Ecological Engineering 80 (2015) 8–19

Contents lists available at ScienceDirect

Ecological Engineering

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

Protecting the Florida Everglades wetlands with wetlands: Can stormwater phosphorus be reduced to oligotrophic conditions?

William J. Mitsch[a,b,*], Li Zhang[a], Darryl Marois[a,b], Keunyea Song[b,c]

[a] Everglades Wetland Research Park, Florida Gulf Coast University, 4940 Bayshore Drive, Naples, FL 34112, USA
[b] Olentangy River Wetland Research Park, The Ohio State University, Columbus, OH 43210, USA
[c] School of Natural Resources, University of Nebraska, 3310 Holdrege Street, Lincoln, NE 68583-0974, USA

ARTICLE INFO

Article history:
Received 23 June 2014
Received in revised form 23 September 2014
Accepted 3 October 2014
Available online 25 October 2014

Keywords:
Phosphorus
Florida Everglades
Treatment wetlands
Stormwater treatment
Cladium jamaicense
Nymphaea odorata
Typha domingensis
Najas guadalupensis

ABSTRACT

The Florida Everglades is being threatened by high-nutrient stormwater coming from agricultural runoff. The main nutrient problem is phosphorus, which causes the highly oligotrophic sawgrass (*Cladium jamaicense*) communities in the northern Everglades to become eutrophic *Typha latifolia*/*T. domingensis* communities. Current government directives require that the total phosphorus concentration of storm water drainage into the Everglades be limited to approximately 10 ppb (μg-P/L). Over 23,000 ha treatment wetlands, referred to locally as stormwater treatment areas (STAs), have been created from farmland to treat the stormwater. They are generally effective in removing 60–80% of the total phosphorus; however, the 10 ppb goal has rarely been achieved. A three-year experiment, involving mesocosms planted with Everglades-native wetland plants was conducted in the Florida Everglades from March 2010 to March 2013. Eighteen flow-through mesocosms (6 m × 1 m × 1 m with 40-cm water depth) received about 2.6 cm/day inflow. The eighteen mesocosms were randomly assigned with six different plant communities with three replicates of each treatment, consisting of sawgrass (*C. jamaicense*); waterlily (*Nymphaea odorata*); cattail (*Typha domingensis*); submerged aquatic vegetation (SAV) including *Najas guadalupensis*, and *Chara* sp. and a *Nymphaea*–*Eleocharis* sp. mixed community; and soil without vegetation as a control. Total phosphorus (TP) in the inflow water was 25 ± 1 μg-P/L ($n = 55$) over the 3 years. Through 2012 the average outflow of all of the treatments was 34 ± 1 μg-P/L, a 51% decrease from the average outflow of 69 ± 6 μg-P/L for 2011. Outflows began to be routinely lower than the inflow in the 3rd year of the study. The average total phosphorus concentration decreased overall to 19 ± 1 ($n = 5$) at the end of the study in 2013 suggesting that the suspected phosphorus reflux from the mesocosm soils into the water column slowed after 2–2.5 years of mesocosm operation. Comparing outflows of the individual treatments for 2013, the *Nymphaea*, control/*Chara*, and *Typha* treatments were lower ($p < 0.05$) than the inflow with average outflow concentration of 11 ± 1, 15 ± 3 and 16 ± 1 μg-P/L respectively. When the 2013 data are isolated, 4 of the 6 vegetation treatments showed total phosphorus removal, ranging from mixed community (17% removal), to *Typha* (28% removal), to the control (34% removal) and to *Nymphaea* (51% removal). We conclude that any treatment wetland constructed with local Florida soils and designed to achieve low (∼10–15 ppb P) concentrations would probably take a minimum of 2 years to become sinks of phosphorus. We also conclude that wetlands can be created to achieve these low thresholds if low TP loading and self-design strategies are incorporated into the project design.

1. Introduction

The Florida Everglades, one of the largest and most unique wetland systems in the world, and especially its “river of grass,” are being threatened by high-nutrient stormwater coming from the highly fertilized Everglades Agricultural Area to the north. The main nutrient problem is phosphorus, which causes the highly oligotrophic sawgrass (*Cladium jamaicense*) in the northern Everglades to become a partially eutrophic *Typha latifolia*/*T.*

* Corresponding author at: Florida Gulf Coast University, Everglades Wetland Research Park, 4940 Bayshore Drive, Naples, FL 34112, USA. Tel.: +1 239 325-1365; fax: +1 239 732 7043.
E-mail address: wmitsch@fgcu.edu (W.J. Mitsch).

http://dx.doi.org/10.1016/j.ecoleng.2014.10.006
0925-8574/

domingensis community. Current government directives are requiring that the total phosphorus concentration of storm water drainage be limited to about 10 ppb (μg-L), the approximate concentration of phosphorus in rainfall.

1.1. Stormwater treatment areas in the Florida Everglades

There are currently six stormwater treatment areas (STAs) covering 23,000 ha that have been restored from former farmland to treat the agricultural runoff from the Everglades Agricultural Area (EAA) south of Lake Okeechobee (Fig. 1). Some of these systems have been in operation for almost 20 years (Fig. 2a). Overall, from their start through 2012, these wetlands reduced phosphorus loads by 73% and lowered the average phosphorus concentrations from 140 to 37 ppb (Pietro, 2012; Fig. 2b). There is significant adaptive management associated with the operation of the STAs including water depth management, water diversions, and drought contingency planning. The dynamics of phosphorus in these wetlands has been evaluated and modeled in several studies (Newman and Pietro, 2001; Juston and DeBusk, 2006, 2011; Dierberg and DeBusk, 2008; Paudel et al., 2010; Paudel and Jawitz, 2012; Entry and Gottlieb, 2014). Juston and DeBusk (2006) found in an investigation of four of these STAs that mass loadings at or below 1.3 $g P m^{-2} yr^{-1}$ provided "a high likelihood of achieving outflow total P (TP) concentrations less than 30 μg/L". Furthermore they found that in submerged aquatic vegetation (SAV) wetlands and emergent vegetation wetlands restored from historic wetlands rather than agriculture, loading rates at or below 2 $g P m^{-2} yr^{-1}$ led to outflow P concentrations consistently between 10 and 20 ppb and mass removal efficiencies consistently above 85%. Entry and Gottlieb (2014) concluded that as a result of $1.35 billion spent on the STA's over 17 years and investments in best management practices in the basin, total phosphorus decreased by 10–58% in various locations in the Greater Everglades. Phosphorus concentrations decreased from 12 to 7 ppb in the Everglades National Park itself over that time.

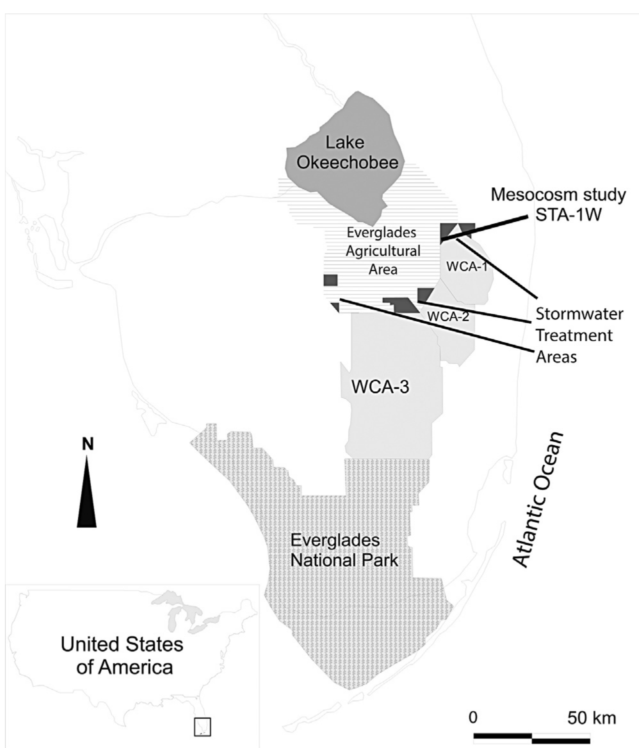

Fig. 1. Location of the mesocosm study site near stormwater treatment area (STA) 1W in south Florida (from Villa et al., 2014).

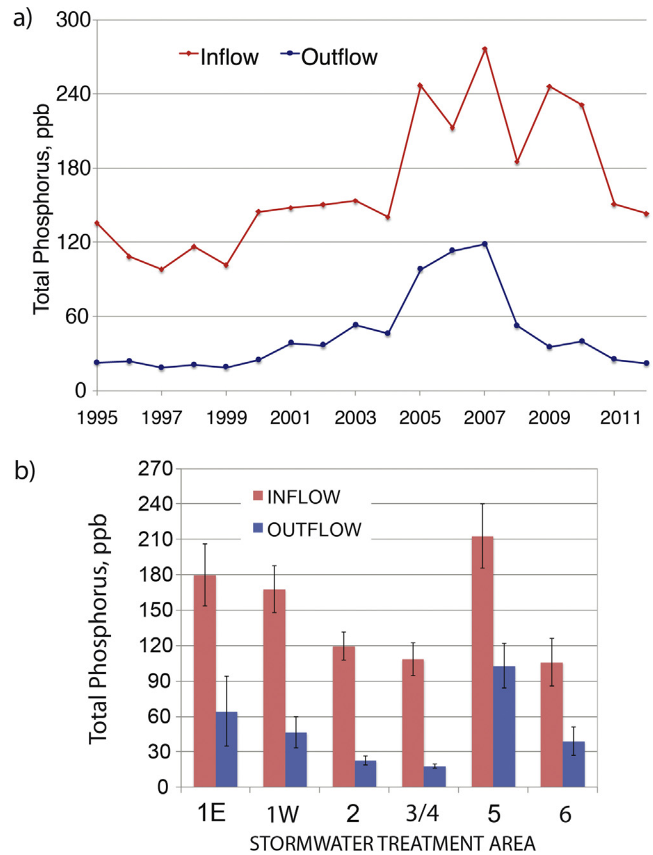

Fig. 2. Total phosphorus inflow and outflow from stormwater treatment areas (STAs; created and restored wetlands) in south Florida: (a) STA-1W for 18 years 1995–2012; (b) average ± standard error of inflows and outflows for six STAs shown in Fig. 1.

Our review of data from STA-1W, the oldest operating STA system (started in 1994), shows that the inflow concentration for the latest 5 years (2008–2012) is 191 ppb and an average outflow concentration has been 35 ppb, resulting in an average retention rate, by concentration, of 82%. Analyzing 17 years of data from this same wetland, an average retention rate of 1.25 $g P m^{-2} yr^{-1}$ was realized. This is well within the "sustainable" range of phosphorus retention of 1–2 $g P m^{-2} yr^{-1}$ for low-nutrient (non-municipal wastewater) treatment wetlands as summarized by Mitsch et al. (2000). All said, however, reaching the mandated 10 ppb threshold of total phosphorus has not been achieved with any consistency from the STAs.

1.2. Mesocosm study on achieving low phosphorus concentrations

Although the created and restored wetlands (STAs) have substantially reduced phosphorus (P) loading to the Everglades over the past decade, efforts continue to investigate new management strategies to enhance the treatment performance of these wetlands. One such effort was to initiate a three-year proof-of-concept study mesocosm phosphorus study, starting in 2010. The study examined whether several species of native aquatic macrophytes can be used to enhance the treatment performance of the STAs. We hypothesized that fragrant waterlily (*Nymphaea odorata*) and/or sawgrass (*C. jamaicense*), both common in the oligotrophic waters of the Florida Everglades, may be able to reduce water-column P concentrations to levels below that of the *Typha*-submerged aquatic vegetation (SAV) systems currently