Ecological Engineering 101 (2017) 107–119

Contents lists available at ScienceDirect

Ecological Engineering

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

Dominating aquatic macrophytes for the removal of nutrients from waterways of the Indian River Lagoon basin, South Florida, USA

Xiaohong Zhou [a,b], Zhenli He [a,*], Kimberly D. Jones [a], Liguang Li [a], Peter J. Stoffella [a]

[a] Indian River Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, Fort Pierce, FL, 34945-3138, USA
[b] School of the Environment and Safety Engineering, Jiangsu University, Zhenjiang, Jiangsu, 212013, China

ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form 5 January 2017
Accepted 5 January 2017
Available online 22 January 2017

Keywords:
Aquatic plants
Nitrogen
Phosphorus
Uptake
Nutrients storage
Harvesting

ABSTRACT

Aquatic macrophytes have an important role in cleaning eutrophic runoff water from agriculture and urban areas. However, minimal information is available regarding the quantity of nutrients and/or pollutant they can remove each year from the water and sediments in waterways. This study investigated the biomass productivity of eight dominating aquatic plant species, the concentrations of nutrients in plant tissues and their capacity to absorb and store nutrients. Samples of plant, water, and sediment were collected from October 30 to November 19, 2014 at 22 representative sites in the waterways of the Indian River Lagoon basin, South Florida, USA. The biomass yield of the plant species decreased in the order: cattail (*Typha orientalis*)> pickerelweed (*Pontederia cordata*)> water lettuce (*Pistia stratiotes*)> hydrilla (*Hydrilla verticillata*)> maidencane (*Panicum hemitomon*)> spatterdock (*Nuphar advena*)> pondweed (*Potamogeton* spp.)> salvinia (*Salvinia* spp.). Cattail had the highest biomass productivity, but only a small part (35.8%) of the total biomass productivity was harvestable, whereas, water lettuce and hydrilla were mostly harvestable and could contribute almost 100% to harvestable biomass. Concentration of nutrients in plant varied significantly among the eight plant species and with the sampling sites, suggesting that in addition to genetic differences, physicochemical parameters of overlying water and surface sediment influenced uptake of nutrients by the plants. Among the eight plant species, cattail had the highest total nitrogen (N) (23.4 g N m^{-2}) and phosphorus (P) (1.59 g P m^{-2}) storage but water lettuce and hydrilla exhibited the highest total N (14.6 g N m^{-2}) and P (1.04 g P m^{-2}) net storage capacity in this survey. In addition, the highest N and P uptake per year occurred with water lettuce and hydrilla, with the peak of 146 kg N ha^{-1} y^{-1} and 10.4 kg P ha^{-1} y^{-1}, respectively. The results also indicate that multiple harvests of biomass are necessary to realize the removal potential of nutrients/pollutant by the aquatic plants, as the harvesting (cutting) practice can enhance plant growth and prevent release of nutrients/pollutant back into water from plant residue decomposition, which are estimated at 1.87×10^3 to 72.4×10^3 kg N and 0.07×10^3 to 4.80×10^3 kg P per year in the IRL basin.

1. Introduction

Water pollution, caused by excessive input of N and P from agriculture, urbanization, and industrial discharge has become a global issue (Sherwood and Qualls, 2001; Dodds, 2007; Yang et al., 2008a, 2008b; Schindler and Hecky, 2009; Liu et al., 2011; Dai et al., 2012; Kearney and Zhu, 2012). Therefore, removal of N and P is an effective method for mitigating the serious situation of eutrophication (Liu et al., 2011; Li et al., 2015). Aquatic macrophytes are considered to be the crucial biological components in the fresh surface water ecosystems and have important roles in water purification (Reddy, 1983; Lu et al., 2010, 2011; Wu et al., 2011; Zhu et al., 2011; Zhao et al., 2012a, 2012b; Li et al., 2015). Aquatic plants are widely used for ecological remediation of eutrophic lake, polluted river, and other water bodies. They directly absorb N and P from eutrophic water for growth and reproduction (Ellis et al., 1994). Ultimately, the biomass is harvested to remove the N and P from the water systems. Therefore, plant uptake is an important mechanism of water remediation (Gottschall et al., 2007). However, the capacity of plant uptake is related to nutrient concentration in plant and biomass yield. Potential of plants for removing nutrients/pollutant from water systems varies with species and is affected by environmental factors such as climate and hydrological conditions and nutrient enrichment in water and sediment (Jampeetong and Brix, 2009; Zhang et al., 2009).

* Corresponding author at: 2199 South Rock Road, Fort Pierce, Florida, 34945-3138, USA.
E-mail address: zhe@ufl.edu (Z. He).

http://dx.doi.org/10.1016/j.ecoleng.2017.01.006
0925-8574/

In Florida, owing to heavy irrigation and/or frequent rainfall, dissolved nutrients such as N and P from fertilized soils, are readily lost into waterways which results in eutrophication of surface water systems including the Indian River Lagoon (IRL) and Lake Okeechobee (He et al., 2006; Yang et al., 2008b, 2009). Eutrophication of IRL has been a major public concern in the last decade (Lu et al., 2010). Agricultural practices and urban development are considered as major nonpoint sources of pollution. Runoff water that is laden with nutrients delivers a large amount of nutrients (N, P) to the IRL through waterways of farm ditches and canals in the IRL basin. Previous studies indicated that concentrations of N and P in runoff water were considerably attenuated in the waterways due to biological assimilation (He et al., 2006; Yang et al., 2008a, 2008b, 2009). In addition to microbial fixation, nutrient uptake by plants may have significantly contributed to the purification of eutrophic runoff water, as these waterways are often fully-grown with various ecotypes of aquatic plants including hydrilla, water lettuce, and cattail, and other aquatic plants, due to warm weather and adequate nutrient supply. Aquatic vegetation takes up nutrients from the water, rendering the waterways like a natural phytoremediation system. However, to date, minimal information is available regarding the amounts of nutrients/pollutant that can be removed by aquatic macrophytes and their potential impact on water quality, which is critical for the development of best management practices (BMPs) to minimize impact of agriculture and urbanization on the environment, particularly water quality.

The objectives of this study were to evaluate the potential of representative aquatic macrophytes in the removal of nutrients (N and P) from waterways in the IRL basin, South Florida, USA. The specific objectives were to: 1) determine the concentrations of N and P in plant of dominant aquatic macrophytes and their correlations with N and P concentrations in water and sediment in the waterways of the IRL basin; 2) determine the annual biomass yield of the dominant aquatic plant species so that the amounts of nutrients removed by each plant species can be quantified; and 3) evaluate the potential of the aquatic plants in removing N and P from waterways of the IRL basin on the condition that plant biomass could be adequately harvested.

The information is expected to improve our understanding of the aquatic plants' contribution to water quality improvement and to facilitate the development of BMPs in the Indian River area.

2. Materials and methods

2.1. Sampling sites and aquatic plants survey

Field surveys were conducted from August 10 to October 20 of 2014 to determine species distribution and composition patterns of aquatic macrophytes in waterways of the IRL basin, South Florida, USA. Based on survey results, 22 representative sites were established for sampling plant, water and sediments (Table 1 and Figs. 1 and 2).

2.2. Sample collection and pre-treatments

Triplicate samples of the overlying water, surface sediments and macrophytes were collected from each site from October 30 to November 19 of 2014.

Overlying water was collected and stored into 500 mL precleaned polyethylene bottle. Surface sediment samples (from 0 to 20 cm depth) were collected using a grab sampler from the same location of the water samples and were sealed in plastic ziplock bags. Meanwhile, triplicate 0.25–0.30 m^2 quadrats of each plant species were collected from the same site. Percentage of surface coverage by each dominant plant species was also estimated by visual observation. All the samples were placed in iced chest to the laboratory within 4 h. In the laboratory, pH and electricity conductivity (EC) of water samples were immediately determined using a pH/ion/conductivity meter (Model 220, Denver Instrument Inc., CO, USA). Subsamples of the water were stored at −20 °C for further analyses. Sediment samples were air-dried, ground, sieved through a 1-mm sieve and stored at 4 °C for further analyses. Plants were washed thoroughly with tap water to remove any adhered impurities. Pickerelweed (*Pontederia cordata*) and spatterdock (*Nuphar advena*) were separated into roots (plus rhizomes), stems, leaves and flower; maidencane (*Panicum hemitomon*) was separated into roots, stems and leaves; cattail (*Typha orientalis*) was separated into roots (plus rhizomes) and leaves; water lettuce (*Pistia stratiotes*) was separated into roots and leaves (plus stems); and hydrilla (*Hydrilla verticillata*), pondweed (*Potamogeton* spp.) and salvinia (*Salvinia* spp.) were kept as whole plant. All plant tissue samples were oven dried at 70 °C for 7 days to constant weight, and dry biomass was recorded. The oven-dried plant samples were powdered <1 mm prior to chemical analyses. All samples were pretreated in three replicates.

2.3. Physicochemical analysis

Water samples were filtered through a 0.45 μm membrane filter for measuring the concentrations of dissolved organic carbon (DOC), total dissolved P (DP), ortho-phosphate (PO_4^{3-}-P), ammonia (NH_4^+-N), nitrate (NO_3^--N), and total Kjeldahl N (TKN). Both unfiltered and filtered water samples were digested for TKN by acidified cupric sulfate and potassium sulfate, and the concentrations of NH_4^+-N and NO_3^--N in water and digested samples were determined using a discrete auto-analyzer (EasyChem, Systea Scientific, IL, USA) (US EPA 350.1) Total N was calculated as the sum of TKN and NO_3^--N in the unfiltered samples; particulate N (PN) was calculated as the difference in total N between the unfiltered and filtered samples; organic N (ON) was calculated as the difference between TKN and NH_4^+-N in the unfiltered samples; dissolved N (DN) was calculated as the sum of TKN and NO_3^-N in the filtered samples. Total P (TP) in the filtered and unfiltered water samples is determined by the molybdenum-blue method using U-3010 Spectrophotometer after digestion with acidified ammonium persulfate (US EPA 365.1). Concentration of reactive P in water samples was determined with the colorimetric method and total dissolved P in water was calculated by the difference in total P between the filtered and unfiltered water samples. The concentration of DOC was determined using Liquid TOC analyzer (liquid TOC trace, Elemental Analysensystem GmbH, Hanau, Germany). Triplicate samples were performed for each measurement.

Sediment pH and EC were determined in water at a solid: water ratio of 1:1 and 2:1 using a pH/ion/conductivity meter (Model 220, Denver Instrument Inc., CO, USA), respectively. Total organic C and total N of sediment samples were determined using C/N-Analyzer (vario MAX CN elementar Analysensysteme GmbH, Hanau, Germany). NH_4^+-N and NO_3^--N in the sediment were extracted with 2M KCl and then measured using a discrete auto-analyzer (EasyChem, Systea Scientific, IL, USA). Extractable P (Exc-P) in the sediments samples was extracted with Mehlich 3 reagent according to previous studies (He et al., 2006; Yang et al., 2013) and P concentration in the extracts was determined using an inductively coupled plasma optical emission spectrometer (ICP-OES, Ultima, JY Horiba group, Edison, NJ, USA). All measurements were performed in triplicates.

Total N concentration in dry plant samples was determined using TOC analyzer (vario MAX CN elementar Analysensysteme GmbH, Hanau, Germany). For measurement of total P, plant samples (0.4 g each) was soaked with 5 mL concentrated nitric acid (HNO_3) overnight, digested at 80 °C for 180 min, and 140 °C for