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Development/ripening of ecosystems services in the first two growing seasons of a regional-scale constructed stormwater wetland on the coast of North Carolina

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ABSTRACT

A well-functioning constructed stormwater wetland (CSW) will provide many ecosystem services. However, there has not been an effort to monitor and evaluate these services as a CSW develops in the first years after construction – the 'ripening' period. In this study, ecosystem services development was assessed during the first two growing seasons of a CSW located on the coast of North Carolina. The CSW research site was a regional-scale stormwater project with two different flow regimes: event and base flow. The full potential of some ecosystem services of this CSW were realized immediately such as volume reduction, TSS and $NO_{2,3}$ treatment. Others were fully developed after the 1st growing season, e.g. TAN, ON, TN, and TP treatment. Mostly, ripening of the CSW was complete, as areal C densities exceeded median C densities observed in other stormwater wetlands, and vegetation biodiversity measurements aligned with other stormwater wetlands in North Carolina, just one year after construction. The establishment of vegetation was deemed the most important design goal during this vital period, as vegetation is interlinked with other services: evapotranspiration, water quality improvement, and C input to the soil.

1. Introduction

Negative ecological effects of stormwater runoff are of increasing concern, especially in areas of rapid urbanization. Federal, state, and local programs have been developed to mitigate the effects of runoff, many of which require the implementation of stormwater control measures (SCMs) (NC Administrative Code, 2008; MDE, 2015). These SCMs, such as constructed stormwater wetlands (CSWs), wet ponds, and bioretention cells, are typically designed to retain a specific water quality event, and then slowly release it (NCDENR, 2009). Constructed stormwater wetlands have become popular SCMs in low-lying coastal environments, offering a hybrid between larger detention practices (wet ponds) and newer green infrastructure technologies. The main characteristics of CSWs, such as shallow water (low marsh) depth, emergent vegetation, and the use of in situ soils, mimic those found in natural wetland ecosystems (Harrington et al., 2005). A well-functioning CSW will provide a diverse ecosystem that includes many plants and animals. These diverse ecosystems can provide services to society (Moore and Hunt, 2012), hence the term: ecosystem services (Costanza et al., 1997; MEA, 2005). These services include but are not limited to: provisioning services (food and raw materials), regulating services (water quality, peak flow mitigation), and cultural services (recreation and education) (De Groot, 2006; MEA, 2005). Regulating services, such as water quality and peak flow mitigation, of CSWs have been, understandably, the primary focus for evaluation and research, but these systems also offer biodiversity, carbon sequestration, and educational and recreational features (Moore and Hunt, 2012; Greenway, 2010; Anderson and Mitsch, 2006; Bolund and Hunhammar, 1999). Previous studies have demonstrated the first years after construction, the 'ripening' period, to be vital and highlighted two key maintenance and design mistakes that can affect the development of ecosystem services: (1) setting a normal pool elevation too deep and (2) clogging of the outlet structure, which artificially raises the normal pool elevation for extended periods of time (Greenway et al., 2007; Hunt et al., 2011). Greenway et al. (2007) observed poor vegetation survival due to extended periods of inundation and deeper water levels – transforming this CSW into a wet pond just 5 years after construction. Hunt et al. (2011) appraised a CSW in eastern North

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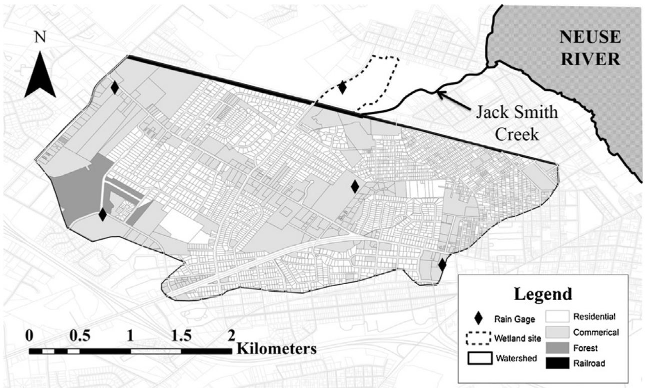

Fig. 1. Jack Smith Creek CSW contributing watershed and installed rain gauge locations in New Bern, North Carolina, USA.

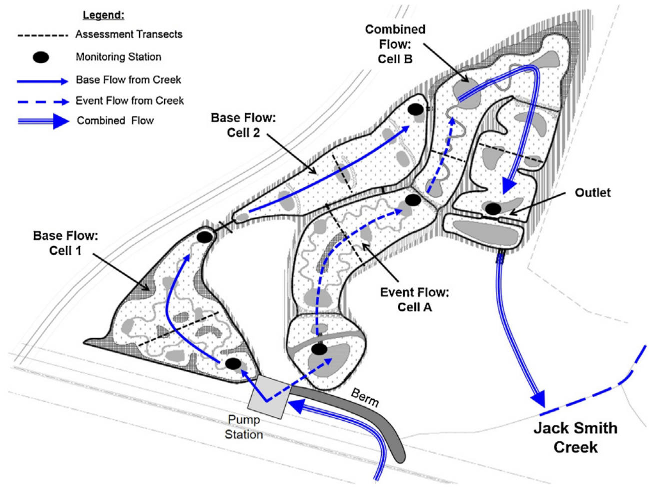

Fig. 2. Schematic of Jack Smith Creek constructed stormwater wetland.

Carolina with high water levels shortly after construction due to an absent outlet orifice, and the CSW was transformed into a wet pond just 1.5 years after construction. Vegetation loss detrimentally impacted water treatment by CSWs as vegetation supports several pollutant removal mechanisms: filtration of particles, stabilization of sediments, nutrient uptake, microbial-rhizosphere interaction to promote nitrification and denitrification, and the provision of increased surface area for biofilm/periphyton growth (Greenway, 2004). These pollutant removal mechanisms set CSWs apart from wet ponds. Loss of vegetation and prolonged periods of stagnant water can also lead to a loss in healthy macroinvertebrate communities and increased mosquito populations (Greenway et al., 2003; Hunt et al., 2006).

In this study, ecosystem services development was assessed during the first two growing seasons of a CSW located on the coast of North Carolina. The influent for this CSW is pumped only with event and base flow regimes. The site has a contributing watershed area of 621 ha and a footprint of approximately 7 ha. This design and scope is unique as most CSWs have catchments and CSW surface areas less than 80 ha and 2 ha, respectively. (Pier et al., 2015; Hathaway and Hunt, 2010; Wadzuk et al., 2010; Line et al., 2008).

The objective of this study was to assess ecosystem service development during the 'ripening' period of a regional-scale CSW with two flow regimes: event and base flow. These ecosystem service assessments focused on regulation services: hydrologic regulation and water quality improvement but also ancillary services such as vegetative biodiversity, which was second only to flood control in a review of the general public's value of services provided by constructed wetlands (Ghermandi et al., 2010), and carbon sequestration – a topic gaining international attention due to interest in regulating atmospheric carbon dioxide. The CSW design features that promoted or inhibited service development were also noted.

2. Materials and methods

2.1. Site description

The Jack Smith Creek constructed stormwater wetland (CSW) was located in the coastal plain of North Carolina and Neuse River Basin in the city of New Bern (35°07′26″N, 77°03′ 50″W). The CSW earth and concrete work were completed in January 2013, planted in April and May 2013, and full construction was complete and operation commenced in June 2013. The CSW serviced a 621 ha watershed, 48% of which was impervious (Fig. 1). The composite curve number for the watershed was estimated to be 82. Soils in the watershed were mostly Arapahoe fine sandy loam (NRCS, 2013).

Prior to construction of the CSW, Jack Smith Creek was prone to flood many low-lying residential areas in the city due to very low hydraulic gradient in this area and tidal influences on the receiving water body: the Neuse River. A pump station was constructed to pump nearly all creek water to the CSW, which then discharged back to the creek and flowed to the Neuse River, 1.2 km away (Fig. 1). This CSW was comprised of multiple cells and had two inlets with one outlet (Fig. 2). One influent source was a smaller, electric pump (3785 lpm) that ran daily and controlled base flow and storm events less than 25 mm. The second influent source was a larger, diesel pump (75,700 lpm) that controlled high creek stage from storm events larger than 25 mm. The CSW was specifically designed to maintain necessary water depths and velocities to support wetland vegetation and maximize water quality improvements (Greenway, 2004; Greenway et al., 2007). The design included a mixture of deep pools, channels, islands, and densely vegetated zones, which mix water and habitats to promote ecological balance.

The size and multi-cell design of the CSW produced a treatment train. The cells had a combined area of 6.78 ha and a total storage of 10,935 m^3 (Table 1). The design incorporated varying bathymetry (Greenway et al., 2007; Hunt et al., 2007) with temporary inun-

Table 1
Descriptions of Jack Smith Creek CSW cells shown in Fig. 2.

Cell	Area (ha)	Ponding Depth (cm)	Storage (m^3)	Average HRT (days)*	Shortest Hydraulic Distance (km)
Cell 1	1.67	10	1670	0.2–0.4	0.22
Cell 2	1.15	10	1150	0.2–0.4	0.25
Cell A	1.45	30	4350	0.4–0.7	0.22
Cell B	2.51	15	3765	1.75–2.0	0.32
Total	6.78	–	10,935	2.0–3.0	0.5–0.8

* Hydraulic Retention Time (HRT) = Volume of Cell\Q where Q = ($flow_{in}$ + $flow_{out}$)\2 (USEPA, 1988).