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Research article

Indicators of nutrient removal efficiency for riverine wetlands in agricultural landscapes of Argentine Pampas

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ABSTRACT

Main objectives of this study were (a) to assess wetlands contribution to regulation of surface water quality of riverine wetlands in agricultural landscapes through their nutrient removal efficiency (RE), (b) to understand how RE of wetlands is related to hydrological, morphological, chemical and biological attributes, and (c) to identify RE indicators suitable for remote RE assessment. Macrophytes composition, hydrological, chemical, and morphological properties were estimated for 14 riverine wetlands of the Argentinean Pampas, and related to empirically estimated removal-exportation levels of phosphorus (dissolved and total) and nitrogen (inorganic and total). Nutrient inputs and outputs were assessed in four opportunities, two under baseline and two after storm events. A discriminant function based on remotely assessed wetland attributes was able to discriminate three wetland groups according to their contrasting mean RE for total phosphorus and total nitrogen. Descriptors of wetland size (area, length, perimeter) and vegetation (cover of the tall emergent macrophytes) showed the main weights and hence the main value as indicators for conservation and/or management of wetlands according to their nutrient removal capacities.

1. Introduction

One of the main causes of downstream degradation of freshwater ecosystems within agricultural basins is the transport of nutrients excess in the runoff from non-point sources (Carpenter et al., 1998; de Jonge et al., 2002). Excess of phosphorus (P) and nitrogen (N) that are transported to water courses reduce water quality, produce anoxia and favor algae proliferation, with the consequent biodiversity loss and the impairment of water sinks to satisfy different social demands (irrigation, commercial fishing, drinking water, recreation).

Wetlands can play an important role in water quality maintenance within the basins through the removal of nutrients (Fisher and Acreman, 2004; Jordan et al., 2011; Mitsch and Gosselink, 2000; Verhoeven et al., 2006) thus contributing to reduction of eutrophication in adjacent water bodies. Wetlands contribution to water quality in agricultural landscapes was recently estimated by Hansen et al. (2018) in the Minnesota River basin, who conclude that at moderate–high streamflow conditions, wetland conservation or restoration is several times more efficient per unit area at reducing riverine nitrate concentration than land-based nitrogen mitigation strategies (i.e. crops replacement by pastures).

Due to the degradation of wetland ecosystems resulting from changes in the composition of land use of their catchments (Papastergiadou et al., 2008) general models and reliable indicators that prioritize the conservation of wetlands according to their contribution to water quality are urgently needed (Zedler, 2000). Several studies have focused their efforts on identifying wetlands that are critical for maintaining the water quality of basins through the removal of the nutrients that flow through them (e.g. Cohen and Brown, 2007; Moreno-Mateos et al., 2010; Tomer et al., 2003). Most studies addressing wetlands functionality as filters have focused on linking nutrient removal to a limited number of hydrological, chemical and biological attributes, generally for constructed wetlands (Fink and Mitsch, 2004; Kadlec, 2003; Reddy et al., 2013), but adoption of simple indicators of nutrient removal pose serious limitations to the assessment of ecosystem services and proper decision-making in different contexts.

Nutrient removal in the wetlands is influenced by several factors include such as the hydraulic residence time (HRT), flow, depth, soil type, water chemistry, coastline development, pH, and temperature (Ambus and Christensen, 1993; Hansson et al., 2005, 2005; Kadlec, 2003; Kadlec and Knight, 1996; Machefert et al., 2002; Mander et al., 1991; Mitsch and Gosselink, 2000; Richardson, 1985; Uusi-Kämppä

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Table 1
P-values for different sources of variation of nutrient concentrations and removal efficiencies, according to a series of repeated measures ANOVA independently applied for each nutrient, according to sampling condition (base flow vs. post-rain flow), sampling place (inlet vs. outlet) and sampling time (first vs. second sample). Bold numbers indicate significant p-values (p ≤ 0,05).

Sources of variation	p-values for Nutrients concentrations				p-values for Removal efficiencies			
	DP[a]	TP	DIN	TN	DP	TP	DIN	TN
Condition (C)	0.089	0.284	**0.001**	0.286	0.609	0.865	0.354	0.307
Place (P)	0.278	0.428	0.403	0.302	–	–	–	–
C * P	0.953	0.682	0.298	0.787	–	–	–	–
Time (T)	**0.001**	**0.001**	**0.001**	**0.001**	0.116	0.306	0.721	0.359
C * T	0.129	**0.003**	**0.001**	**0.001**	–	–	–	–
P * T	0.433	0.663	0.427	0.704	0.881	0.424	0.656	0.396
C * P *T	0.884	0.429	0.404	0.611	–	–	–	–

[a] DP: dissolved phosphorus, TP: total phosphorus, DIN: dissolved inorganic phosphorus, TN: total nitrogen.

et al., 1996; Zurayk et al., 1997).

Vegetation can also indirectly influence N removal through nitrification and denitrification processes by affecting oxygen concentration, particularly in the rhizosphere (Greenway, 2007; Tanner, 2001) and increasing the supply of potentially limiting organic carbon and nitrate to denitrifying bacteria (Brix, 1997; Reddy et al., 1989). Vegetation presence within wetlands may also promote nutrient removal by decreasing flow speed and increasing HRT (Greenway, 2007) and reducing sediments resuspension (Braskerud, 2001).

In order to contribute to the development of reliable indicators for nutrients removal efficiency (RE) by wetlands, main objectives of this article were (a) to assess wetlands contribution to regulation of surface water quality of riverine wetlands in agricultural landscapes through their nutrient removal efficiency (RE), (b) to understand how RE of wetlands is related to hydrological, morphological, chemical and biological attributes, and (c) to identify RE indicators suitable for remote RE assessment. Field work was performed in the Argentinean south-eastern Pampa, where economic pressures and low regulations are leading to the replacement of perennial pastures by annual crops and strong increments of fertilizers consume (10 times from 1990 to 2010, CIAFA, 2017), at the same time that wetlands are being impaired by eutrophication and channelization (Booman et al., 2012; Brandolin et al., 2013; Quirós et al., 2006).

2. Materials and methods

2.1. Study area

Mar Chiquita watershed was selected as representative of the main land uses in the Pampas region (León, 1991), covering a surface of 1,000,000 ha within the Buenos Aires province of Argentina (34°55′17″S, 57°57′17″W). This watershed is characterized by the presence of lowland streams, floodplains, permanent and intermittent shallow lakes and the Mar Chiquita coastal lagoon that is a sink of many streams. The watershed gives place to multiple land uses, including extensive annual crops (soybean, maize, sunflower, wheat, and potato), cattle livestock and mixed agriculture-livestock systems. The climate is temperate and humid, and the average annual rainfall of about 900 mm is distributed throughout per the year.

With the aid of Google Earth images and terrain observations, we searched for wetlands that meet satisfying three conditions: a) they were located within or nearby the study area, b) they have identifiable single water entries and exits which feed and drain the main water body, and c) both, water entries and water exits were relatively accessible after severe storms. A total of 14 riparian wetlands were chosen for this study, 12 wetlands located within Vivoratá (VI, V2, V3), Tajamar (T1, T2, T3), Junco (J1, J2, J3) and Dulce (D1, D2, D3) streams that correspond to Mar Chiquita basin and the other two wetlands are within Malacara (M1, M2) stream, close to the basin. In riverine wetlands that have superficial and unidirectional flow, it is possible to quantify the nutrient removal by considering the balance concentrations between tributaries and effluents, without affecting the natural flow. The selection of sampling wetlands was made in order to cover the widest variability of sizes (from 0.1 ha to 70.3 ha), macrophytes cover and adjacent land uses (agriculture, livestock or mixed).

2.2. Water sampling

Water samples were carried out four times in each selected wetland, two sampling dates under base flow conditions, and two sampling dates during peak flows. In November 2008 and 2009, under base flow conditions (at least 1 week without rain events) water samples were taken manually using 1 L opaque plastic bottles which were placed at the entry and exit of selected wetlands. Additionally, in December 2009 and June 2010, water samples were obtained during peak flows due to rain events (post-rain samples). Both the 2008–2009 drought and human activities (due to drainage and channeling works) ruined several samples for different wetlands and sampling dates, so 44 input/output from 56 potential samples were obtained and processed.

In December 2009 and June 2010, water samples were obtained during peak flows due to rain events (post-rain flow samples). Water samples were collected in the field within 24 h of a storm event of 63 mm on 19 December 2009 and 39 mm on 14 June 2010. Post-rain-sampling method was based on 120 mL siphon samplers described by (Graczyk et al., 2000), which consisted of two tubes with different lengths inserted into the bottle cap. Samplers were placed at the entrance and exit of wetlands tied to iron rods firmly stacked into the sediment. Height of the siphon was regulated so that the sample was taken at the time when the peak flow occurred. The peak flow of each point was previously calculated, using the rational method (Cronshey, 1986), for an event of 20 mm that produces expected elevations of the water table between 10 and 18 cm depending on properties of the drainage area to each point. The simulation was made with 20 mm-rain events, and despite they cause runoff in the area, are within the minimum rain events that can result in rise peaks detectable by the siphons.

The siphons remained in the field for approximately a month in 2009 and a week in 2010 (until the rain occurred) and were periodically inspected for checking their functionality. All water samples taken after rainfalls were placed in a cooler in the field, and transported to the laboratory for analysis.

Parallel to each sampling the following variables were surveyed: turbidity, total dissolved solids (TDS), salinity, conductivity, pH and temperature of the wetland water, water depth, wetland perimeter (P), maximum width (MW), cross-sectional area, maximum total length (MTL) and area, as well as land use type (annual crops or perennial pastures at each wetland margin) in adjacent fields.

Wetlands contour was mapped only once in October 2009 using a GPS and walking along the limits, considering as such the transition from dry to saturated soil and/or the presence of hydrophytic