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Floating treatment wetland nutrient removal through vegetation harvest and observations from a field study

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ABSTRACT

Nonpoint source pollution from urban areas has been identified as a leading contributor to impaired water quality. Floating treatment wetlands (FTWs) are cultivated plants growing on floating mats in open water. FTWs can be used to remove pollutants from runoff, but data on their effectiveness is limited. We conducted a field study of FTWs in a nutrient enriched urban wet pond to investigate vegetation biomass and phosphorus (P) accumulation/distribution, sustainability under ice encasement stress (which is a concern in temperate regions), and to assess the use of the FTW by species. Planted perennial macrophytes successfully adapted to stresses of the low dissolved oxygen (DO) concentrations (minimum: 1.2 mg/L) in summer, ice encasement in winter, and relatively low nutrient concentrations in the water (median: 0.15 mg/L TP and 1.15 mg/L TN). Pickerelweed produced more biomass and demonstrated higher P removal performance (10.44 g dry weight/plant and 7.58 mg P/plant) than softstem bulrush (2.20 g dry weight/plant and 1.62 mg P/plant). Based on the observed seasonal changes in biomass and P, we recommend harvest of above-ground vegetation is conducted in June for maximum P removal or in September to prevent P release due to senescence. Submerged tissues of pickerelweed, softstem bulrush, and yellow iris (*Iris pseudacorus*) survived ice encasement and regrew in the second year. Additionally, plant diversity increased during the study period through recruitment of both native and exotic wetland plants. Systematic observation of wildlife activities indicated eight classes of organisms inhabiting, foraging, breeding, nursing, or resting in the FTWs. This study suggests above-ground plant harvest can enhance P removal, and that softstem bulrush, yellow iris, and pickerelweed can be sustained over winter on the FTW. Future study is recommended to investigate the feasibility of multiple vegetation harvest and document the possible habitat creation by the use of FTWs.

1. Introduction

Urban development increases the transport of nutrients, metals, and other pollutants to streams and other receiving waters through the creation of impervious surfaces. Nutrients, nitrogen (N) and phosphorus (P) are required by all living things for survival. However, excessive nutrients can damage biotic integrity and increase the rate of eutrophication in rivers, lakes, estuaries, and coastal waters on a global basis (Anderson et al., 2002; Dodds, 2010). Nonpoint source (NPS) pollution from urban runoff (including excessive nutrients such as N and P), is one of the largest uncontrolled sources of pollution to waterways and has been identified as a leading cause of impaired water quality and eventual decline in aquatic ecological

Abbreviations: *A*/*B* ratio, above/below-ground ratio; BMP, best management practice; Chl-*a*, chlorophyll *a*; DO, dissolved oxygen; DW, dry weight; FTW, floating treatment wetland; N, nitrogen; NH_4^+—N, ammonia nitrogen; NO_x—N, nitrite–nitrate nitrogen; NPS, nonpoint source; OP—P, orthophosphate; Org-N, Organic nitrogen; P, phosphorus; TN, total nitrogen; TP, total phosphorus; TPP, total particulate phosphorus; TSI, trophic state index.

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health (Novotny, 2003). In order to mitigate NPS impacts in urban areas, the U.S. Environmental Protection Agency (U.S. EPA) recommends the use of urban best management practices (BMPs), which use a variety of physical, chemical, and biological processes to restore receiving waters. Structural BMPs mitigate stormwater effects by settling and filtering pollutants before they enter receiving water bodies. Retention ponds (also called wet ponds) are one of the most common urban stormwater BMPs (Borne et al., 2013; Winston et al., 2013). Wet ponds are generally effective for removal of coarse and/or heavy particles with attached pollutants through settling, but are much less so for pollutants in dissolved form (Shilton, 2005). Implementation of stormwater BMPs normally requires the use of land, thus incurring an opportunity cost because other land uses are precluded. FTWs are a relatively new stormwater treatment practice that may enhance the effectiveness of retention ponds. FTWs consist of macrophytes growing on floating mats which can be deployed in many existing water bodies (Hubbard et al., 2011). Nutrients and other pollutants are absorbed or filtered by the plants and attached periphyton, which are driven by solar energy through photosynthesis. Although new to management of water pollution, practices similar to FTWs have been used in aquaculture and agriculture for over 50 years in Asia (Li, 1957; Sidle et al., 2007). The first documentation of an FTW-like system, called "floating field" was made in Taiwan, in the Year 1717 (Zhou, 2005). FTWs have been studied across the world with different plant species and environments, from tropical to temperate regions (Chua et al., 2012; Headley and Tanner, 2012). While several studies have evaluated FTW effectiveness using agricultural wastewater or polluted surface water, only a few studies have documented FTW behavior with urban runoff (Headley and Tanner, 2012; Ladislas et al., 2013).

FTWs may be uniquely sustainable and economical as a potential treatment practice with widespread applicability. This attribute of FTWs is due to the scalable nature, relative ease of construction, and potential utilization of locally available (wetland) plants and materials, such as man-made plastic bottles, and natural bamboo. Land acquisition and on site construction expenses associated with other structural BMPs are avoided. FTWs may enhance the performance of existing retention ponds and reduce NPS pollution in the urban areas without land acquisition (Headley and Tanner, 2012; Winston et al., 2013). In addition to lower installation costs, the harvested biomass could provide economic benefits. Vegetation has been grown on FTWs or similar practice for animal or human consumption (De Stefani et al., 2011; Li et al., 2007). For example, "floating gardens" have been used to cultivate tomatoes and potatoes since the early 1960s in Lake Inle, Myanmar (Sidle et al., 2007).

In order to assess the role of aerial tissue harvesting in pollutant removal, knowledge of the temporal variation of nutrient distribution in FTW plant tissues is needed. However, few studies have focused upon this attribute. Macrophytes adjust their biomass growth and nutrient distribution according to external conditions and growth stages. While wetland studies do provide data on vegetative behavior, the information may not adequately evaluate plant performance in soilless and low nutrient environment as is found in FTWs in urban ponds. Typical nutrient concentrations in urban stormwater ponds in the U.S. are low, which may affect plant growth. For example, FTW plants may allocate more resources to below-ground tissues, increase root length, and produce thinner roots to increase their food acquisition efficiency (Marschner, 1995; Williamson et al., 2001). High nutrient use efficiency is another physiological response to low nutrient availability (Lorenzen et al., 2001). As plants experience different stages in their lifespan, absorbed nutrients are remobilized and translocated to different parts of the plant (Marschner, 1995). In a constructed wetland, Meuleman et al. (2002) suggested that nutrient removal efficiency could be increased from 9% to 20% of TN and from 6% to 25% of TP by harvesting above-ground tissues in September instead of winter when most nutrients were translocated to the rhizome/root system. However, plant nutrient distribution is another research gap of FTWs, because whole plant harvest is not universally practiced. As the plants grow on the FTW growth media, such as coconut fiber or plastic foam, their roots and rhizomes are embedded in these materials and cannot be easily extracted for analysis (Winston et al., 2013). Therefore, published FTW plant data are typically based on samples from aerial tissues only and sometimes from roots hanging under floating mats (Chua et al., 2012; Tanner and Headley, 2011; Winston et al., 2013).

We investigated FTW nutrient removal performance and the distribution of P within FTW macrophyte tissues over time in an urban wet pond in a temperate region with stormwater as a source water input. Additionally we systematically observed use of the deployed FTWs by wildlife. The objectives of this study were to (1) evaluate P uptake by two native wetland plants and assess the temporal variation of P distribution within the plants, (2) investigate the survivability of the perennial macrophytes on the FTW, (3) assess which additional floral and faunal species use and/or colonize the FTWs, and (4) provide recommendations for management strategies such as harvesting to optimize nutrient removal.

2. Materials and methods

2.1. Study site

The FTW experiment was conducted at Ashby Pond (38°51″N, 77°17″W), an existing wet pond located at the City of Fairfax, Virginia in a residential area of the Greater Washington, D.C. Metropolitan Area. The pond has surface area of 5,689 m^2, and is part of a small neighborhood park, which provides non-contact recreational use for property owners in the vicinity. The catchment has an average annual precipitation of 1160 mm and monthly precipitation ranged from 65 to 119 mm between 2003 and 2012. Monthly temperatures ranged from 0.7 to 24 °C in January and July, respectively (NOAA, 2012). The watershed draining to Ashby Pond is 0.57 km^2 and consists of approximately 38% impervious surfaces. The land use type in the Ashby Pond watershed is mainly residential and commercial mixed with a high traffic arterial street (average daily traffic of 38,000) (Virginia Department of Transportation (VDOT), 2011).

2.2. FTW experiments

There were two kinds of the FTWs used in this study: (1) vegetation sampling FTWs, which were designed for plant harvest, below-ground tissues especially, from May 17 to October 31, 2012 (first phase experiment); and (2) regular FTWs deployed within the pond to study the survivability of the vegetation on the FTWs from April 27, 2012 to September 11, 2013 (second phase experiment). The major difference between the two designs was growth media (coir fiber). In the vegetation sampling FTWs, the plant below-ground tissues were prevented from contacting with the coir fiber and kept in bare root condition throughout the first phase experiment for sampling purposes (Section 2.2.1). In contrast, on the regular FTWs, macrophytes grew with their roots and rhizomes completely tangled within the coir fiber. Sampling of below-ground plant tissues on the regular FTWs without damaging was unavailable according to our pilot FTW experiment.

2.2.1. Vegetation sampling FTWs (first phase experiment)

The vegetation sampling FTWs were used to study plant biomass and P accumulation/distribution from May 17 to October 31, 2012. Two plant species, pickerelweed (*Pontederia cordata* L.) and