Ecological Engineering xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Aridland constructed treatment wetlands I: Macrophyte productivity, community composition, and nitrogen uptake

Nicholas A. Weller[a], Daniel L. Childers[a,*], Laura Turnbull[b], Robert F. Upham[c]

[a] School of Sustainability, Arizona State University, Tempe, AZ 85287, United States
[b] Department of Geography, University of Durham, UK
[c] Water Services Department, City of Phoenix, Phoenix, AZ, United States

ARTICLE INFO

Article history:
Received 26 September 2014
Received in revised form 8 May 2015
Accepted 30 May 2015
Available online xxx

Keywords:
Constructed treatment wetlands
Macrophyte productivity
Arid
Nitrogen
Macrophyte community composition

ABSTRACT

Urbanized areas increasingly rely on constructed treatment wetlands (CTW) for cost effective and environmentally-based wastewater treatment. Constructed treatment wetlands are particularly attractive treatment options in arid urban environments where water reuse is important for dealing with scarce water resources. Emergent macrophytes play an important role in nutrient removal, particularly nitrogen (N) removal, in CTW. However, the role of plant community composition in nutrient removal is less clear. Numerous studies have shown that macrophyte species differentially affect N uptake processes (e.g., direct plant uptake, coupled nitrification–denitrification, soil accretion). However, many of these studies have been based on small-scale experiments and have been carried out in mesic environments, which means that their findings are difficult to extrapolate to aridland CTW systems. Our study sought to examine the relationships among emergent macrophyte productivity, plant community composition, and N uptake [by both the plants and the entire ecosystem] at a 42 ha CTW in arid Phoenix, Arizona, USA. We quantified above- and belowground biomass bimonthly and foliar N content annually for four species groups (*Typha latifolia* + *Typha domingensis*,*Schoenoplectus californicus* + *Schoenoplectus tabernaemontani*, *Schoenoplectus acutus*, and *Schoenoplectus americanus*) from July 2011 to September 2013. We quantified dissolved inorganic N fluxes into and out of the system and compared plant N removal to total system fluxes. Additionally, we estimated monotypic N content for each to compare the system's current community composition and plant N removal to hypothetical scenarios in which the system was dominated by only one species.

Peak aboveground biomass ranged from 1586 ± 179 (SE) to 2666 ± 164 (SE) gdw m^{-2} of which *Typha spp.* accounted for an increasing portion (>66%). We observed widespread 'thatching' – the toppling of large stands of macrophytes – that was likely related to a decline in peak biomass from July 2011 to July 2012. The foliar N content was similar among the species groups and N content for all species combined, at peak biomass, was 31 ± 8 N g m^{-2}. This measured foliar N content was higher than our estimates of the foliar N content in hypothetical monotypic stands, suggesting that the system's actual community composition performed better, in terms of direct plant N uptake, than if the system had been planted with only one species group. Overall, direct plant N uptake accounted for 7% of inorganic N inputs and 19% of whole-system inorganic N removal. Our findings suggest that managers and designers should consider diverse plant communities rather than monotypic stands when designing, constructing, and managing CWT wetland systems. Future research is needed to elucidate those management strategies that might best promote or preserve diverse plant communities in these systems in a cost effective manner.

1. Introduction

Over the last 150 years, an ever-growing portion of the world's population lives in cities. To deal with the wastes and problems associated with dense human populations, city managers, engineers, and policy-makers have crafted "sanitary cities" predicated on the separation of human populations from potential health hazards such as human waste (per Melosi, 2000). These highly engineered urban systems are energetically and monetarily expensive to build, maintain, and expand. Environmental and fiscal concerns place additional pressure on cities and municipalities to adopt alternative, cost effective, and environmentally-based

* Corresponding author. Fax: +1 480 965 8087.
E-mail address: dan.childers@asu.edu (D.L. Childers).

http://dx.doi.org/10.1016/j.ecoleng.2015.05.044
0925-8574/© 2015 Elsevier B.V. All rights reserved.

approaches to managing problems associated with urban systems, such as water scarcity in arid climates.

Constructed treatment wetlands (CTW) are effective options for the treatment of domestic wastewater (Kadlec and Wallace, 2009). Constructed treatment wetlands are wetland ecosystems created to remove various forms of pollution and excess nutrients from influent waters (Fonder and Headley, 2013). There are a wide variety of CTW designs that encompass various hydrological and ecological configurations and that are designed for a range of applications (wastewater treatment, stormwater treatment, etc.), although the majority can be categorized as surface-flow treatment wetlands (Fonder and Headley, 2013). Surface-flow CTW are usually dominated by rooted macrophytes (i.e., not floating macrophytes) and characterized by horizontal water flow. Surface flow CTWs provide effective removal of pollutants and nutrients with low management, maintenance, and operating costs due to their relatively simple design (Fonder and Headley, 2013; Kadlec and Wallace, 2009).

While CTW can be utilized to remove a variety of pollutants from wastewater, the macronutrients nitrogen (N) and phosphorus (P) are of particular interest due to concerns with eutrophication in recipient waters. In the United States, local, state, and federal laws often impose limits on N and P discharge into surface waters, mandating tertiary treatment (i.e., the removal of N and P from treated wastewater) in many places. Numerous biological and physical processes (e.g., nitrification–denitrification, soil accretion, assimilation into plant or microbial biomass) make CTW particularly suited for removing N and P from wastewater. Significant academic research in mesic systems and application of this knowledge has proven CTW to be reliable and cost effective for N and P removal (Huang et al., 2000). In Arizona, more than 40 CTW have been constructed over the last 20 years, mostly to treat and remove N from domestic wastewater because most surface waters in Arizona are N-limited (Grimm & Fisher, 1986). Because N is the primary concern at our Arizona study site, we focused this research on N removal and processing in this study.

Many CTW utilize emergent macrophyte vegetation to enhance nutrient removal or to provide other desirable services. Emergent macrophytes contribute to N removal through direct N assimilation into plant tissues, contributions to soil organic matter pools that fuel microbial N processing, and the regulation of other soil conditions critical to coupled nitrification–denitrification—such as oxygen availability (Faulwetter et al., 2009; Gebremariam and Beutel, 2008; Ingersoll and Baker, 1997; Reddy and Graetz, 1988). Thus, CTWs without emergent macrophytes are often less effective at N removal than those with emergent macrophytes (Brisson and Chazarenc, 2009). Plant culms within the water column also serve to reduce water velocities, increasing the opportunity time for N-processing and surface sedimentation (Brix, 1997). Thus, the use of emergent macrophytes in CTWs to provide beneficial services is becoming increasingly important to water resource managers (Thullen et al., 2005).

The effect of macrophyte community composition on nutrient removal, however, is less well understood. The interaction of community composition and nutrient removal is obscured by confounding factors (e.g., climate, wastewater type and quality, wetland design) and is generally only examined by comparing the performance of two species to each other (Brisson and Chazarenc, 2009). Nonetheless, there is reason to believe that community composition does influence CTW performance (Brisson and Chazarenc, 2009; Miller and Fujii, 2010). Different species of emergent macrophytes have varying nutrient uptake efficiencies and growth rates, suggesting differential effects on their uptake of N. Different growth rates and physical characteristics influence the quantity, quality, and timing of organic matter contributions to the soils, affecting denitrification and other microbial processes (Bachand and Horne, 1999; Bastviken et al., 2007; Gebremarium and Beutel, 2008 Hume et al., 2002). Wetland plants drive variable rates of oxygen diffusion and active oxygen transport to soils, and thus have different influences on soil characteristics critical to coupled nitrification–denitrification (Gebremariam and Beutel, 2008; Reddy and Graetz, 1988; Tanner, 1996). Understanding the role community composition plays in CTW performance will aid in improving CTW designs and management strategies while providing insight into the cost effectiveness of planting and maintaining diverse macrophyte communities in CTWs.

While the interactions among specific wetland plant species, water, and soils have been studied at the microcosm scale, fewer studies have examined them at the whole-system scale in fully operational CTWs, and those studies that have been carried out at the whole-system scale have been carried out in mesic climates where the water budget of the CTW is vastly different to that of CTWs in arid climates where evapotranspiration rates are high (Dunne et al., 2013; Hernandez and Mitsch, 2007; Kadlec, 2006). The complex soil–water–plant interactions that take place at the whole-system scale in arid climates may influence the relationship between macrophyte community composition and nutrient removal in subtle ways that are not detectable in more reductionist studies or in mesic climates. There are several mechanisms by which a hot, arid climate may affect wetland function: (1) During hot summer months, extreme temperatures may potentially inhibit plant or microbial activity; (2) conversely, warm winters may promote plant growth and microbial activity; (3) different macrophyte species may be affected by a hot, arid climate in different ways; (4) high temperatures may increase decomposition rates of senesced plant material, potentially reducing the accumulation of nutrients in dead plant material (Thullen et al., 2008), and; (5) high temperatures and low vapor pressure deficits may increase evaporation and transpiration, with concomitant impacts on wetland hydrology (Ong et al., 1995; Sanchez et al., 2015). Studying the dynamics and function of CTWs in arid environments will thus build valuable knowledge for improving arid CTW management and design.

Our research used a whole-system approach to study an operational CTW where vegetation has been relatively unmanaged since planting, lending insights into how changes in plant community composition may have impacted whole-system N uptake. Studying the impact of community composition at this holistic scale provides a valuable context for extrapolating small-scale experimental findings to ecosystem-level management practices.

For this paper, our goal was to quantify the interaction between macrophyte community composition and N dynamics at the 42 ha Tres Rios CTW in Phoenix, Arizona, USA. We sought to quantify: (1) aboveground plant biomass, productivity, and community composition; (2) assimilation of N into plant tissues, and; (3) N flux into and out of the wetland. Using aboveground biomass, plant productivity, and plant N assimilation data, we developed estimates of monotypic peak biomass N assimilation for each species group present (i.e., the mass of N assimilated by plants if the system was planted with or managed to maintain only that species group). We compared plant N uptake from our direct observations and these hypothetical monotypic estimates to total N flux into and out of the system to better understand the role direct plant uptake plays in system N storage and removal. Our overall objective was to better inform design and management decisions regarding the benefits and costs of planting and maintaining diverse macrophyte communities in CTWs.

Please cite this article in press as: N.A. Weller, et al., Aridland constructed treatment wetlands I: Macrophyte productivity, community composition, and nitrogen uptake, Ecol. Eng. (2015), http://dx.doi.org/10.1016/j.ecoleng.2015.05.044