# Response of Fish Populations to Floating Streambed Wetlands

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*Abstract*: A new tool to provide wetland services is the floating streambed wetland (FSW), an active hydroponic system consisting of a polymer matrix floating substrate in which living plants are established. Water is circulated from beneath the FSW and across a streambed on the upper FSW surface, coming into contact with biofilms attached to the polymer matrix and associated root structures. Research has shown that FSW technology is efficient in removing nutrients and water contaminants, and recent manufacturer reports claim that FSW technology may also increase total fish biomass in small water bodies. We evaluated this claim using a replicated small (526 $m^2$) pond experiment and FSWs that covered 2.3% of pond surface area. FSWs were installed and planted in August 2013, and ponds were stocked at equal densities with bluegill (*Lepomis macrochirus*) in October 2013 and largemouth bass (*Micropterus salmoides*) in August 2014; populations were allowed to develop naturally prior to harvest in April 2016. Total fish biomass at time of harvest was 19.9% greater in ponds with FSWs than in control ponds. No differences in growth rates were observed for either species. This exploratory study suggested that FSWs can increase fish production in ponds, but further study is warranted. The high cost of FSWs would likely limit their use for strictly fisheries management purposes.

*Key words*: floating island, water treatment, artificial wetland, wetland effect

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Natural wetlands have traditionally served as filter systems for flowing waters by regulating biogeochemical cycles (Reddy and DuLaune 2008). Unfortunately, the United States has lost more than half its historic wetland area due to draining and conversion to other uses, stream channelization and levees, and deposition of fill material (Johnson 1994). Many of the remaining wetlands have been degraded by contamination, sedimentation, and invasive species to a level where many of their functions are lost (Dahl 2011). In response, society has sought alternatives to natural wetlands that provide similar ecosystems services, including constructed wetlands and retention ponds, both of which have been employed with some success (e.g., Mitsch and Wilson 1996, Hansson et al. 2005).

A newer tool for providing wetland services are floating treatment wetlands, also known as floating islands. These devices are hydroponic systems that, when fully vegetated, essentially are wetlands that float on the water's surface. Floating islands consist of a polymer matrix floating substrate in which living plants are established. The plant roots hang beneath the floating mat, and can greatly expand surface area (e.g., 4.6–9.3 $m^2$ of primary roots per $m^2$ of mat; Tanner and Headley 2011) and become an attachment surface for periphyton and biofilms. Periphyton and biofilms also attach to the polymer matrix directly. The devices are typically anchored in deep water so that root canopies do not reach underlying sediments or adjacent littoral areas. The periphyton community provides a concentrated wetland effect to trap fine suspended particles and to remove nutrients and transition them through the food web (Stewart et al. 2008). Because all plants, periphyton, and biofilm are attached to the island, a state shift away from phytoplankton can occur, resulting in increased water clarity and reduced downstream movement of phytoplankton and associated nutrients (Moss et al. 1996).

Manufacturers claim additional benefits resulting from the use of these islands, including tripling the oxycline (presumably due to increased photic zone) and increasing removal of suspended sediment due to the stilling effect of the root canopy. Preliminary unpublished data from one manufacturer suggested that floating island technology was more effective in reducing total suspended solids, total phosphorus, total nitrogen, and biochemical oxygen demand than traditional stormwater treatment technologies including retention ponds and constructed wetlands. Tanner and Headley (2011) examined floating treatment wetlands in replicated mesocosms and reported similar rates of phosphorus removal (21%–40%) as constructed wetlands (20%–50%; Braskerud 2002, DeBusk et al. 2004), suggesting similar functionality between the two treatment techniques. Conversely, Tanner and Headley (2011) reported that the removal rates for soluble reactive phosphorus by floating treatment wetlands exceeded those reported for another

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constructed wetland (Maine et al. 2006), which did not effectively remove phosphorus from the water.

Recently, a more advanced design of the floating island has become available, which incorporates aeration and circulation via an on-island streambed. This floating streambed wetland (FSW) is an improvement on the original passive design because it actively circulates water, bringing nutrients and dissolved oxygen to the artificial wetland structure. The FSW uses a directional air-lift system to pump water from any depth up to and across a floating streambed incorporated within the island. This accelerates oxygenation of anoxic waters, reduces thermal stratification, and augments biological processes facilitated by the FSW. In a case study by the manufacturer, a FSW system reportedly improved water clarity from 0.37 to 5.8 m, cut total phosphorus concentration by nearly half (0.041 to 0.025 mg $L^{-1}$), reduced total nitrogen from 0.20 mg $L^{-1}$ to 0.01 mg $L^{-1}$, and increased available oxygenated habitat from 2.4 m to more than 6.4 m depth (Floating Island International 2011).

The manufacturer also reported that FSW operation may increase harvestable fish production, either via habitat improvement or changes in the trophic web. Although the nutrient remediation potential of floating islands and FSWs has been experimentally tested, the assertion that these devices increase fish biomass has not been independently evaluated. In this manuscript, we describe a simple exploratory experiment using small replicated ponds to determine the response of a sportfish community to FSW operation. The specific objectives were to determine if FSWs affect 1) fish growth rates or 2) fish biomass when compared to ponds without FSWs.

## Methods

This research was conducted from August 2013 to April 2016 at Mississippi State University's South Farm Aquaculture Facility in Starkville, Mississippi, using small, shallow (1.0–1.5 m) experimental ponds of 526 $m^2$ surface area. Four of eight ponds were randomly selected to receive 11.9-$m^2$ FSWs (2.3% of pond surface area; Figure 1). This size was chosen because Ambulkar et al. (2011) reported that 2%–4% coverage provides effective nutrient control in secondary wastewater treatment facilities, and most applications target this level of surface coverage. The remaining four ponds were used as a control and received no FSWs. All islands were anchored in the pond center and connected via 5-cm air lines to a 1-hp blower on shore.

Ponds were filled with water within one week prior to install-

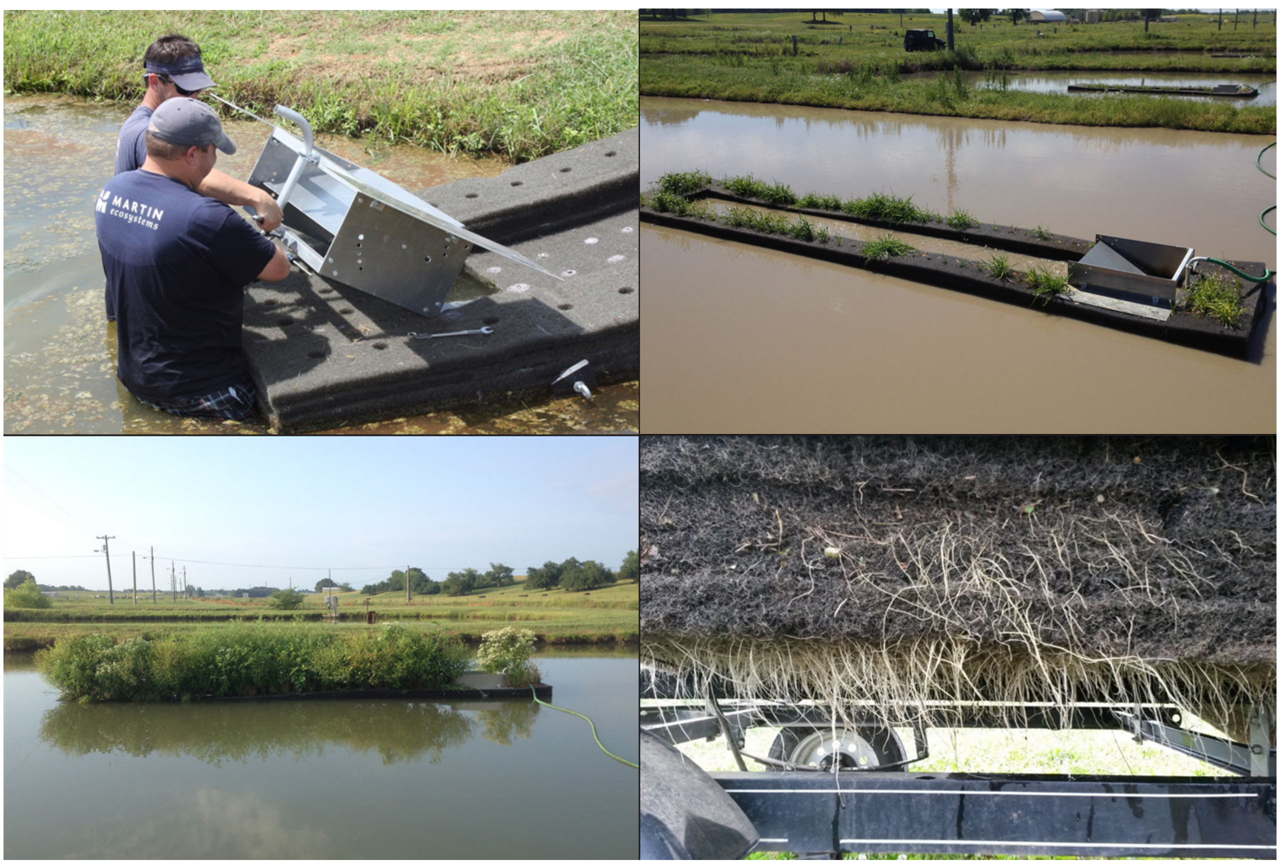


**Figure 1.** Installation of directional airlift system to streambed of FSW (top left), view of the on-island streambed (top right), plant establishment (bottom left), and root canopy beneath FSW at study's end (bottom right).

**Table 1.** Plant species by weight (PLS weight, pure live seed weight) initially seeded on experimental FSWs on 3 October 2013.

| Common name | Scientific name | PLS weight (g) |
|---|---|---|
| Virginia wild rye | *Elymus virginicus* | 3.500 |
| Button bush | *Cephalanthus occidentalis* | 1.981 |
| Yellow wingstem | *Verbesina alternifolia* | 1.844 |
| Eastern gamma grass | *Tripsacum dactyloides* | 1.250 |
| Fox sedge | *Carex vulpinoidea* | 1.050 |
| Blue flag | *Iris virginica* | 0.825 |
| Ohio spiderwort | *Tradescantia ohiensis* | 0.743 |
| Rosemallow | *Hibiscus moscheutos* | 0.596 |
| Swamp milkweed | *Asclepias incarnata* | 0.511 |
| Bushy bluestem | *Andropogon glomeratus* | 0.500 |
| Sneezeweed | *Helenium autumnale* | 0.438 |
| Frank's sedge | *Carex frankii* | 0.400 |
| Nodding sedge | *Carex crinita* | 0.300 |
| Fowl fanna grass | *Glyceria striata* | 0.250 |
| Rice cut grass | *Leersia oryzoides* | 0.250 |
| Boneset | *Eupatorium perfoliatum* | 0.238 |
| Joe-pye weed | *Eupatorium fistulosum* | 0.238 |
| Seed box | *Ludwigia alternifolia* | 0.212 |
| Green bulrush | *Scirpus atrovirens* | 0.200 |
| Monkey flower | *Mimulus ringens* | 0.159 |
| Creeping spike rush | *Eleocharis palustris* | 0.150 |
| Soft rush | *Juncus effusus* | 0.150 |
| Great blue lobelia | *Lobelia siphilitica* | 0.119 |
| Cardinal flower | *Lobelia cardinalis* | 0.096 |

ing FSWs on 27 August 2013. FSWs were covered on 3 October 2013 with a mixture of planter's soil, peat, and wetland plant seed (Table 1). It was determined that excessive FSW buoyancy was limiting soil and matrix moisture content, so pea gravel was added to increase weight and lower FSW freeboard to approximately 10 cm. Blowers were turned on once seeding was complete and operated continuously until the end of the study. All ponds were stocked with bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*). Bluegill were stocked at a density of 1900 ha$^{-1}$ (100 pond$^{-1}$; mean TL = 77.7 mm, SE = 0.8 mm) in October 2013, followed by largemouth bass at 190 ha$^{-1}$ (10 pond$^{-1}$; mean TL = 58.3 mm, SE = 0.5 mm) during August 2014. These rates fall within the range recommended by the Extension Service for ponds in Mississippi (bluegill: 1235–2470 ha$^{-1}$, largemouth bass: 124–24 ha$^{-1}$; Neal et al. 2015). All stocked fish were measured (mm, TL) and weighed (g) prior to stocking, and the right pelvic fin was removed for future identification.

All ponds were allowed to develop naturally until draining and harvest on 15 April 2016. Ponds were partially drained and seined two to three times, followed by complete draining for recovery of remaining fish. All marked largemouth bass and bluegill were measured and weighed, and a subsample of juvenile bluegill were counted, individually measured, and collectively weighed. Remaining juvenile bluegill were weighed in bulk and total numbers were estimated using the subsample count and weight following procedures described by Bettoli and Maceina (1996). Largemouth bass had not successfully spawned at the time of harvest, and no juveniles were collected.

Growth rates of marked largemouth bass and bluegill were calculated by subtracting the mean length at stocking from the length of individual fish at recapture and dividing by the number of days at large. Comparisons of total fish biomass and mean daily growth rates between FSW and control ponds were performed using a *t*-test assuming unequal variance in Microsoft Excel, and were considered significant at an alpha-level of 0.05. One control pond during this study leaked consistently for the duration of the trial. This required frequent water additions and the fluctuating water level resulted in development of water primrose (*Ludwigia* spp.) in the littoral area of the pond. Because nutrient inflows and the effect of inundated shoreline macrophytes could not be determined, this pond was censured from analyses. This left an unbalanced design with three control and four treatment replicates.

## Results

Ponds with FSWs yielded 19.9% greater fish biomass than control ponds ($t = 2.02$, df = 5, $P = 0.02$; Figure 2). This biomass increase was driven primarily by juvenile bluegill biomass. Bluegill successfully reproduced in all ponds (Figure 3), but juvenile bluegill biomass was 29.8% greater in ponds containing FSWs. Mean growth rate of largemouth bass appeared lower in FSW ponds

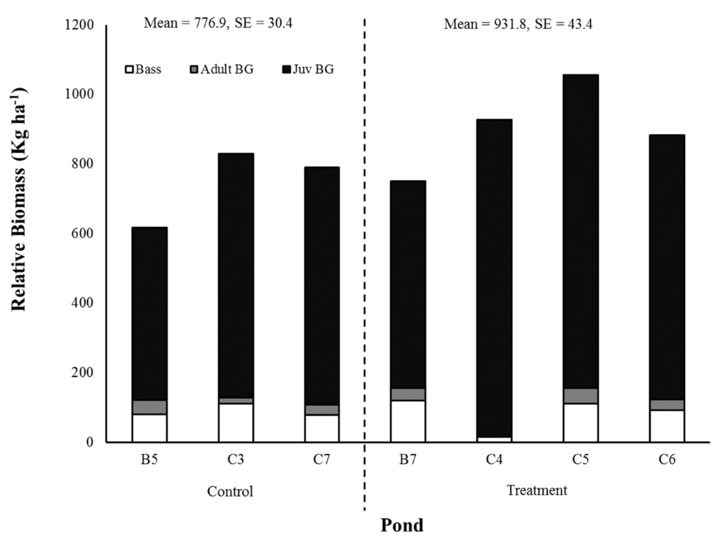


**Figure 2.** Individual relative biomass (kg ha$^{-1}$) for ponds with and without FSWs. Overall mean relative biomass and one standard error for is presented for control and treatment ponds ($t = 2.02$, $P = 0.02$).

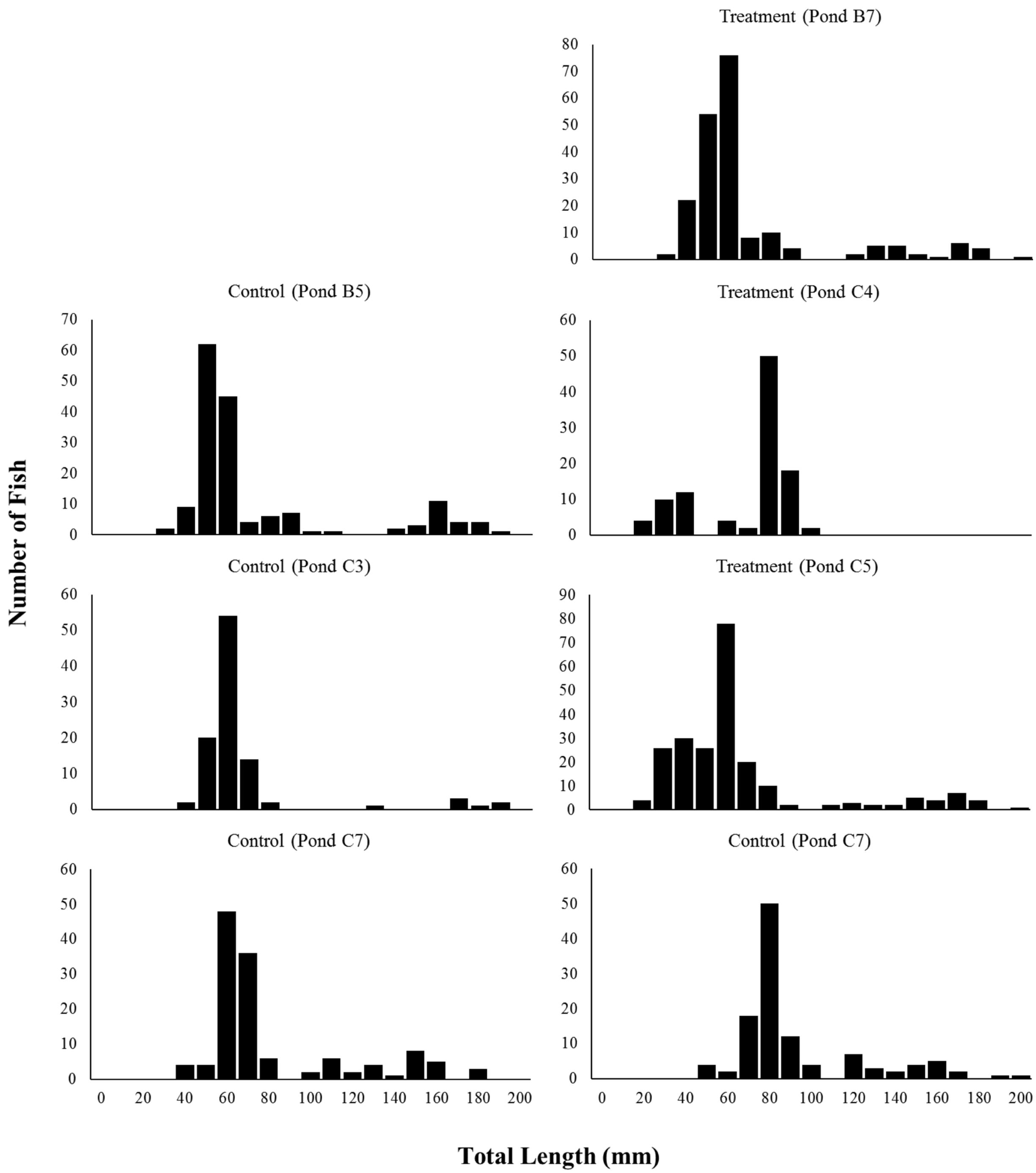


**Figure 3.** Bluegill length distributions collected at the time of harvest. Only marked bluegill from the original stocking and a subsample of juvenile bluegill were individually measured and are presented. A fourth control pond was censured for analyses due to unstable water level.

($0.80 \pm 0.21$ g $d^{-1}$) than in control ponds ($1.08 \pm 0.09$ g $d^{-1}$), but this finding was not statistically significant ($t = 1.17$, $df = 4$, $P = 0.30$) and was primarily driven by a single FSW pond where growth was greatly reduced (Figure 4). None of the originally-stocked bluegill were recovered in this pond, although juvenile bluegill were abundant. This suggested that poor survival and limited reproduction of the initial bluegill stocking led to slow largemouth bass growth during the year following stocking, and that the abundant juvenile bluegill present at harvest represented a recent population expansion during the final year of the study. Adult bluegill growth rate in control ponds ($0.10 \pm 0.02$ g $d^{-1}$) and FSW ponds ($0.08 \pm 0.00$ g $d^{-1}$) was similar ($t = 0.79$, $df = 2$, $P = 0.51$; Figure 4).

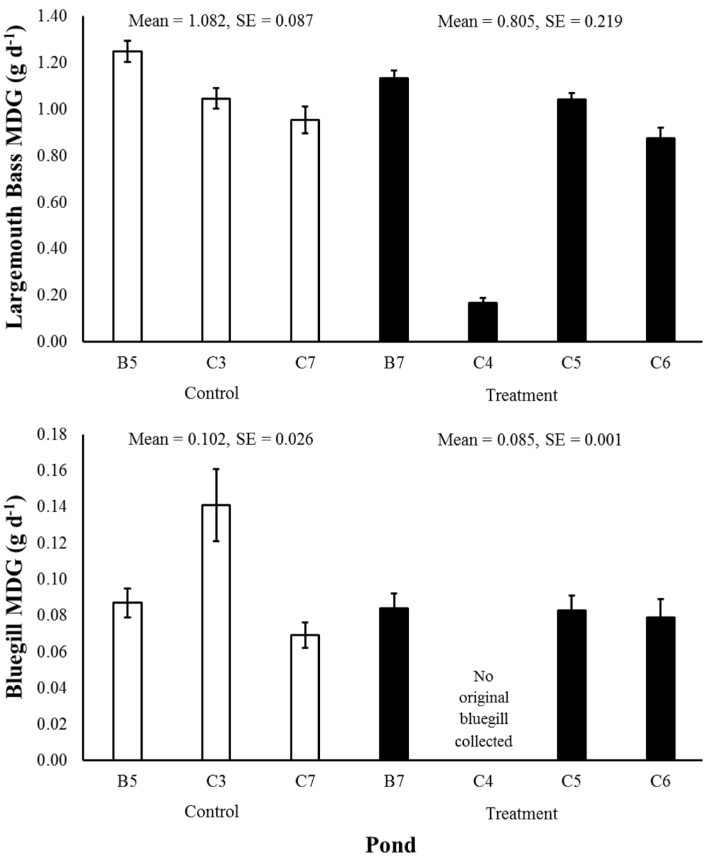


**Figure 4.** Mean daily growth rates in weight for largemouth bass (Top) and bluegill (Bottom) within individual ponds. Overall control and treatment means and standard error (SE) are presented. Error bars represent one standard error.

## Discussion

Installation and operation of FSWs in small, shallow ponds appeared to increase overall fish biomass by about 20% over ponds without FSWs. Tanner and Headley (2011) proposed that root systems below FSWs from macrophytes growing on the surface expand surface area for periphyton and biofilms in the water column below the artificial structure, thus driving the concentrated wetland effect. Bacteria, algae, cyanobacteria, heterotrophs and other microbes develop into three-dimensional communities which cycle nutrients and form the foundation for diverse food webs (Azim et al. 2005). This increase in periphyton abundance is hypothesized to be responsible for increasing fish carrying capacity within water bodies containing FSWs, as these communities should have provided a nutrient-rich food source for grazing invertebrates, which in turn supported larger predators including small fish. For example, Pardue (1973) explored the response of bluegill to increasing periphyton availability in mesocosms and reported that fish production increased linearly with increasing attachment surface area. In that study, doubling periphyton attachment surface resulted in an increased production of 384 kg ha$^{-1}$ of bluegill in 180 days and was linked to the increased macroinvertebrates on the substrates, particularly those in the orders of Diptera, Hemiptera, Odonata, and Plectoptera. Similar responses have been reported for freshwater prawn (*Macrobrachium rosenbergii*; Cohen et al. 1983, Tidwell et al. 1998), Nile tilapia (*Oreochromis niloticus*; Bender et al. 1989, Shrestha and Knud-Hansen 1994), and many other species.

The current study did not examine trophic pathways that may have influenced overall pond productivity, and it is possible that the observed FSW increase in biomass may not have been the result of a concentrated wetland effect. Aeration and water circulation associated with the FSW could have influenced productivity, as these manipulations have been shown to increase phytoplankton diversity and prevent dominance by less palatable species (e.g., Sipaúba-Tavares et al. 1999). Also, the added cover provided by the FSWs and associated root canopies may have increased juvenile bluegill survival over that of habitat-poor control ponds (Hayse and Wissing 1996). Further, differences in productivity may not have persisted once largemouth bass reproduction occurred and predation pressure increased. These are all valid explanations for differences we observed and warrant further evaluation. It is also possible that simple differences in pond productivity are responsible, although the randomized and replicated study design reduces the risk of random pond effects influencing the observed results.

The significant increase in fish biomass in ponds with FSWs occurred despite a number of mechanical failures as well as issues with plant establishment. Maintenance of air lines was increasingly required during this study, as the plastic air lines cracked due to ultraviolet exposure, reducing or eliminating air flow. This interrupted stream flow periodically, but was quickly repaired each time. Other FSW components, including the polymer matrix, aluminum water lift structure, and onshore blower cabinet worked flawlessly during the study. Plant establishment was slower than expected. Installation and seeding of islands during October was not ideal, as seedling growth was limited during late fall and winter periods. Plant establishment the following spring and summer was slow due to mortality of seedlings over winter, but a combination of planted species and volunteer species that arrived to the FSW via other means covered the FSWs by the end of summer 2014. This allowed all ponds to operate at maximum efficiency for more than a year and a half, likely minimizing the effect of variable initial plant survival among ponds. Grazing was an issue, as muskrats (*Ondatra zibethicus*) were observed consuming plant growth on the FSW surface. Dense root growth beneath the FSW structure was present but still developing at the end of the study. Suspended root structures were associated with larger plant species including button bush (*Cephalanthus occidentalis*) and rushes (*Juncus* spp.) on most of the devices.

Headley and Tanner (2012) used experimental mats that were 150 mm thick on the edges and only 50 mm thick in the central depression, which held the growth media and plants. In the current study, the experimental FSWs were much thicker (250 mm). Thus, roots appeared to take more time to extend beneath the FSW. Experimentation to find the proper balance between buoyancy and thickness for encouraging plant root development is warranted. The FSWs used in this study were scaled-down for use in experimental ponds, and the smaller size may have affected both buoyancy and plant establishment. Planting on FSWs should be conducted in a manner to offer plants the greatest chance for rapid and successful establishment to maximize the benefits of these structures to aquatic systems. Future considerations would be to use a blanket of grass sod and sow seedlings directly into the sod to accelerate plant development, and supplemental watering until plants become established.

Increased fish biomass did not translate into increased growth rates or larger fish, and was driven exclusively by greater production of juvenile bluegill. However, because ponds in this study were not managed as fisheries, no harvest occurred during the study. Under normal pond management conditions, this increased biomass could be channeled into fewer, larger, faster-growing fish using a well-planned harvest strategy (Stone et al. 2012, Schramm and Willis 2012).

Future research could explore the most effective FSW-to-pond surface area ratio for increasing fish biomass in order to optimize FSW applications to augment fish biomass and improve water quality. Research could also explore FSW efficacy in deeper waterbodies, as the ponds used in this study were small and shallow, and it is likely that stratification and hypolimnetic hypoxic conditions were not present in treatment or control ponds. One likely benefit of FSWs is the circulation, destratification, and aeration of anoxic hypolimnetic waters via the air lift system, which should increase productivity by improving the cycling of nutrients and the habitability of benthic habitats (e.g., Soltero et al. 1994, Doke et al. 1995, Sipaúba-Tavares et al. 1999).

In conclusion, FSW operation appeared to increase total fish biomass in simple phytoplankton-driven ponds. However, use of FSWs for fisheries management in small ponds and lakes will be limited as the cost will be prohibitive for most landowners. Commercially-produced floating islands currently cost about US$270 to $310 per square meter not including anchors or shipping. The FSWs are more expensive than traditional floating islands due to the need for air compressors, hoses, and aluminum airlift system. Thus a large scale system to provide 2% coverage of a 5-$ha^{-1}$ lake could easily cost $300,000. It is likely that if demand increases, costs may decline, and it may also be possible to construct similar structures with alternate materials (e.g., coconut fiber, Nakamura and Mueller 2008) for a fraction of the cost. However, similar or greater biomass increases can be much more economically achieved using water quality management, including fertilization (Boyd and Boyd 2012, Neal and Kröger 2012, Stone et al. 2012). For storm and wastewater treatment and nutrient remediation of high-nutrient systems, the initial and operational costs of FSWs, floating islands, and other artificial wetlands can be justified more easily, and most current applications are for these purposes (Stewart et al. 2008). When FSWs are utilized for water treatment, a secondary benefit may be an overall increase in fish biomass.

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