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Evaluation of commercial floating treatment wetland technologies for nutrient remediation of stormwater

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ABSTRACT

Floating treatment wetlands (FTWs) are a relatively new water treatment practice that consists of emergent wetland plants planted on floating mats constructed of buoyant material. This study utilized batch-fed mesocosms, with a seven-day retention time, to investigate the total nitrogen (TN) and phosphorus (TP) remediation capability of two commercially available FTW technologies using runoff from a combined irrigation holding and stormwater retention pond. Nutrients in the pond water are attributed to runoff from nearby fertilized research plots upgradient. The FTW technologies included Beemats (Beemats LLC, New Smyrna Beach, FL, USA) and BioHaven® floating islands (Floating Island International, Inc. Shepard, MT, USA) planted with *Juncus effusus* (soft rush). Due to an increase in TN and TP in the initial phase of the experiment during the plant establishment phase (weeks 1–8), BioHaven® nutrient removal was lower over the entire experimental period than the Beemat treatment. Differences between the two treatments, such as mat material or substrate materials and/or additives may account for this difference. The BioHaven® FTW removed 25% and 4%, while the Beemat removed 40% and 48% of the TN and TP, respectively expressed in terms of net removal over the entire study. During the plant growth season (weeks 9–18 of the study), the two technologies showed similar nutrient removal rates: for TN:0.026 ± 0.0032 and 0.025 ± 0.0018, and for TP:0.0074 ± 0.00049 and 0.0076 ± 0.00065 g/m^2/day for Beemat and Biohaven®, respectively. A control treatment, meant to reflect nutrient removal within the pond without the presence of plants, yielded 28% and 31% removal of TN and TP, respectively. Thus, the Beemat mat yielded a significant positive net removal of TN and TP. The BioHaven® biomass was significantly greater than the Beemat treatment. Both treatments showed greater biomass accumulation in shoots rather than in roots. Plant nutrient content was similar between the two treatments.

1. Introduction

Urban runoff is a growing contributor of nonpoint source pollution (NPS) to receiving waters in the United States (Novotny, 2003). Urban runoff, also known as stormwater, is generated from impervious surfaces such as roads, sidewalks, driveways, parking lots and rooftops.With the removal of vegetation and the sealing of the soil surface by pavement and buildings, infiltration decreases, resulting in increased runoff rates and volumes, and reduced baseflow to streams (Fletcher et al., 2013; Yang et al., 2011). Urban development contributes to: flooding (Meierdiercks et al., 2010), decline of base flows (Hamel et al., 2013), bank erosion and downcutting (Cianfrani et al., 2006; Navratil et al., 2013; Nelson and Booth, 2002); and declining water quality from excess sediment, nutrients, and heavy metals (Carey et al., 2013; Hatt et al., 2011), resulting in a decline in diversity of aquatic biota (Alberti et al., 2007). Urban runoff transports a variety of pollutants from pavement wear, fuel combustion, deicing salts, nutrients

Abbreviations: ANOVA, Analysis of Variance of means; BMP, best management practice; EC, conductivity; DO, dissolved oxygen; EMC, Event Mean Concentration; ET, evapotranspiration; FTW, floating treatment wetland; HRAREC, Hampton Roads Agriculture Research and Extension Center; MS4, Municipal Separate Storm Sewer System; NPDES, National Pollutant Discharge Elimination System; N, nitrogen; P, phosphorus; TN, total nitrogen; TMDL, total maximum daily load; TP, total phosphorus; U.S.EPA, United States Environmental Protection Agency.

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from fertilizer, sediment and organic matter (Burton and Pitt, 2002; Driver and Tasker, 1990; Waschbusch, 1999).

Runoff water quality is influenced by site land use and can be estimated by consulting historical datasets. One of these, the National Urban Runoff Program (NURP), assessed 29 prototype urban sites (U.S. EPA, 1983) during the 1970s and 1980s. Observed event mean concentrations (EMCs) of TP and TN for urban open land were 2.2 ± 1.5 mg/L and 0.30 ± 0.16 mg/L, respectively (U.S. EPA, 1983). TN is assumed to be the summation of oxidized nitrogen (NO_x) and total Kjeldahl nitrogen (TKN). AMWCOG (Metropolitan Washington Council of Governments, 1983) report showed similar ranges for TN:0.78–9.70 mg/L, and TP:0.15–1.58 mg/L. More recent data is provided within the National Urban Runoff Quality Database (Pitt, 2009). This source was created from reporting entities under the National Pollutant Discharge Elimination System (NPDES) MS4 phase I program. From this database, EMC values were 2.96 mg/L for TN and 0.27 mg/L for TP for Virginia coastal plain urban residential land (Hirschman et al., 2008).

Excess N and P can adversely impact receiving waters. For example, negative impacts have occurred within the Chesapeake Bay estuary due to nutrient (N and P) and sediment pollution (i.e. suspended solids). As a result, a total maximum daily load (TMDL) for those pollutants was established (U.S. EPA, 2010). The reductions imposed by the TMDL will require significant efforts from Municipal Separate Storm Sewer System (MS4) programs. A key issue is addressing legacy development, i.e., those properties which have limited stormwater treatment. Development from the mid-70s through the 2000s used retention ponds (i.e. wet ponds) almost exclusively as the best management practice (BMP) of choice for water quality treatment (Schueler, 2011). Retention ponds hold water year-round, provide storage to attenuate peak runoff rates, and provide limited water quality treatment through sedimentation. While they are effective at treating pollutants that are attached to sediment particles, they are not effective at treating dissolved pollutants in runoff (Shilton, 2005). Opportunities exist for a BMP that could enhance retention pond performance and improve water quality while providing reductions in nutrient and sediment loads to receiving waters without requiring additional space.

Available land for created wetlands and stormwater retention ponds is limited in urban areas, and land acquisition is a major cost component of an urban BMP (Thurston, 2006). Recent interest has focused upon floating treatment wetlands (FTWs) for treatment of stormwater (Borne et al., 2013; Wang and Sample, 2014; White and Cousins, 2013; Winston et al., 2013). FTWs are a new tool for N and P management and can be employed in existing retention ponds. A key advantage of FTWs is they do not require additional land area. FTWs consist of emergent wetland plants growing on buoyant mats which are placed on the water surface. The plants grow through the mat and into the water, assimilating nutrients directly from the water. In addition, the plant roots create a large surface area beneath the floating mat for nutrient adsorption and biofilm attachment, mimicking natural wetlands (Headley and Tanner, 2006, 2012). Generally, the mechanisms for N removal in a FTW are assimilation and denitrification and P is removed by assimilation and sorption (Jayaweera and Kasturiarachchi, 2004). Borne (2014) suggests sorption, entrapment in roots, and settling are more dominant P removal processes; Wang and Sample (2014) suggest decomposition and sorption onto attached root-based biofilms. In a field scale FTW application, Borne et al. (2013) found that significant denitrification occurred in summers, when dissolved oxygen was low, resulting in a high N removal during this period. According to Stewart et al. (2008), laboratory scale testing of a proprietary FTW (BioHaven® Floating Island) removed 117.8 g/m^2/d of nitrate (NO_3), 3.0 g/m^2/d of ammonium (NH_4), and 4.8 g/m^2 of phosphate (PO_4) from domestic wastewater. Early research of FTWs was directed at treating agricultural wastewater. Hubbard et al. (2004) applied FTWs (planted with cattail, *Typha* sp.) to a wastewater lagoon treating swine effluent where they removed 534 and 79 g/m^2 of N and P, respectively with a 14 day hydraulic retention time.

Additional advantages of FTWs as a stormwater management tool are that they can easily fit in existing retention ponds and adjust to varying water depths typical of event-driven stormwater systems (Headley and Tanner, 2012; White and Cousins, 2013). These advantages make FTWs appealing as a potential stormwater BMP for enhancing treatment within existing stormwater retention ponds. The Florida Department of Environmental Protection has assigned a 12% treatment credit for FTWs towards meeting watershed N and P nonpoint source reduction goals (Wanielista et al., 2012). Hunt et al. (2012) recommended an additional 5% total nitrogen (TN) and total phosphorus (TP) removal credit for FTWs

Table 1
Summary of treatment type and nutrient removal rates of selected FTW studies.

Reference	Treatment Type	Results
Chang et al. (2012a)	Mesocosm study using BioHaven® mat with soft rush (*Juncus effusus*) and pickerelweed (*Pontederia cordata*) subjected to simulated stormwater.	Average removal rates were 30–31% TN and 49–52% TP with 5% surface area coverage[a].
Chang et al. (2012b)	Mesocosm study using Beemat mat with canna (*Canna flaccida*) and soft rush (*Juncus effusus*) subjected to simulated stormwater.	Concluded a 5% surface area coverage can achieve 61% TN and 53% TP removal within 15 day time span[a].
Chua et al. (2012)	Mesocosm and field studies using Bestmann Green Systems™ mat and three plant species to remove nutrients in baseflow from an urban catchment area.	Net nutrient reduction was 8–40.8% for TN and 19–46% for TP in mesocosm study.
Headley and Tanner (2007)	Mesocosm study using BioHaven® mat and four plant species for removal of fine particulates, copper and zinc from simulated stormwater.	After 6.7 days, mean concentration reduction in planted treatments was 72–96% for NH_4-N and 20–51% for dissolved reactive phosphorus[a].
Wang and Sample (2014)	Mesocosm study using floating PVC frame with plastic mesh and pickerelweed (*Pontedera cordata L.*), softstem bulrush (*Schoenoplectus tabernaemontani*) and water obtained from a stormwater retention pond.	Planted and unplanted floating mats significantly improved phosphorus and nitrogen removal efficiency compared to a control.Planted treatments enhanced TN and TP removal efficiency by 8.2% and 18.2%, respectively.
Wen and Recknagel (2002)	Polyethylene foam floats with four creeping-stem water plant species in controlled-environment growth chambers subjected to simulated agricultural drainage water.	P removal rates of 0.043–0.086 g P/m^2/day measured as P bioaccumulation in plant tissue.
White and Cousins (2013)	Beemat mat with golden canna (*Canna flaccida*) and soft rush (*Juncus effusus*) in flow-through troughs treated with simulated stormwater solution.	Daily N load reduced by 87.9% and 66.9% and average daily P concentration reduced by 75% and 45.5% during 2008 and 2009 spring-fall season, respectively[a].
Winston et al. (2013)	BioHaven® mats planted with a mixture of eight macrophytes and retrofit into two urban stormwater ponds.	Mean TP and TN were reduced by 39–88% and 48–88%, respectively, in two separate ponds[a].

[a] Indicates total removal, including both FTW and pond.