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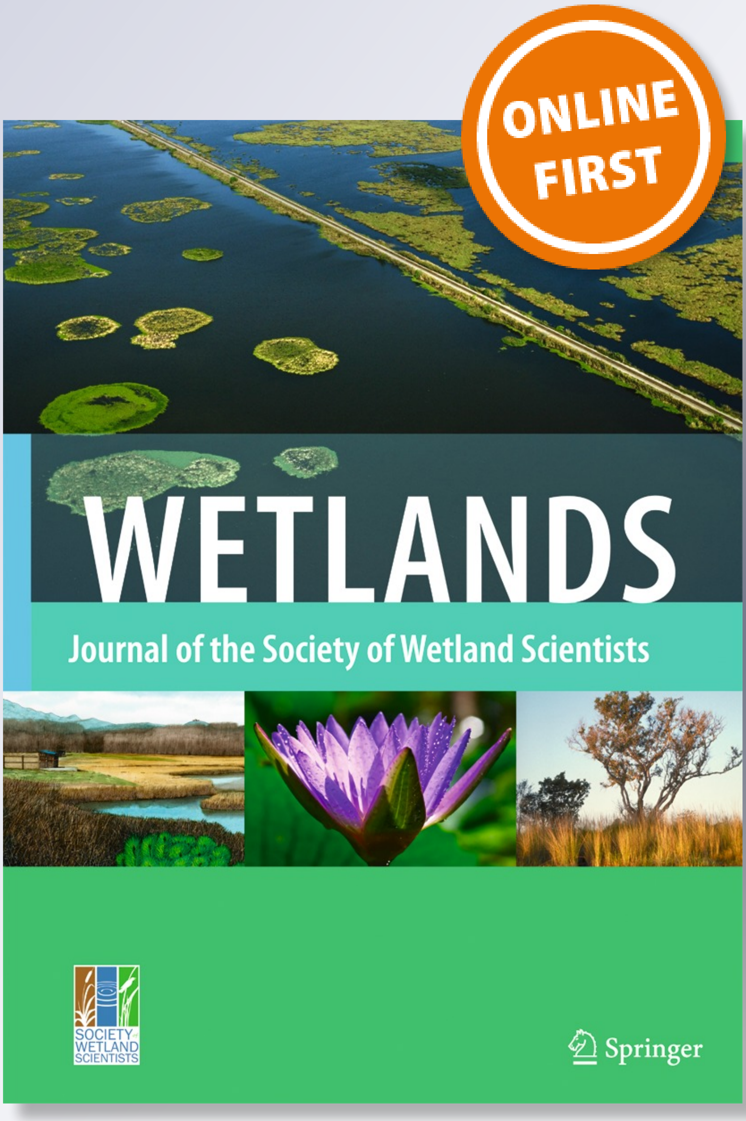
Wetlands
Official Scholarly Journal of the Society of Wetland Scientists

ISSN 0277-5212

Wetlands
DOI 10.1007/s13157-015-0699-2



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ORIGINAL RESEARCH

Nutrient Dynamics in Wetlands of the Middle Paraná River Subjected to Rotational Cattle Management

Leticia Mesa[1] · **Gisela Mayora**[1] · **Miguel Saigo**[1] · **Federico Giri**[1,2]

Received: 11 March 2015 / Accepted: 9 September 2015

Abstract The progressive degradation of wetlands has stressed the need of developing sustainable management strategies for maintaining their ecological character within the context of sustainable development. Rotational cattle grazing is a common grazing strategy in aquatic systems but its effect on nutrient dynamics in lakes is scarcely known. The objectives of this study were to evaluate if cattle produces a significant increase of TN and TP in wetlands, and if the value of these nutrients decrease after cattle are removed. Samples of water, sediment and macrophytes were collected for nutrient, organic matter and other chemical analyses. Results showed a significant increase in water nutrients during the presence of cattle, decreasing during their absence. These changes occurred surprisingly rapid, suggesting a high resilience of these systems to this impact. The presence of submerged vegetation in lakes ameliorated the effect of cattle on water nutrients, suggesting an important role of these plants in ecosystem management. Rotational management would minimize the increase of nutrients in water, maintaining the ecological integrity of wetlands.

Keywords Land use · Nitrogen · Phosphorus · Shallow lakes

Introduction

Freshwater wetlands provide important ecological and economic services, such as wildlife habitat, regulation of water regimes, filtration of polluted water, production of forage, and perform many ecosystem functions, including receiving and treating excess of nutrients from the landscape (Cooper and Findlater 1990; Reddy et al. 1999). In this context, wetlands have an overwhelming importance, not only because of the services and functions they provide, but also because they are among the most threatened ecosystems in the world (Tockner and Stanford 2002). This situation has stressed the need of developing sustainable management strategies for the maintenance of their ecological character within the context of sustainable development (Ward et al. 1999; Borin and Malagoli 2015).

In recent decades, the introduction of cattle in floodplains has contributed to the degradation of these ecosystems around the world (Kato et al. 2009; Burton et al. 2010). With open access to riparian zones of floodplain lakes, cattle can increase nutrient concentration by depositing manure into surface waters (Bottcher et al. 1999; Alloush et al. 2003) or by stimulating nutrient release from sediments stirred up by cattle activity (Line et al. 1998). Although negative impacts of cattle grazing have been generally assumed in lakes (Hongo and Masikini 2003; Bhadha and Jawitz 2010), the effect of this activity in subtropical floodplain wetlands is scarcely known (Steinman et al. 2003; Sigua 2010).

In Argentina, since the late 20th century, the expansion of soybean production, forced the relocation of cattle in marginal sites for the agriculture, constituting a threat to these ecosystems (PROSAP 2009). This situation determined a change in the livestock density in floodplain systems, increasing from 160.000 in 1997 to 1.500.000 during 2007 (Quintana et al. 2014). The Paraná River drains the second largest watershed

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in South America after that of the Amazon, covering an area of 3.1×10^6 km^2. Most of its course is surrounded by a 10–50 km wide floodplain, occupying an area of 60,000 km^2. Because of their extensive areas of vegetation for forage and high quality of water supply, wetlands of the Paraná River system provide excellent conditions for cattle. In this zone, rotation grazing between paddocks is a common management system (Rossi 2013). This strategy improves and maintains forage resource and increase animal production (Sovell et al. 2000). Cattle are continually faced with younger and more nutritious forage throughout the growing season (Kothmann 1984). Understanding how rotational management affects the physical and chemical characteristics of wetlands is an important step to evaluate trade offs between ecological and economic services, maintaining their biodiversity and productivity. According to that, this study addresses two specific questions: is there a significant increase in nutrients in wetlands during the presence of cattle? Does nutrient concentration decrease after the cattle are removed? We predicted that the presence of livestock in wetlands would produce an increase in the values of nitrogen and phosphorous in water and sediment, decreasing during their absence. We use these results to evaluate the adequacy of this grazing management practice in subtropical floodplain wetlands.

Materials and Methods

Study Sites

This study was conducted in two small isolated shallow lakes of the Middle Paraná River floodplain located near the Santa Fe city, Argentina: Lake 1 (31° 41′ 00″ S, 60° 31′ 24″ W) and Lake 2 (31° 40′ 94″ S, 60° 30′ 62″ W) (Fig. 1). Mean depth of the Lake 1 and Lake 2 were 76 and 82 cm respectively, with minimum values of 45 and 50 cm during low water period, and maximum values of 260 and 180 cm during high water period respectively. These lakes become connected with each other and with other aquatic systems only during high water season. During the studied period, this connection occurred in July and August 2013, when hydrometric level in the main channel of the Middle Paraná River reached 13.6 m above sea level. This was the only period when cattle were removed from the zone.

The two studied lakes are included in two different paddocks: the paddock of Lake 1 has an area of 150 ha, with a stocking rate of 3 AU (animal units). ha^{-1}, whereas the paddock of Lake 2 (area=70 ha) has a stocking rate of 7 AU.ha^{-1} (Fig. 1). Cattle are allowed to graze in a paddock for one/several months, before being rotated to another one. The original paddock is then rested for an extended period, often 30 days or longer. The rotation of livestock between paddocks was considered in order to analyze the effect of cattle on nutrients in each lake during their presence, and the capacity of lakes to return to previous condition during the absence of cattle.

Vegetation of the riparian zone in both lakes comprised *Solanum* sp., *Sesbania virgata* and *Cortaderia* sp. Among the emergent macrophytes, *Ludwigia* sp. was dominant, followed by *Victoria cruziana*, *Polygonum* sp., *Myriophyllum* sp., *Paspalum repens* and *Hydrocotyle ranunculoides. Eichhornia crassipes* was the dominant free floating macrophyte, followed by *Salvinia* sp. and *Azolla* sp.; *Elodea* sp., *Potamogeton* sp. and *Utricularia* sp. were the dominant submerged macrophytes, whereas *Oedogonium* sp. and *Chara* sp. were the macro-algae that dominated in these lakes.

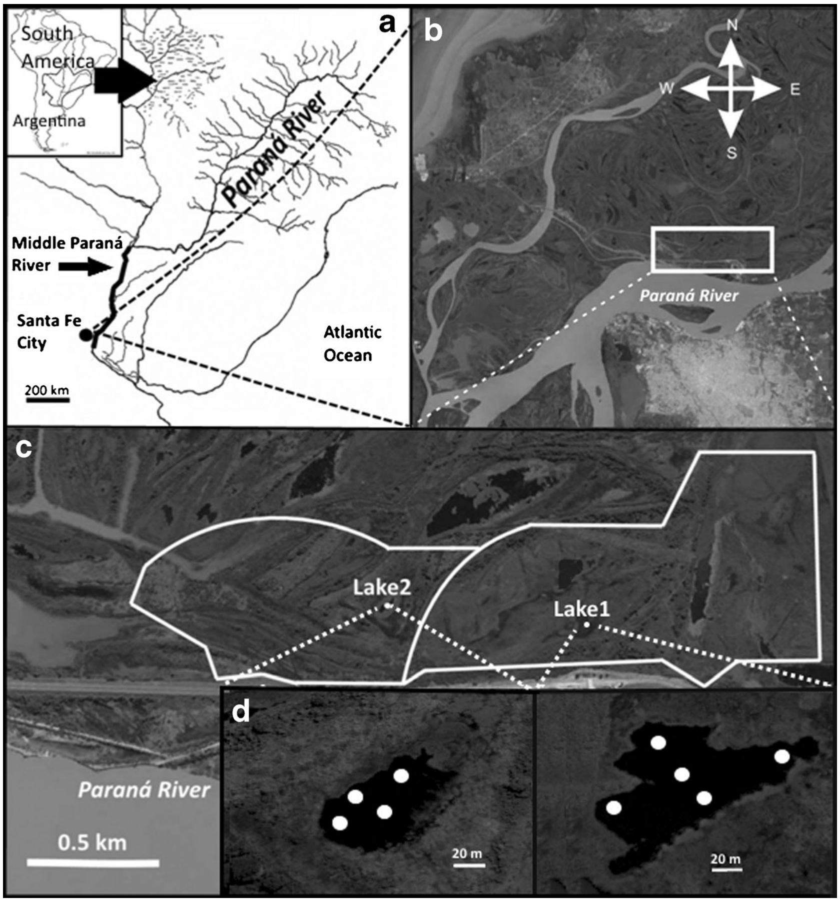
Sampling Procedure

Samples of water and sediment were collected for chemical analyses in five and four sites in Lake 1 and Lake 2 respectively (one sample in the center and the others in the littoral zone, Fig. 1d). The number of sites was determined according to the area of the lakes. The sites of the littoral zone were distributed equidistantly along the shoreline of each lake (Fig. 1d). Samplings were conducted monthly between March 2013 and March 2014 including high, medium and low water periods. Heavy rainfall events and infiltration made the study area inaccessible. Therefore, during May and August in Lake 1, and in May, June, July and September 2013 in Lake 2, the sampling could not be performed.

Subsurface water samples were collected by triplicate in each site of each lake (15 samples in Lake 1, 12 samples in Lake 2) with plastic bottles, stored on ice and darkness for subsequent analyses of nutrients, chlorophyll-*a*, pheophytin-*a*, chromophoric dissolved organic matter (CDOM), and biological oxygen demand. These variables could act as indirect indicators of presence of cattle in aquatic systems (Scrimgeour and Kendall 2003). Water samples for dissolved oxygen determination were taken with glass bottles, fixed and refrigerated immediately for posterior analyses by Winkler method (APHA 1992). Samples of sediment were taken by triplicate in each site in each lake (15 and 12 samples in Lake 1 and 2 respectively) with a Rigosha grab (100 cm^2), and the upper 10 cm was retained for nutrient and organic matter content analyses. In addition, 20 plants of *Ludwigia* sp. and *Eichhornia* sp. were collected at random in each lake and sampling date. These plants were selected due to their dominance as emergent and free floating macrophytes and their presence during all year in both lakes. Roots were separate from the other parts of the plant for nutrient analyses. We analyzed nutrient content of roots instead of leaves because cattle usually graze the leaves of these macrophytes.

Species presence and total coverage of submerged vegetation (percentage respect to the total observed area) were

Fig. 1 **a** Map of the Paraná River system (Middle Paraná River is highlighted) **b** Location of the studied lakes **c** Paddocks where each lake is included **d** Position of the sampling sites in each lake



estimated using a rake in each sampling site. Submerged vegetation had proved to be an effective indicator of the ecological quality of lakes (SØndergaard et al. 2010). In addition, depth (sounding lead), transparency (Secchi disk), pH (Hellige pH-meter), conductivity (Hanna conductivity meter), and water temperature (standard thermometer) were measured in situ in order to determine the physico-chemical characteristics of the lakes during each sampling date according the presence/absence of cattle.

Laboratory Determinations

A variable volume of water (1000–1500 ml) was filtered through Whatman GF/F glass-fibre filters. Filters were stored at −20 °C for analysis of chlorophyll-*a* and pheophytin-*a*. Filtered water was refrigerated for determination of dissolved components within 24 h after sampling, while unfiltered water samples were kept frozen until their processing for total phosphorous (TP) and total nitrogen (TN) determinations. Soluble reactive phosphorous (SRP) was determined by the ascorbic acid method (Murphy and Riley 1962), nitrate+nitrite ($N\text{-}NO_3^- + N\text{-}NO_2^-$) by reduction of $N\text{-}NO_3^-$ with hydrazine sulfate and subsequent colorimetric determination of $N\text{-}NO_2^-$ (Hilton and Rigg 1983), and ammonium ($N\text{-}NH_4^+$) by the indophenol blue method (Koroleff 1970). TP was estimated by digestion with nitric and sulfuric acids followed of SRP determination (Koroleff 1972), and TN by digestion with potassium persulfate in alkaline medium followed of $N\text{-}NO_3^- + N\text{-}NO_2$ determination (APHA 1992). Chlorophyll-*a* and pheophytin-*a* were extracted from the filters with acetone (90 %). The extracts were stored at 4 °C for 24 h in the darkness, clarified and measured with a spectrophotometer at 750 and 664 nm, and at 665 and 750 nm after acidification with HCl 0.1 N (Lorenzen 1967). In addition, filtered water color (platinum-cobalt units) was measured at 455 nm and used as estimator of CDOM (Wetzel 1981), whereas percentage of aromatic carbon of CDOM was estimated from the ratio between the optical density at 250 and 365 nm (Peuravuori and Pihlaja 1997). Biological oxygen demand was estimated from the difference in concentration of dissolved oxygen before and after the sample was incubate for 5 days at 20 °C (APHA 1992).

In the laboratory, roots of *Ludwigia* sp. and *Eichhornia* sp. were carefully rinsed with distilled water to remove adhering sediment. Samples of sediment and roots of macrophytes were dried at 105 °C for 72 h. After drying, both samples were rough ground, and then fine ground to pass through a 1 mm sieve. TP was determined on 1 g of finely ground dried sample that was combusted at 550 °C in a muffle furnace for 4 h. The remaining ash was suspended in 3 M HCl (Andersen 1976) and filtered for the subsequent colorimetric analysis of SRP. TN in sediment and roots of macrophytes was determined by Kjeldahl digestion. In addition, 5 g of dried and grounded sediment sample were shaken with 100 ml of 2 M potassium chloride (KCl) solution for 1 h. Extract was filtered through Whatman GF/F filters and analyzed for sediment $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ + $N\text{-}NO_2^-$ concentrations using the methods described previously. Organic matter content in sediment (OM) was measured by loss on ignition (Dean 1974), where 5 g of dry sample was oxidized at 550 °C in a muffle furnace for 4 h. The preheating and postheating difference in weight represented the organic matter content of the samples. Data of air temperature and hydrometric level at the Paraná harbor gauge were provided by Centro de Información Meteorológica (Universidad Nacional del Litoral, Santa Fe, Argentina).

Statistical Analyses

Non-parametric Wilcoxon Signed-Rank Test for dependent samples was applied to evaluate changes in TP and TN concentration in water and sediment during the study period. A pairwise design was done taking account, in each case, two consecutive month samples and covering all the pairs of TP and TN concentration during presence/absence of cattle in each lake.

In order to evaluate differences in physical and chemical variables in water, sediment and macrophytes among periods of presence/absence of cattle, a pairwise Analysis of Covariance (ANCOVA) without interaction was performed for consecutive samples in each lake. Hydrometric level and air temperature were used as covariates for this analysis. Since the residuals of the model did not meet the assumption of normal distribution, a randomization test with 5000 permutations was conducted in order to estimate the significance of F values. In each permutation, an ANCOVA model was estimated, and the F values obtained were used to build pseudo-F distributions. The P values were estimated as the proportion of F values equal to or greater than the F values resulting of the application of the original ANCOVA model (Manly 2007; Benitez-Vieyra et al. 2012).

The cattle effect (presence/absence) in both lakes considering all variables together was analyzed by a nonparametric Multivariate Analysis of the Variance (npMANOVA). The test performs a one-way multivariate data for small samples, using F-approximations for Wilks' Lambda type. A randomization test with 5000 permutations was performed (NPMV package for R software). In addition, Canonical Discriminant Analysis plot (CANDISC, package for R software) was used to identify variations of physical and chemical variables in water, sediment and macrophytes according to the presence/absence of cattle in both lakes. The data were standardized to the mean and standard deviation. Data were log (x + 1) transformed before all analyses. All statistical analyses were done using R software.

Results

In Lake 1, the concentration of TN and TP in water were significantly higher during the presence of cattle (Wilcoxon test, $p<0.05$) (Fig. 2). However, nutrients in water of Lake 2 and sediment of both lakes did not show a defined pattern of monthly variation according with the presence/absence of cattle, increasing and decreasing their value in both situations (Fig. 2).

Mean values of chemical and physical variables in water, sediment and macrophytes during the presence and absence of cattle in both lakes are shown in Table 1. In general, Lake 1 was characterized by higher value of nutrients and organic matter, lower transparency and coverage of submerged vegetation in comparison with Lake 2. In Lake 1, SRP, TP and TN in water, and TP in roots of *Eichhornia* sp. were significantly higher during the presence of cattle (ANCOVA, $p<0.001$). Percentage of submerged vegetation was higher during cattle absence in this lake, in coincidence with an increase in pH. In Lake 2, mean values of $N\text{-}NH_4^+$ in water, TP in roots of *Ludwigia* sp. and *Eichhornia* sp. and percentage of submerged vegetation were significantly higher during the presence of cattle, whereas $N\text{-}NH_4^+$ in sediment and TN in *Ludwigia* sp. were higher during cattle absence ($p<0.05$). In addition, percentage of aromatic carbon of CDOM and water color increased during the presence of cattle in both lakes ($p<0.01$), whereas transparency decreases in this period (Table 1).

The effect of presence/absence of cattle in both lakes considering all variables in the period studied was tatistically significant (npMANOVA, Wilks Lambda: 11.913, $p<0.0001$). The first two axes of the CANDISC plot accounted for 85.4 % of the variance of environmental data (Fig. 3). Axis 1 (explained variation=51.7 %) showed differences among lakes: Lake 2 with higher conductivity and TP in sediment in the negative side of this axis vs. Lake 1 with higher water color, dissolved nutrients and TN in sediment in the positive side. The second axis (explained variation=51.7 %), showed the different effect of cattle on physical and chemical characteristics in each lake. This axis clearly differentiated samples of Lake 1: variables such as SRP, TP, TN in water and TP *Eichhornia* increased during the presence of cattle, whereas percentage of submerged vegetation and transparency increased during cattle absence. In contrast, no clear distinction of samples according with the influence of cattle was showed for Lake 2, determining their location in the center of this axis.

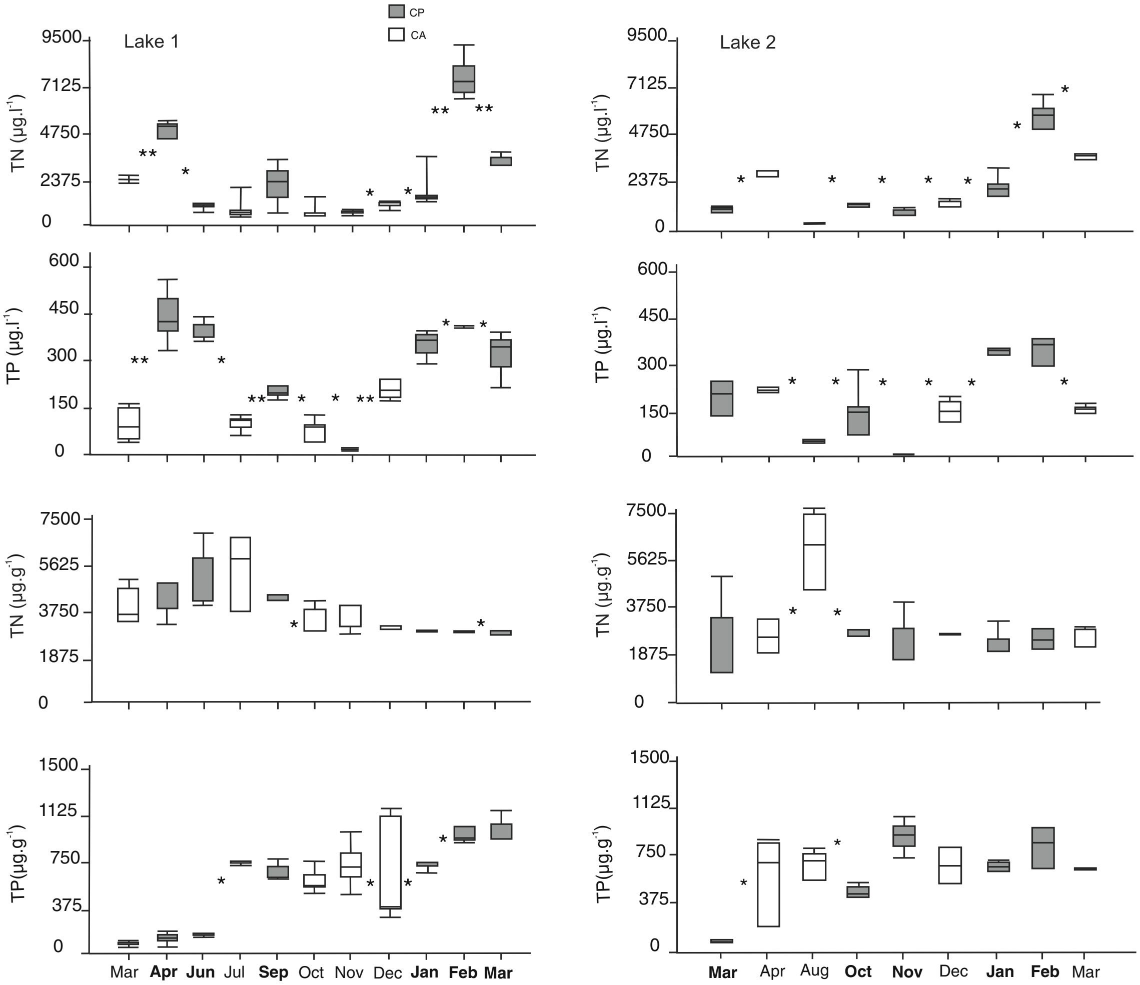


Fig. 2 Box plots showing monthly variations of TN and TP in water (μg.l^{-1}) and sediment (μg.g^{-1}) during cattle presence (CP, month is *bold*) and cattle absence (CA) in each lake, and results of Non-parametric Wilcoxon Signed-Rank Test used to compare mean values among successive months. *$p<0.05$; **$p<0.001$

Discussion

The results of this study showed a significant increase in water nutrients in lakes during the presence of cattle, decreasing during their absence. In accordance with our prediction, values of SRP, TP, TN in water and TP in roots of *Eichhornia* proved to be sensitive to the presence of cattle. Taking into account TP and TN levels, both lakes would be classified as eutrophic following the criteria for tropical and subtropical lakes (OECD 1982; Salas and Martino 1991; Huszar et al. 1998). Indeed, when cattle were present, TP, TN and SRP concentration in Lake 1 were between two and three times higher than those reported in other studies of wetlands of the Paraná river system (Pedrozo et al. 1992; Bonetto et al. 1994; Villar and Bonetto 2000; Unrein 2002; Maine et al. 2004; Devercelli et al. 2015). Pedrozo et al. (1992) found that values of TP ranged from 100 to 150 μg.l^{-1}, and values of SRP were lower than 50 μg.l^{-1} in a study of two lakes. Unrein (2002) reported mean values of TP of 100 μg.l^{-1}, and values of SRP of 50 μg.l^{-1} for a lake of the Lower Paraná River, whereas Devercelli et al. (2015) found that TN varied between 690 and 1500 μg.l^{-1} in isolate lakes of the Paraná River floodplain. In our study, concentration of TP and TN in water in Lake 1 during periods of cattle absence were similar than those reported in these works. Furthermore, changes in nutrient values in this lake according with the presence/absence of cattle occurred surprisingly rapid, suggesting a high resilience of wetlands of the Paraná River system to this impact. According to that, rotational management would minimize the increase of nutrients in water, maintaining the ecological integrity of wetlands. Rotational grazing allow cattle to be stocked in a zone for a time long enough to utilize forage, but short enough to minimize cattle impact, enabling the return of the wetland to the previous state before disturbance.

According to our direct observations in the field, cattle spend a considerable time grazing on riparian vegetation in the studied wetlands, and also get into the lakes to graze the leaves of macrophytes (preferentially *Ludwigia* sp). During

Table 1 Mean values (±) of chemical, physical variables, and organic matter in water, sediment and macrophytes, and results of Covariance Analysis (ANCOVA) without interaction used to compare periods of cattle presence (CP) and absence (CA) in each lake. Hydrometric level and air temperature were used as covariates for this analysis

	Lake 1			Lake 2		
	CP	CA	*P*	CP	CA	*P*
Water						
SRP (μg.l^{-1})	185 (127)	48.3 (26.1)	0.00	47.1 (31.6)	57.2 (31.6)	ns
TP (μg.l^{-1})	346 (92)	99.5 (85)	0.00	228 (152)	155 (75)	ns
N-NH$_4^+$ (μg.l^{-1})	260 (449)	270 (489)	ns	33 (64)	12 (18,8)	0.01
N-NO$_3^-$ + N-NO$_2^-$(μg.l^{-1})	149 (181)	319 (484)	ns	9.8 (15.5)	47.5 (50)	ns
TN (μg.l^{-1})	3424 (2324)	1194 (724)	0.00	2070 (1927)	2008 (1558)	ns
DO (mg.l^{-1})	4.6 (1.5)	5.3 (2.7)	ns	6.2 (2.3)	4.9 (2.5)	ns
DBO$_5$ (mg.l^{-1})	2.4 (1.6)	4.4 (3.7)	ns	3.2 (2.5)	2.2 (1.3)	ns
Chl-*a* (μg.l^{-1})	1.4 (2.2)	1.9 (2.4)	ns	3.3 (4.6)	1.8 (2.4)	ns
Pheo-*a* (μg.l^{-1})	2.5 (4.0)	3.5 (4.4)	ns	5.9 (8.3)	3.2 (4.3)	ns
WT (°C)	19.7 (5.7)	20.6 (5.3)	ns	23.6 (3.8)	20 (6.7)	ns
pH	7.2 (0.5)	7.6 (0.8)	0.001	7.8 (1)	7.4 (0.8)	ns
Cond (μS.cm^{-1})	82.6 (32)	71.2 (14)	ns	110 (25)	96.2 (20)	ns
Trans (cm)	37.2 (29)	54.4 (28)	0.00	66.1 (44)	84 (72)	0.02
%Car	22.8 (3.9)	16.2 (3.9)	0.00	18 (7.4)	9.3 (3)	0.00
Wcolor (Pt-Co units)	91.8 (40)	50.4 (20.3)	0.00	90.2 (71.4)	30.7 (6.2)	0.00
Sediment						
N-NH$_4^+$ (μg.g^{-1})	250 (230)	239 (203)	ns	139 (156)	216 (117)	0.02
N-NO$_3^-$ + N-NO$_2^-$ (μg.g^{-1})	14.8 (9.5)	12.1 (5.9)	ns	13 (5.4)	23.6 (21)	ns
TN (μg.g^{-1})	3760 (1028)	3928 (1123)	ns	2717 (815)	3551 (1739)	ns
TP (μg.g^{-1})	608 (367)	519 (331)	ns	535 (273)	676 (182)	ns
OM (%)	16.7 (5.6)	15.6 (5.8)	ns	12 (3.2)	12.7 (5.1)	ns
Macrophytes						
SubmV (%)	0	46 (44)	0.00	90 (46)	37 (43)	0.02
TP *Ludwigia* (μg.g^{-1})	2017 (913)	1882 (1086)	ns	2586 (554)	1335 (883)	0.00
TP *Eichhornia* (μg.g^{-1})	2220 (777)	1382 (449)	0.00	2112 (700)	1378 (717)	0.01
TN *Ludwigia* (μg.g^{-1})	13,733 (4121)	14,181 (8523)	ns	12,640 (5866)	20,800 (4706)	0.00
TN *Eichhornia* (μg.g^{-1})	18,450 (3634)	23,492 (10,705)	ns	20,280 (8819)	21,475 (2356)	ns

References: *DO* dissolved oxygen, *DBO_5* biologic oxygen demand, *Chl-a* clorophyll-*a*, *Pheo-a* pheophytin-*a*, *WT* water temperature, *Cond* conductivity, *Trans* transparency, *$\%C_{ar}$* percentage of organic carbon, *Wcolor* water color, *OM* organic matter in sediment, *SubmV* percentage of submerged vegetation (macrophytes and algae)

this period within the lakes, cattle defecate and urine several times, determining the incorporation of nutrients directly into the lakes. Runoff represents another mechanism that would increase the propensity of overland flow and the leaching of urine and feces deposited within riparian zones to shallow groundwater or into the lakes. Also, the increase of water level would determine the incorporation of manure deposited in the riparian zone into the aquatic zone.

Topography, area and depth play a central role in the resuspension of sediments in shallow lakes (Douglas Evans 1994; Bloesch 1995). The absence of trees in the riparian zone of Lake 1, added to its larger area, fetch and lower depth in comparison with Lake 2 would determinate a greater effect of wind on sediment resuspension, decreasing water transparency. The consequent light limitation for photosynthetic activity would explain the lower value of chlorophyll-*a* and percentage of submerged vegetation in Lake 1 in comparison with Lake 2. In addition, sediment resuspension would determinate the translocation of nutrients from sediment to the water column, increasing nutrient values in this lake. Cattle could also play a central role stimulating P and N release into water by resuspending nutrient-bound sediments as they walk within wetlands. Sediment resuspension by cattle trampling would explain the increase in the concentration of CDOM, through their effect on the movement of organic matter from sediment to the water. Furthermore, the composition of the

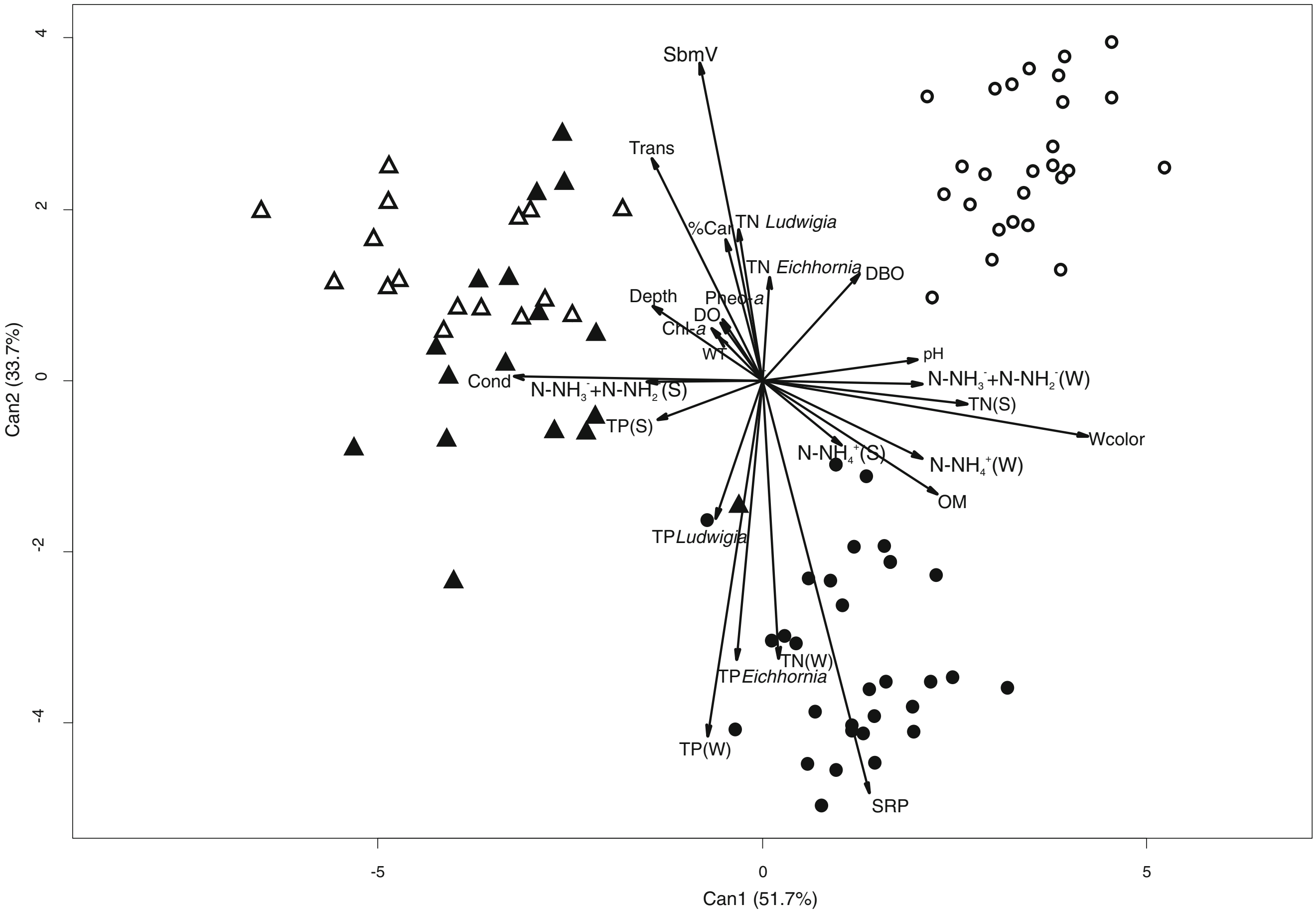


Fig. 3 Canonical Discriminant Analysis plot (CANDISC) of physical and chemical variables in water, sediment and macrophytes during periods of presence (*black* figures) and absence (*white* figures) of cattle in Lake 1 (*circles*) and Lake 2 (*triangles*). References: *DO* dissolved oxygen, *DBO* biologic oxygen demand, *Chl-a* chlorophyll-*a*, *Pheo-a* pheophytin-*a*, *WT* water temperature, *Cond* conductivity, *Trans* transparency, *%Car* percentage of aromatic carbon of dissolved organic matter, *Wcolor* water color, *OM* percentage of organic matter in sediment, *SubmV* coverage of submerged vegetation (macrophytes and algae) in each lake, *(S)* nutrients in sediment, *(W)* nutrients in water

manure, characterized by slightly degraded organic matter, would determine the increase in the concentration of CDOM of high molecular weight and aromaticity, increasing water color (Steinberg 2003). The increase in this variable, on the other hand, would facilitate the maintenance of phosphorous compounds in the water column due to the formation of complexes with humic substances, which constitute a significant fraction of the CDOM (Nürnberg and Shaw 1999; Webster et al. 2008).

In accordance with the high values of TN and TP in water reported in both lakes, concentration of N-NO_3^- + N-NO_2^- and N-NH_4^+ in water in Lake 1 were higher than those reported to isolated lakes of the Paraná River system (from undetectable to 100 μg.l^{-1}, Pedrozo et al. 1992; Bonetto et al. 1994; Villar et al. 1998; Unrein 2002; Maine et al. 2004; Devercelli et al. 2015). In contrast, in Lake 2, mean values of N-NO_3^- + N-NO_2^- and N-NH_4^+ in water were low in comparison with those values expected for eutrophic and hypereutrophic lakes (Quirós 2003). The higher coverage of submerged vegetation in this lake in comparison with Lake 1, and its effect on sediment resuspension and nutrient absorption would explain these results. Submerged macrophytes and algae may substantially prevent sediment resuspension and erosion by wind in Lake 2, thus reducing the concentration of inorganic nutrients in the water (Horppila and Nurminen 2005). Furthermore, submerged vegetation in this lake would ameliorate the translocation of nutrients from sediment to the water column by cattle trampling, determining the lack of a significant increase in nutrients during their presence. In addition, nutrient uptake by submerged macrophytes and algae could play a central role in nutrient cycling, especially in small, shallow lakes (Scheffer and van Nes 2007; Søndergaard et al. 2010). This vegetation can use their shoots and roots effectively for nutrient uptake from the water column and sediment (Sculthorpe 1967; Robach et al. 1996) and by various mechanisms could cause depletion of dissolved nutrients in the water column to below detection levels (Goulder 1969; Van Donk et al. 1993). In addition, emergent and free floating macrophytes could also play a central role in nutrient absorption in Lake 2. The increase in TP in roots of *Eichhornia* sp. and *Ludwigia* sp.

during the presence of cattle is in accordance with our expectations. In water-treatment systems water hyacinth have been found to remove up to 60 % of the incoming phosphate (Reddy et al. 1999; Zhang et al. 2010). Unlike free floating macrophytes, rooted macrophytes such as *Ludwigia* sp. are less dependent on nutrients in the water column as they may take up a large part of their nutrients from the sediment (Hutchinson 1975; Chambers et al. 1989). Therefore, the increase in TN in *Ludwigia* sp. during periods of cattle absence in Lake 2 could be explained by an increase of N-NH_4^+ in sediment, since it is the most bioavailable form of N for plant growth.

In the Middle Paraná River floodplain, it is difficult to find examples of environments without the impact of cattle, given the duration and extent of alterations that have occurred in this system as a consequence of this activity. Whereas cattle play an important economic and social role in this region, it is unlikely to be eliminated as an anthropogenic disturbance. Rotational management would enable the recuperation of wetlands, minimizing the impacts on the aquatic system. Furthermore, the effect of cattle on water nutrient was conditioned to the presence of submerged vegetation in lakes, playing a central role ameliorating this impact. We suggest to study the effect of this grazing strategy in others wetlands of the Paraná River floodplain in order to increase the representativeness of our conclusions to propose general statements. However, we consider that experimental testing is necessary in order to determine if longer periods of cattle absence could enhance their trophic state. Therefore, we recommend applying specific techniques to evaluate cattle behavior in order to gain knowledge in the management of cattle according with the use of natural resources.

Acknowledgments We are grateful to Esteban Creus, Cristian Debonis, Marcelo Piacenza and Germán Pochettino for their field assistance and to Alicia Loteste and Graciela Paporello for laboratory analyses. Special thanks to Dr. Carlos Bonetto, Dr. Mercedes Marchese and Dr. Adonis Giorgi for their useful comments. This research was supported by Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Secretaría de Ciencia, Tecnología e Innovación (Santa Fe, SECTeI 2012) and Agencia Nacional de Promoción Científica y Tecnológica (PICT 2012 N°0906).

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