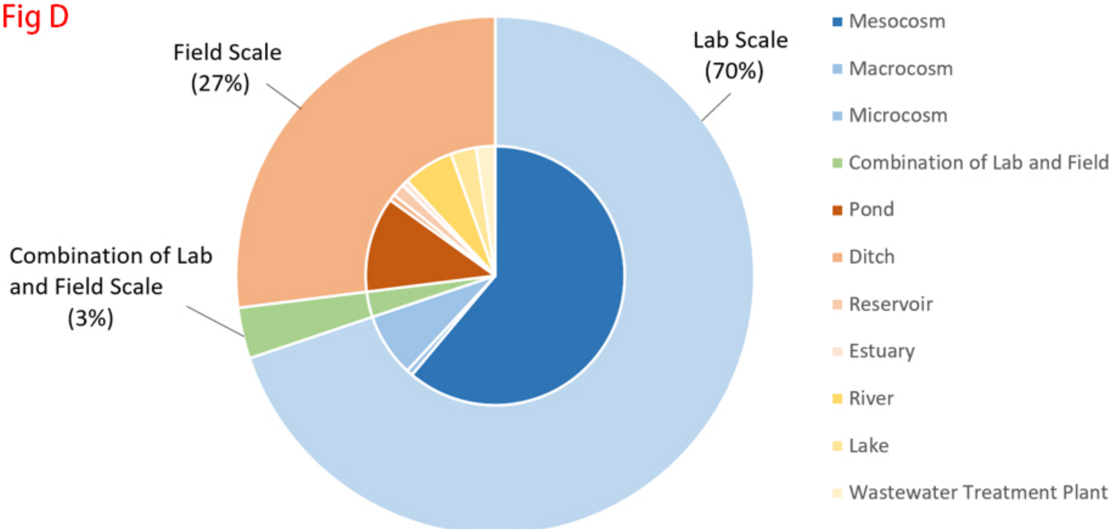
Fig C



A bibliometric analysis was conducted on August 21st, 2020 to investigate the current situation of AFI related publications. Based on the search engine of Web of Science, 573 records were obtained using the keywords “artificial floating island”, “constructed floating island”, and “floating treatment wetland”, of which 496 are articles, 26 are reviews, and 7 are meeting abstracts. A generally rising trend in the publication numbers during the last few decades was observed where the largest increment happened from 2018 to 2019, with a proportional rise of 6.11% (Fig B). The spatial distribution of AFI studies presents that most AFI studies were conducted along coastlines or major rivers worldwide and their tributaries (Fig C).

APPLICATION OF AFI IN DIFFERENT CONDITIONS

Fig D



AFIs can be applied in a wide range of conditions. However, most previous researches were conducted in lab-scale (88/126), while only a small portion was performed in field-scale (38/126) (Fig D). Nonetheless, these field-scale researches have indicated the feasibility of applying AFIs in a variety of natural conditions, including rivers, lakes, ponds, reservoirs, ditches, estuaries, and wastewater treatment plants.

Table 1:

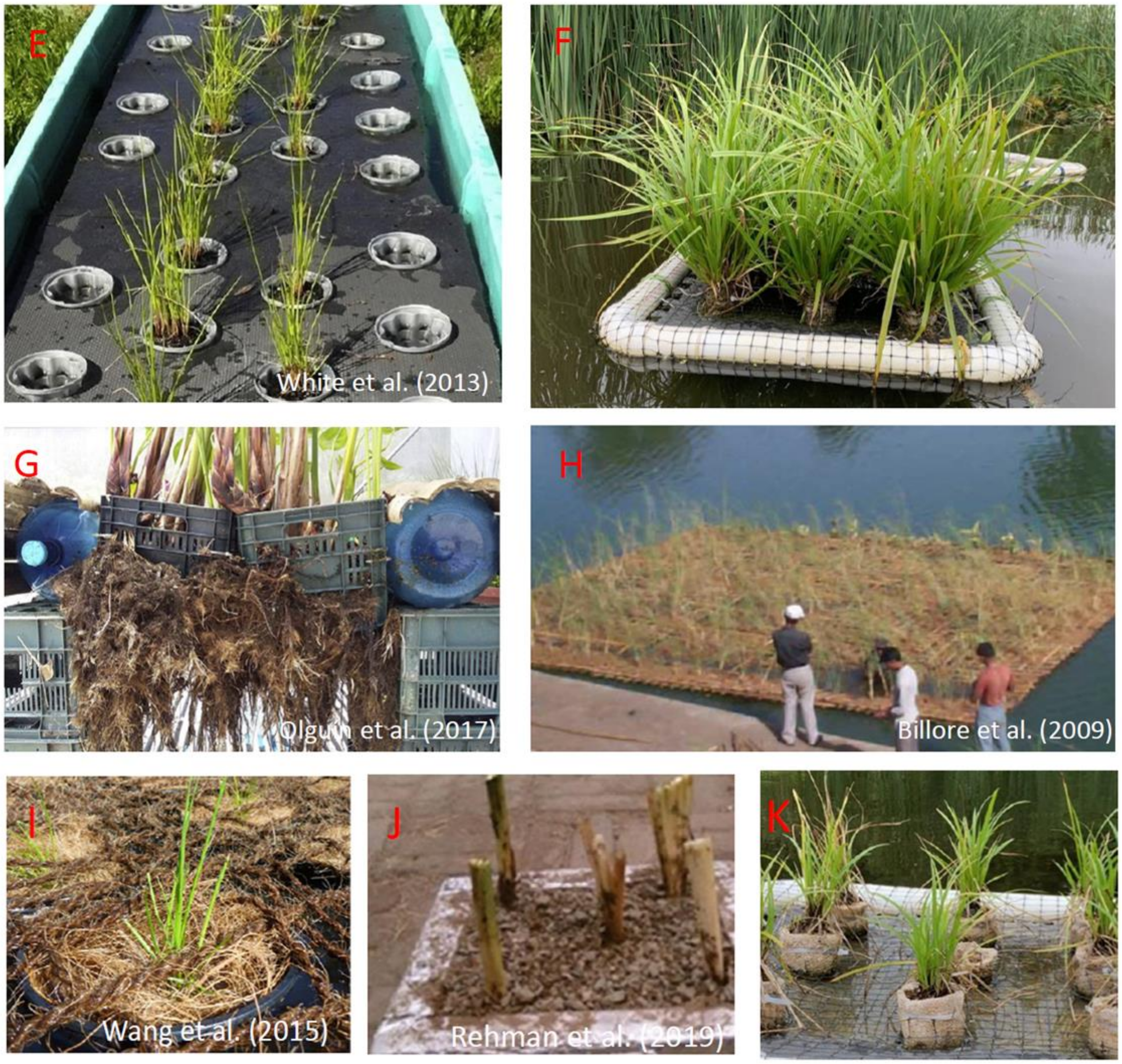
Summary of installed environment, treated effluent and removal efficiencies of major contaminants for several AFI studies.

Scale	Installed environment	Treated effluent	Removal efficiencies	Location	Reference
Field-scale	Reservoir	Baseflow of river	TN: 67.5% TP: 46%	Singapore	Chua et al. (2012)
Field-scale	Pond	Urban pond water	TN: 50.3% NH_4: 59.4% TP: 86.5%	China	Zhao et al. (2012)
Lab-scale	Microcosm	Urban pond water	TN: 18% TP: 8%	USA	Wang et al. (2014)
Field-scale	Wastewater treatment plant	Municipal sewage	COD: 55% BOD: 56% TSS: 78% TP: 37% TKN: 41%	Brazil	Benvenuti et al. (2018)
Lab-scale	Mesocosm	River water	COD: 26.9% TN: 36.9% TP: 29.1%	China	Bu and Xu (2013)
Field-scale	River	Domestic discharge from	COD: 77% Nitrate: 73%	Malaysia	Kusin et al. (2019)

		university campus			
Field-scale	Fishing pond	Fish farming effluent	TN: 66% TP: 27%	Brazil	Saviolo Osti et al. (2020)
Lab-scale	Macrocosm	Textile wastewater	COD: 92% BOD: 91% Color: 86%	Pakistan	Tara et al. (2019)
Lab-scale	Mesocosm	Simulated urban stormwater runoff	COD: 71.17% TN: 69.96% TP: 82.40%	China	Ge et al. (2016)
Field-scale	River	Aquaculture effluent	COD: 66% BOD: 52% TP: 65%	Italy	De Stefani et al. (2011)
Field-scale	Urban artificial lake	Urban landscape water	NH_4: 89.98% Phosphate: 92.49%	China	Wang et al. (2018)
Lab-scale	Mesocosm	Synthetic effluent	COD: 88% TN: 85% TP: 90.2%	Ireland	Shen et al. (2019)
Lab-scale	Mesocosm	Storm runoff	TN: 35.5% TP: 31%	USA	Garcia Chance et al. (2019)
Field-scale	Stormwater detention pond	Urban stormwater runoff	TP: 27%	New Zealand	Borne (2014)

AFI CONSTRUCTION

The floating component is essential to provide buoyancy and primary support for plant growth in AFIs. It can be constructed using PE, EVA, or EPS floating mats alone (Fig E), mostly in stable water conditions, or stabilized by PVC outer frames to adapt to less stable water surfaces (Fig F). Due to the flexibility of AFI design, a widespread of locally available materials can be applied, such as plastic containers (Fig G) and bamboos (Fig H), contributing to the economic and sustainable merits of AFIs.

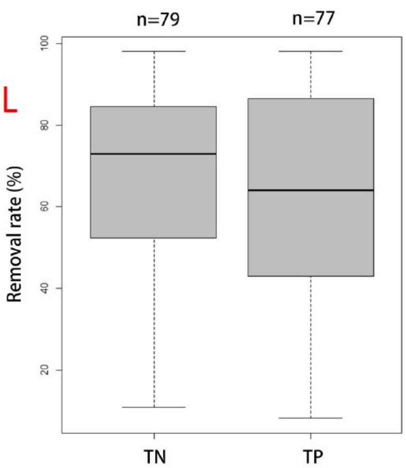


Appropriate selection of substrates in macrophyte installation could possibly improve the purification ability of AFIs, through facilitating macrophyte establishment, serving as adsorbents, providing additional surface area for microbial attachment, and offering anaerobic environments to enhance specific
microbial processes. Common substrates include coconut coir (Fig I), sand, gravel (Fig J), and luffa sponges (Fig K).

AFI DESIGN PARAMETERS

The removal efficiency of AFIs for TN and TP ranges from 11% to 98% and 8.2% to 98%, respectively (Fig L), depending upon multiple design parameters including AFI coverage, water depth, hydraulic retention time, initial nutrient concentration, macrophyte species, composition and abundance of biofilm bacteria, and physicochemical conditions of the aquatic environment.

L



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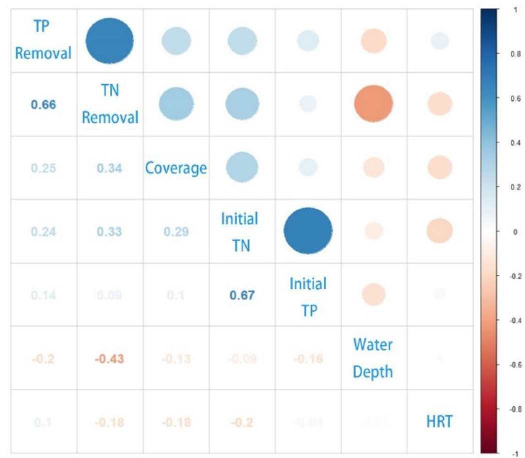

TN removal = 57.15 + 0.22 Coverage – 17.79 Water depth + 1.67 Initial TN + 6.26 Initial TP – 0.22 Coverage * Water depth -0.52 Initial TN * Initial TP (R^2=0.47)

CONCLUSION

AFI provides an economic, environmental-friendly, and efficient approach to tackle nutrient pollution. Well constructed structures and proper selection of design parameters could optimize the nutrient removal efficiency. Meanwhile, field-scale studies are still in demand to provide more insights into the application of AFIs in natural conditions.

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ABSTRACT

Nutrient pollution is considered one of America's most widespread, costly, and challenging environmental problems. Artificial Floating Islands (AFIs), a phytoremediation technology, has been proven as an efficient, environmental-friendly, and cost-effective strategy to address this issue. However, most previous studies of AFIs were done in controlled conditions at mesocosm experiments. In addition, limited information exists on the use of AFIs as a nutrient remediation/prevention strategy in Ohio. This study aims to fill these gaps. We are currently undertaking a combination of mesocosm and natural experiment to assess the nutrient-removal efficiency of AFI systems in the Milliron Research Wetlands (at the Ohio State University Mansfield campus), and establish a performance baseline for two native aquatic plant species, *Carex comosa* and *Eleocharis palustris.*

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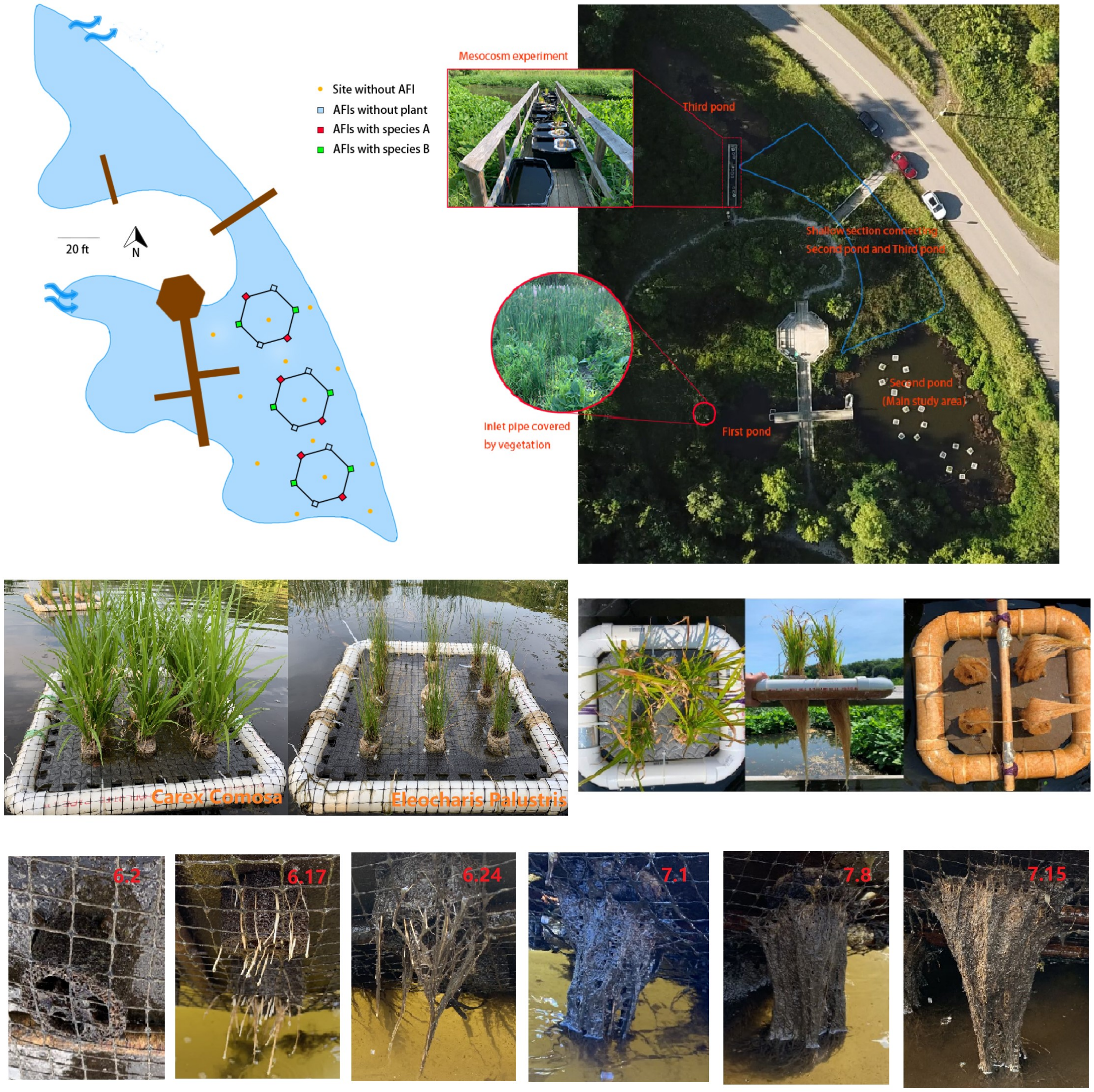

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