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Limnology of a lateral lagoon system connected to a Neotropical reservoir (Rosana reservoir, São Paulo/Paraná, Brazil)

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ABSTRACT. The aim of this work was to perform a comparative analysis of four lateral lagoons and of the main channel of the Rosana Reservoir (Paranapanema river), southeast Brazil. The fieldwork was conducted during dry and rainy periods of 2004 and 2005. The analyzed variables were chlorophyll *a*, turbidity, total phosphorus, total nitrogen, dissolved nutrients (ammonium, nitrate, nitrite, phosphate and silicate), Secchi disk transparency, suspended solids, temperature, pH, dissolved oxygen and electrical conductivity. Intense summer rainfall provided a high input of allochthonous material into the system, resulting in conspicuous changes - high turbidity and nutrient concentrations and low transparency, especially in the reservoir channel. The cluster analysis showed a clear segregation between the reservoir sampling site and the lagoons. The results evidenced the strong influence of regional factors on the limnological structure and functioning of these environments. The alternation between dry and rainy periods changes significantly the characteristics of the main channel and lagoons, mainly due to the contribution of tributaries. Spatially, the system exhibited a remarkable limnological variability. This shows the need to consider these distinct habitats in regional conservation strategy, presently focused on terrestrial habitats.

Keywords: floodplain, nutrients, Paranapanema river, limnological variables, spatial variability, eutrophication.

Limnologia de um sistema de lagoas laterais conectadas a um reservatório Neotropical (reservatório de Rosana, Estado de São Paulo/Paraná, Brasil)

RESUMO. O objetivo desse estudo foi realizar uma análise comparativa de quatro lagoas laterais e do canal principal do reservatório de Rosana (rio Paranapanema, Brasil). O trabalho de campo foi realizado no período de setembro e novembro de 2004 e janeiro, março, maio e agosto de 2005. As variáveis analisadas foram clorofila *a*, turbidez, fósforo e nitrogênio total, nutrientes dissolvidos (amônio, nitrato, nitrito, fosfato e silicato), transparência do disco de Secchi, sólidos em suspensão, temperatura, pH, oxigênio dissolvido e condutividade elétrica. As chuvas de verão forneceram grande quantidade de material alóctone ao sistema, o que resultou em mudanças conspícuas - elevada turbidez e altas concentrações de nutrientes, e diminuição da transparência, especialmente no canal do reservatório. A análise de agrupamento mostrou clara a distinção entre o ponto do reservatório e as lagoas laterais. Os resultados evidenciaram a forte influência dos fatores regionais para a estrutura e funcionamento limnológico desses ambientes. A alternância entre períodos de seca e chuva muda significativamente as características do canal do reservatório e das lagoas, principalmente pela contribuição dos rios tributários. Espacialmente, o sistema apresentou uma notável variabilidade limnológica. Isso demonstra a necessidade de se considerar estes habitats em estratégia de conservação regional, focada atualmente nos ecossistemas terrestres.

Palavras-chave: lagoas marginais, nutrientes, rio Paranapanema, variáveis limnológicas, variabilidade espacial, eutrofização.

Introduction

The presence of lateral habitats associated with large rivers and reservoirs has a major influence on the whole system, due to their high productivity, prominent role in the nutrient dynamics and maintenance of trophic resources and regional biodiversity (NEIFF, 2001). These attributes are directly related to the fact that these environments are zones of intense interactions (ecotones) with terrestrial ecosystems, receiving significant inputs of organic detritus, which change seasonally due to the phenological cycles of the marginal vegetation, and supporting complex biological communities (DOMITROVIC, 2002; JOSÉ DE PAGGI; PAGGI, 2008; MITSCH, 1996; WARD et al., 1999; NAIMAN et al., 1988).

Lateral compartments in large Brazilian reservoirs, such as lagoons and river mouths, favors the development of large stands of aquatic macrophytes.

These plants can absorb and store nutrients available in the water column during periods of biomass increase. However, during periods of senescence, the intense decomposition process promotes the return of the nutrients to the water column (BARBIERI; ESTEVES, 1991; POMPÊO; HENRY, 1998; THOMAZ et al., 2006). Lateral lagoons can also minimize the reservoirs aging process. These adjacent systems act as sediment traps (or filters), with the retention of soil particles transported along the basin (HENRY, 2009). Therefore, the preservation of these environments contributes to the maintenance of water quality and biotic resources in reservoir ecosystems.

Hydropower generation from dammed rivers is the main electrical energy source in Brazil and studies considering the effects of reservoirs structure and functioning on limnological compartmentalization have been performed (HENRY; MARICATTO, 1996; NOGUEIRA et al., 1999, 2012; PAGIORO; THOMAZ, 2002; SOARES et al., 2008). The emphasis is given on longitudinal changes and there is still a lack of information about the role of the lateral dimension, especially the effects of lagoons, river mouths and other adjacent habitats.

The focus of this work is to reinforce the evidences that lateral lagoons of the Rosana Reservoir are distinct limnological environments, which add structural and functional complexity to the reservoir channel and contribute to support diverse biotic communities, as previously demonstrated for fish (FERRAREZE; NOGUEIRA, 2011a), zooplankton (FERRAREZE; NOGUEIRA, 2011b) and phytoplankton (FERRAREZE; NOGUEIRA, 2013). The results of the investigation can subsidize the improvement of the management capacity of the reservoir, especially in terms of conservation and multiple uses.

Material and methods

Study area

The study was conducted in the upper stretch (tail zone) of the Rosana reservoir (State of São Paulo/State of Paraná, Brazil), which is located in the low Paranapanema river, 25 km from the confluence with the Paraná river (Figure 1).

This is the last in a cascade of eleven reservoirs constructed along the river for hydropower generation. Additional information on the limnology of this series of reservoir is provided by Nogueira et al. (2008, 2010, 2012), Naliato et al. (2009) and Perbiche-Neves et al. (2011).

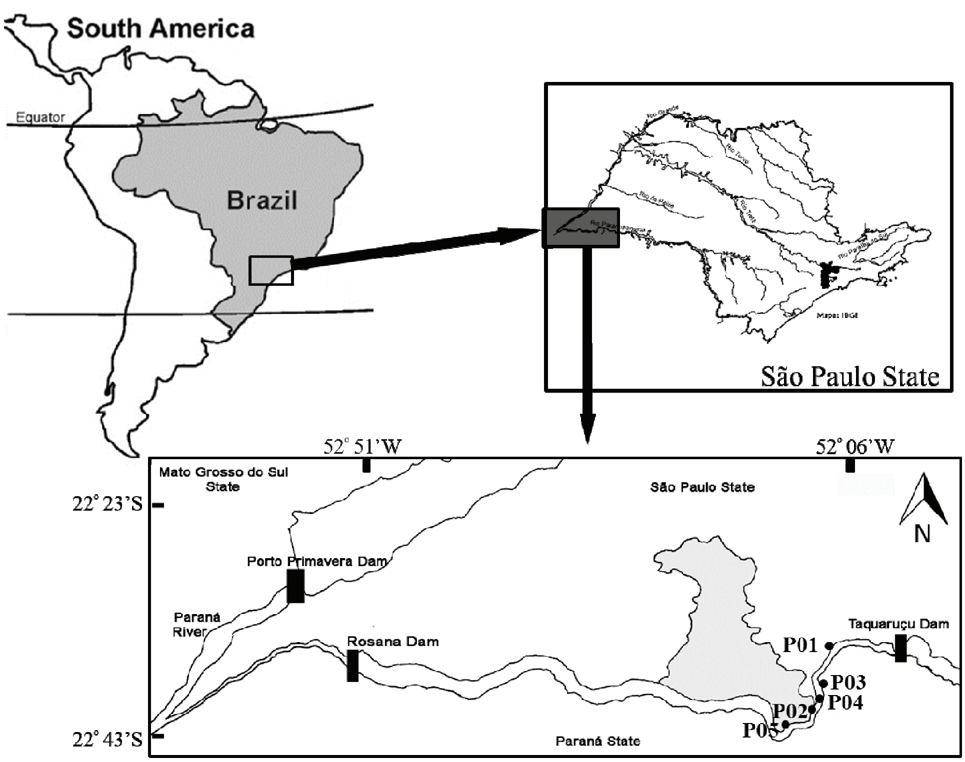

Figure 1. Study area in the region of the confluence of the Paraná and Paranapanema rivers (States of São Paulo/State of Paraná, and State of Mato Grosso do Sul), showing the location of Rosana, Taquaruçu and Porto Primavera dams, the State Park of Morro do Diabo (gray area), and the location of the sampling sites.

The dam is located at 22º 36'S e 52º 52'W, the reservoir area is 276 km^2, corresponding to a drainage basin of 11,000 km^2, it is relatively shallow (max. depth of 30 m) and the water retention time is about 21 days.

The regional climate can be characterized by a dry season during autumn and winter, gradual return of rainfall in spring and intensive rainfall in summer. Another remarkable regional characteristic is the presence of a significant large conservation area of Atlantic Rain Forest, the State Park of Morro do Diabo (33,845 ha), adjacent to the right margin of Rosana Reservoir.

After the dam construction, the studied lagoons remain connected permanently to the river-reservoir, despite the wide variation of connection of each individual lagoon (mouth) with the main channel (Table 1).

Sampling and analyses

The fieldwork was carried out during the dry (September/2004, May and August/2005) and rainy (November/2004 and January, March/2005) periods. Data were simultaneously (on the same day) collected at five sampling sites: four lateral lagoons, named lagoons A, B, C and D and one site in the main channel of the Rosana Reservoir - Paranapanema River. Lagoons A, B and D are located in the right margin and lagoon C in the left margin of the reservoir. Table 1 lists the coordinates of the sampling sites, denomination of the sites in an upstream → downstream sequence, dominant macrophytes as well as the lagoons area and their connectivity area with the reservoir channel - mean values of the lagoons opening (aperture) considering the different sampling periods.

Daily rainfall data along the studied period were provided by the meteorological station of the State Park of Morro do Diabo, located in municipality of Teodoro Sampaio, São Paulo State, Brazil.

In the central zone (limnetic zone) of each lagoon and in the reservoir channel, it was determined vertical profiles (measurements at every 0.5m from the surface to the bottom) of temperature, dissolved oxygen, conductivity and pH, using a daily calibrated Horiba probe (U-22). The transparency was estimated through the readings of the Secchi disk (30 cm in diameter) (WETZEL; LIKENS, 1991). Due to the reduced depth of the lagoons (between 1.5 and 4.5m), and relatively shallowness (maximum of 9m) and predominance of high turbulence at the reservoir channel sampling site, samples for analysis of turbidity, chlorophyll *a*, nutrients (total and dissolved) and suspended solids were obtained only under the water surface (ca. 1.0 m depth).

Turbidity was measured using a MSTecnopon digital equipment (0 to 1000 NTU; accurate to 2 NTU). To determine chlorophyll *a* concentration, it was filtered (vacuum system) a volume of 500 mL, followed by cold acetone (90%) extraction, manual maceration of the filters (Millipore AP40; pore size of 0.7 μm) and posterior spectrophotometer reading and calculation (GOLTERMAN et al., 1978, modified by WETZEL; LIKENS, 1991). Total nitrogen (MACKRETH et al., 1978) and phosphorus (STRICKLAND; PARSONS, 1960) were measured in unfiltered samples, after physical and chemical digestion (VALDERRAMA, 1981).

Dissolved nutrients were obtained using filtered samples (Millipore AP40). Ammonium was determined by Koroleff (1976) method; nitrite and silicate by Golterman et al. (1978); nitrate by Mackreth et al. (1978) and total (after digestion), inorganic and organic (difference between total and inorganic) phosphate by Strickland and Parsons (1960). Suspended solids (total particulate solids) were determined by gravimetry (COLE, 1979), using samples of 500 mL and Millipore AP40 filters previously dried (1 hour at 450ºC) and weighed. Back to laboratory, the filters were dried (24h at 65ºC) and weighed again.

Table 1. Sampling sites, geographical location, lagoons surface area, main aquatic macrophytes and connectivity area (mouth area) of each lagoon with the reservoir channel.

Sampling sites	Geographical coordinates	Area (km^2)	Dominant macrophytes	Connectivity (m^2)
Lateral lagoon A (P01)	22º 34' 03.3"S / 52º 09' 11.4"W	0.110	*Tipha dominguensis*, *Eichhornia azurea*, *Brachiaria* spp., *Pontederia chordata* and *Salvinia* sp.	50
Lateral lagoon B (P02)	22º 36' 56.5"S / 52º 09' 47.3"W	0.024	*Eichhornia azurea*, *Brachiaria* spp., *Pontederia chordata*, *Salvinia* sp., *Pistia* sp., *Egeria* spp. and *Nymphaea* sp.	6.5
Lateral lagoon C (P03)	22º 37' 28,9"S / 52º 09' 21.1"W	0.721	*Eichhornia azurea, Brachiaria* spp., *Pontederia chordata*, *Salvinia* sp. and *Egeria* spp.	525
Paranapanema River (P04)	22º 37' 51.6"S / 52º 09' 30.5"W	-	*Tipha dominguensis*, *Eichhornia azurea*, *Eichhornia crassipes*, *Brachiaria* spp., *Pontederia chordata*, *Salvinia* sp and *Pistia* sp.	-
Lateral lagoon D (P05)	22º 38' 22.0"S / 52º 09' 29.0"W	0.063	*Eichhornia azurea*, *Brachiaria* spp., *Pontederia chordata*, *Salvinia* sp., *Pistia* sp. and *Nymphaea* sp.	60.2

Results are presented as mean values and respective standard deviations, in order to facilitate comparisons between sampling sites (spatial dimension) as well as to provide the magnitude of the temporal (seasonal) variation.

In order to detect similarities between sampling sites it was run a cluster analysis using Pearson-r correlation (Statistic 5.0; STATSOFT, 2001). A principal components analysis (PCA) was also applied, maintaining the discrimination between the sampling periods, with data previously standardized (log x+1, except pH). For both multivariate analyses, it was used the mean values for variables measured along vertical profiles. From PCA analysis, resulting loading and score plots were derived. The differences between the bouquets were tested by Monte Carlo permutation test using redundancy data analysis (PCord 4.1 for Windows; MCCUNE; MEFFORD, 1999).

Finally, the differences between the mean values of the analyzed variables, spatial (reservoir channel versus lagoons) and temporal (dry versus rainy periods), was verified through a Two-way ANOVA (Factor 1: sites; Factor 2: periods). When differences were detected, the Tukey test was used to determine the level of significance. The differences were considered significant for values of $p < 0.05$. Previously, data normality and homoscedasticity was checked by Shapiro-Wilk and Levene tests, respectively. For temporal comparisons, data were pooled into two sets, representing the rainy (September, November and January samplings) (spring-summer) and dry (March, May and August samplings) (autumn-winter) periods. These tests were performed using StatisticaTM 6.0 (STATSOFT, 2001).

Results

During the study period the cumulative annual rainfall was 1,207 mm, with the typical regional pattern of seasonality, maximum rainfall in January (summer), 370 mm, and minimum in August (winter), 12 mm (Figure 2).

Mean values for the water column of pH, dissolved oxygen, temperature, conductivity, transparency (Secchi Disc) and turbidity are presented in Table 2. In general, pH values were higher in the lagoons than in the reservoir channel ($p = 0.003$). Seasonally, the values were slightly acidic during the rainy period and basic during the dry period ($p = 0.001$). The dissolved oxygen concentrations were higher in the reservoir channel than in the lagoons ($p < 0.001$). Higher values were observed during the dry period (autumn/winter), due to the positive influence of lower temperatures. Transparency (Secchi disk) was higher in the lagoons than in the reservoir channel ($p = 0.03$) and the opposite was found for turbidity, higher in the reservoir channel ($p < 0.001$). Due to the input of allochthonous material, the rainy period exhibited lower transparency ($p < 0.001$) and a higher turbidity ($p < 0.001$). The water temperature was higher in the lateral lagoons compared to the reservoir channel ($p = 0.02$). Seasonally, lower values were verified during the dry period ($p < 0.001$). Conductivity values were higher in the lateral lagoons, especially due to the influence of lagoons C (P03) and D (P05), compared to the reservoir channel (P04) ($p = 0.04$). Temporally, lower values were observed during the dry period ($p = 0.03$).

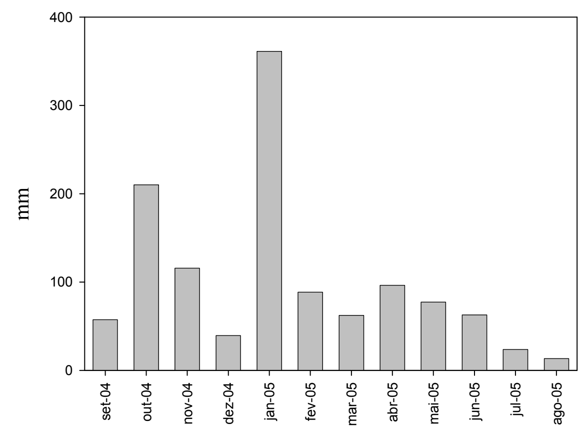

Figure 2. Rainfall in the study area during the sampling period.

In general, the chlorophyll *a* values were relatively low, with mean values inferior to 4 μg L^{-1} (Figure 3a). Among the sampling sites, values were higher in the lateral lagoons, especially in lagoons A (P01) and D (P05), than in the reservoir channel (P04) ($p = 0.01$). For all sites, the values in the dry season were lower than in the rainy season ($p < 0.001$). The suspended solids concentration was higher in the reservoir channel compared with lateral lagoons ($p = 0.01$) (Figure 3b). Higher variability was also observed in the river, as indicated by the standard deviation range. Seasonally, higher values of suspended solids were observed in the rainy period ($p < 0.001$).

Total nitrogen (Figure 4a) and total phosphorus (Figure 4b) exhibited a similar trend of variation. Among the sampling sites, higher values of total nitrogen and total phosphorus were observed in the reservoir channel ($p = 0.02$ and $p = 0.3$, respectively). Seasonally, the concentrations of these nutrients were higher in the rainy period ($p < 0.001$).

Table 2. Mean values (between depths) (except for Secchi disk transparency) of limnological variables measured at the different sampling sites and periods.

	pH						Dissolved oxygen (mg L^{-1})						Temperature (ºC)					
	Sep 4	Nov 4	Jan 5	Mar 5	May 5	Aug 5	Sep 4	Nov 4	Jan 5	Mar 5	May 5	Aug 5	Sep 4	Nov 4	Jan 5	Mar 5	May 5	Aug 05
P01	7.2	7.5	6.2	6.6	7.3	6.1	8.7	6.5	6.2	8.4	6.2	8.0	23.0	25.5	27.2	27.6	25.4	22.2
P02	7.3	6.6	6.3	6.6	7.3	7.6	8.6	7.7	6.3	5.0	9.5	8.3	22.1	25.5	27.1	27.4	25.3	22.4
P03	7.2	6.3	5.9	6.5	7.2	7.6	9.7	8.0	5.9	5.2	10.0	9.0	20.8	25.7	26.9	27.2	25.2	22.1
P04	7.2	6.2	5.2	6.4	6.9	7.2	9.6	7.8	6.0	6.4	9.2	12.0	20.5	25.2	27.1	26.9	24.6	22.4
P05	7.4	6.2	5.5	5.9	7.0	7.1	8.8	7.6	5.4	9.2	13.2	12.0	21.0	25.6	27.0	27.3	25.2	22.5

	Conductivity (μS cm^{-1})						Transparency (m)						Turbidity (NTU)					
	Sep 4	Nov 4	Jan 5	Mar 5	May 5	Aug 5	Sep 4	Nov 4	Jan 5	Mar 5	May 5	Aug 5	Sep 4	Nov 4	Jan 5	Mar 5	May 5	Aug 05
P01	46	70	70	70	48	64	2.8	1.5	0.4	1	2	3.5*	8.2	36.7	52.4	17.3	15.1	9.0
P02	70	70	70	70	44	64	2.3	1.6	0.1	0.8	2.2	2.8*	4.5	33.4	40.2	12.3	7.4	4.2
P03	90	80	90	80	80	65	2.2	1	0.2	1	2.7	3*	5.1	55.1	83.4	14.0	7.8	6.0
P04	60	70	70	70	52	65	2.1	1.3	0.1	0.7	2.2	5.8*	5.1	98.0	135.5	20.3	6.5	5.7
P05	60	70	90	80	85	65	2.7	1.9	0.2	1	2.5	3.5*	5.0	94.7	140.0	21.0	6.9	5.8

*bottom.

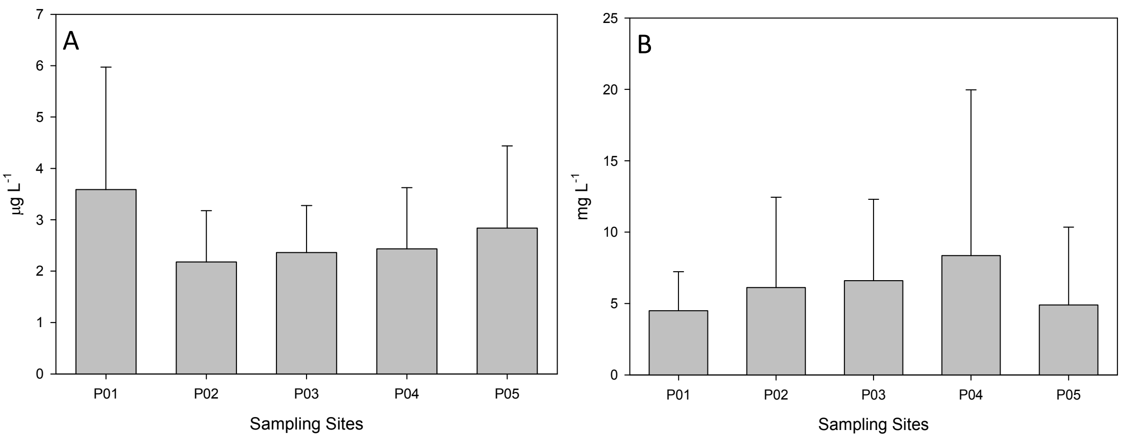

Figure 3. Mean and standard deviation of chlorophyll *a* (a.) and suspended solids (b.) in the different sampling sites during the study period.

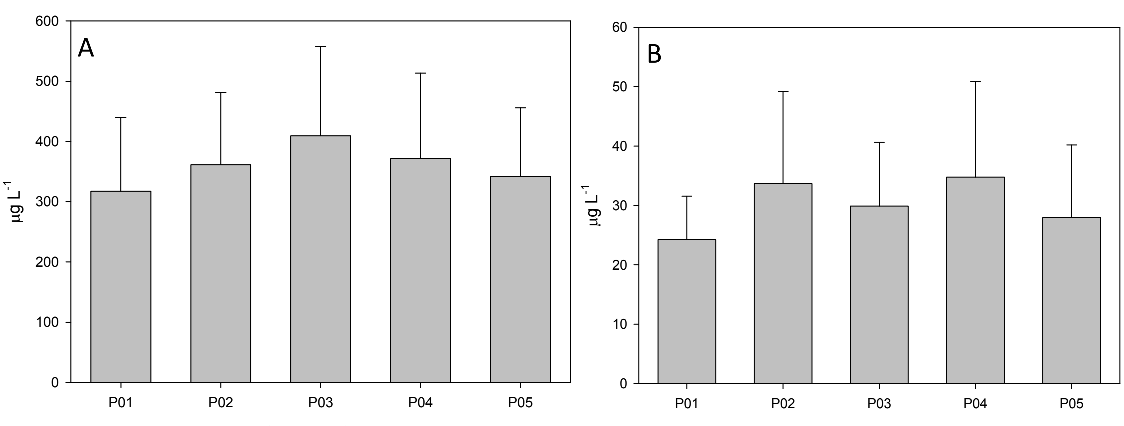

Figure 4. Mean and standard deviation of total nitrogen (a.) and total phosphorous (b.) in the different sampling sites during the study period.

Nitrate values were higher in the reservoir channel than in the lateral lagoons ($p = 0.03$) (Figure 5a). Seasonally, the values were higher in the dry period ($p < 0.001$). For nitrite, there was an opposite trend, with higher values in the lateral lagoons ($p = 0.04$) and in the rainy season ($p < 0.001$) (Figure 5b). High values of ammonium were registered in the reservoir channel ($p = 0.04$) (Figure 5c). Seasonally, the dry period showed lower values of this nutrient ($p < 0.001$).

Total dissolved phosphate (Figure 6a), and its inorganic (Figure 6b) and organic (Figure 6c) fractions, exhibited an increase during the rainy period ($p < 0.001$). The reservoir channel showed higher values of these nutrients compared with lagoons ($p < 0.001$).

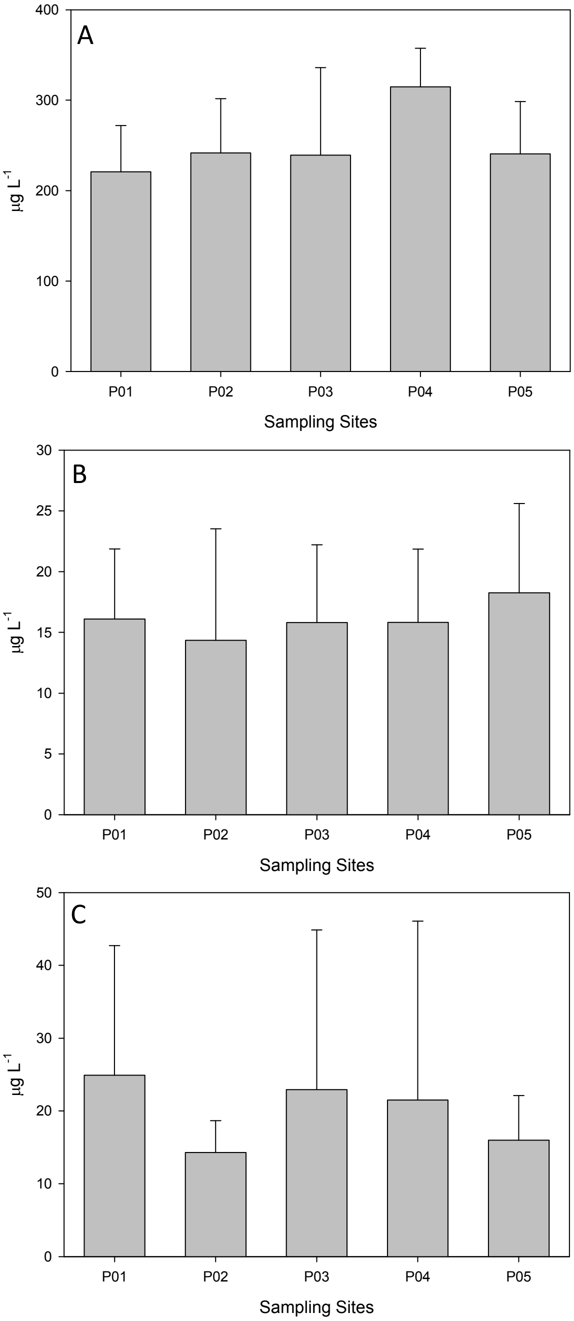

Figure 5. Mean and standard deviation of nitrate (a); nitrite (b) and ammonium (c) in the different sampling sites during the study period.

The concentration of silicate was higher in the reservoir channel than in the lagoons ($p = 0.01$) (Figure 7). However, the seasonal variation was different from the other dissolved nutrients. This nutrient showed a higher concentration during the dry period ($p < 0.001$).

Limnological differences between the sampling sites were evidenced by the similarity analysis (Figure 8). The reservoir channel (P4) was the most distinct sampling site, contrasting with the lagoons. This analysis also showed that the P3, with the highest mouth area to the reservoir channel, exhibited a higher similarity with the reservoir channel sampling site as well as more distinct limnological features in relation to the other lagoons.

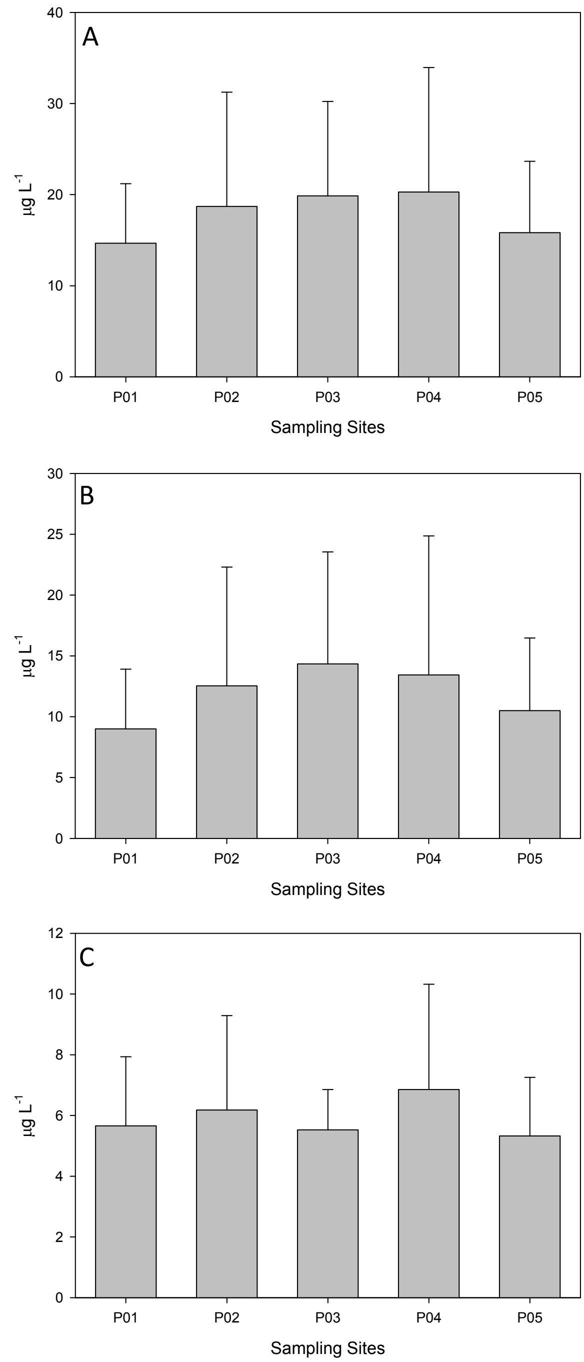

Figure 6. Mean and standard deviation of total dissolved phosphate (a); dissolved inorganic phosphate (b) and dissolved organic phosphate (c) in the different sampling sites during the study period.

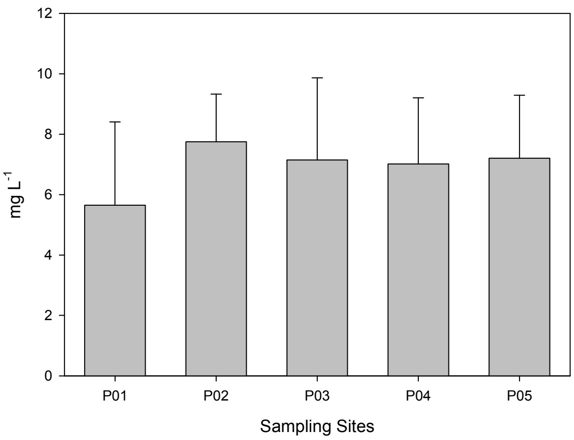

Figure 7. Mean and standard deviation of dissolved silicate in the different sampling sites during the study period.

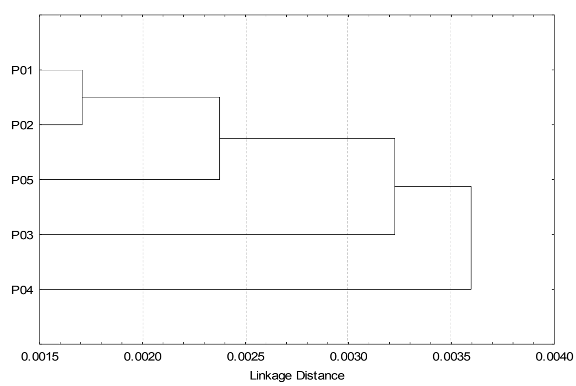

Figure 8. Similarity analysis of the different sampling sites according to limnological variables.

The PCA (Figure 9; Table 3) explained 84% of data variability ($p = 0.01$), considering the first two ordination axes (axis 1 = 73%, axis 2 = 11%). This analysis clearly evidenced the seasonal influence on the sampling sites ($p < 0.0001$). On the positive side of the axis 1 were located the sites sampled in September 2004, May and August 2005, associated with high pH values, high concentration of dissolved oxygen and high transparency ($r > 0.4$).

On the negative side of the axis, were located most sampling sites of November 2004 and January and March 2005, associated with high turbidity, high concentration of suspended solids ($r > 0.4$). On the positive side of the axis 2 were located the sites sampled in March, May and August 2005, associated with higher concentration of ammonium ($r > 0.4$), while on the negative side were located the sites of September and November 2004 and January 2005, with high concentrations of total phosphorus, total dissolved phosphate, dissolved inorganic phosphate and dissolved silicate ($r > 0.4$). Seasonal changes (increase of rainfall and increase of nutrients carried into the system) constituted the major environmental force influencing the variability of limnological conditions. Spatially, the discrimination between the reservoir channel and lagoons was evidenced in the most contrasting periods – late dry season (September) and, especially, in the peak of the rainfall period, January. In this last occasion the reservoir channel was clearly associated with higher nutrient concentrations and high turbidity (negative side of the axis 1).

Table 3. Correlations of limnological variables with the main components 1 and 2 (PCA analysis).

Variable	r (axis1)	r (axis 2)
Ammonium	-0.1281	0.3959
Total phosphorus	-0.1436	-0.4431
Total dissolved phosphate	-0.1907	-0.3967
Dissolved inorganic phosphate	-0.2616	-0.5664
Dissolved silicate	0.0242	-0.3962
pH	0.6422	0.0177
Dissolved oxygen	0.3964	-0.0053
Transparency	0.4002	-0.0383
Turbidity	-0.4466	0.2328
Suspended solids	-0.4548	0.1951
Inorganic solids	-0.4471	0.2499

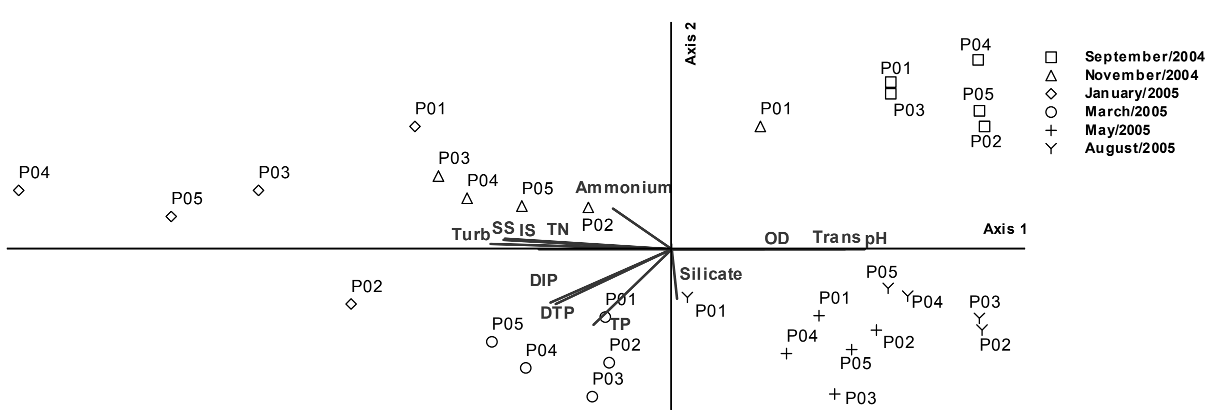

Figure 9. Ordination of the principal components analysis (PCA) showing the distribution of the sampling sites in the different sampling periods, according to limnological variables.

Discussion

The variability of limnological variables, especially nutrient concentrations, in the lateral lagoons of Rosana Reservoir was lower than the observed in the river/reservoir channel. This is probably related to the fact that lateral environments are less affected by 'pulses' of changes produced by intense rainfall, seasonally or during isolated (storm) events.

The reservoir exhibited higher concentrations of nutrients and lower values of transparency and temperature compared with the lagoons. The conditions in the reservoir channel are directly influenced by the input of the main tributary rivers, whose mouths are located upstream (ca. 13 km). High loads of allochthonous material flow into the superior region of the reservoir, especially from the rivers Pirapó (coming from Paraná State) and Pirapozinho (from São Paulo State), mainly during the rainy period. These inflows correspond to the main nutrient source for the Rosana Reservoir (FERRAREZE et al., 2006). During storm events the rivers inflow change immediately the limnological conditions of the upstream zone of the reservoir.

Despite the high abundance of aquatic macrophytes in the lateral lagoons, nutrients originated from the decomposition of the plants seem to have a secondary role in the biogeochemical cycles of the studied environment. Probably because in that region there is no typical and seasonal decaying period, and the plants are found all over the year (field observations).

In undammed rivers, the seasonal flood pulses promote a strong homogenization between the main River and lateral areas during the overflow period. The increase of the connectivity between the lateral lagoons and the main river can potentiate the flow of organisms and mineral material (STRIPARI; HENRY, 2002; THOMAZ et al., 2007; WARD, 1989; WARD et al., 1999). Lateral lagoons can receive inorganic nutrients from the river and export organic material (JUNK et al., 1989). Local and regional variability of the limnological factors is reduced by the increase of water levels, when there is a dominance of fluvial conditions (AGOSTINHO et al., 2000; THOMAZ et al., 2006). Nevertheless, the results obtained in the present study do not confirm this hypothesis, as the segregation between the different sampling sites was higher during summer (rainy season) compared to the winter (dry season) (PCA analysis). This is probably because the studied system is strongly influenced by the reservoir cascade located upstream, which attenuates the summer pulse effect (NOGUEIRA et al., 2008, 2010).

The increase of the water level in Rosana Reservoir does not follow, necessarily, the regional precipitation cycle, due to the dam operational control. This is a run-off-the river reservoir with short water retention time (NOGUEIRA et al., 2012). Thus, the increase of flow with rain events may not be strong enough to cause the homogenization between the reservoir channel and lateral environments. Some studies demonstrate that the influence of regional processes is significant only when the pulse generates a water level increase above 3.2 m (THOMAZ et al., 1997; VERÍSSIMO, 1994). Therefore, in regulated river stretches with moderate level variation the pulse effect would not be so influent and local processes (local precipitation, resuspension of sediments, nutrient cycles and decomposition of aquatic macrophytes) would be the main factors influencing the limnological functioning (THOMAZ et al., 2006). Another interesting hydrodynamic factor, not properly investigated, is the effect on lateral habitats of pronounced daily fluctuation of flow, downstream of dams, because of peaks of energy production/consumption along 24 hour periods. In case of the studied river stretch, the flow can vary from 500 to 1500 $m^3 s^{-1}$ in less than 12 hours (NALIATO et al., 2009).

The effects of seasonality on limnological variables (reduction of Secchi depth and increased turbidity) were clearly observed, especially in the river sampling site. In general the conductivity values were higher in the rainy period, probably due to the overall increase in nutrients and lower pH, mainly in the lagoons.

Furthermore, the increase of chlorophyll *a* and transparency during the dry period is a common pattern for large rivers and lakes of tropical/subtropical floodplains (BONETTO, 1986; CARVALHO et al., 2001; GARCIA DE EMILIANI, 1990; NEIFF, 1990; WELCOME, 1986). However, in the present study the increase in values of chlorophyll was associated with the reduction of transparency. The input of allochthonous nutrient in the river/reservoir and lagoons (FERRAREZE; NOGUEIRA, 2013) enables the increase in phytoplankton abundance and consequently the transparency decline. This pattern was previously verified for the Paranapanema River reservoir cascade and lotic stretches during summer (FERRAREZE; NOGUEIRA, 2006; NOGUEIRA et al., 2010), due to the growth of phytoplankton groups more tolerant to low light penetration, such as Cryptophyceae and Pennales (MINEEVA et al., 2008; REYNOLDS et al., 2002).

Besides that, the increase in the suspended solids during summer is explained by the entrance of external material originated from the drainage basin, as previously mentioned. This sediment input from the watershed also explains the increase of total nitrogen and total phosphorus. The increment rate of these nutrients was not proportional to the suspended solids. Probably, this is related to the type of soil of the basin, which is predominantly oligotrophic. In this region, the traditional land use is the extensive cattle breeding or familiar, low-scale agriculture with limited addition of industrial fertilizers.

The concentrations of ammonium were higher in summer, under lower oxygen concentrations. This suggests that ammonium is produced by the mineralization (ammonification) of the organic components from particulate and dissolved materials, probably exported from lagoons. Nitrate was the main nitrogen compound in the lagoons, due the permanent oxidation condition of the water column. The maximum values in the nitrite and nitrate, in addition to the allochthonous contributions, may also have been influenced by the ammonium nitrification.

For the dissolved phosphorus, the seasonal trend varied, with the inorganic fraction exhibiting higher values in summer, and organic, in winter. This corroborates the high influence of the sediment transport from adjacent soil into the river in the rainy period, once, its availability comes from the mineral decomposition, while the highest values of dissolved organic phosphate in the dry season should be associated to internal processes, such as the action of decomposers (bacteria and fungi) in the nutrients cycle and in environmental features.

Higher silicate concentrations were observed in the dry period, different from other nutrients. Silicate is probably accumulated in the lagoons during the rainy period and resuspended during the beginning of the dry period, due to the total circulation of the water column (temperature homogeneity), and it is also influenced by strong winds observed in this period.

Our results indicated that regional factors were the main responsible for the limnological dynamics of the study environments. The alternation between dry and rainy period changes significantly river and lagoons, mainly due to the contribution of tributaries located upstream. Magnitudes of changes were higher in the reservoir channel compared to the lagoons, which were more resilient. Spatially, even in the peak of the rainfall period, the system exhibited a remarkable limnological variability. This fact shows the complexity of river-reservoir-lagoons system and the need to consider these distinct habitats in regional conservation strategy, presently focused on terrestrial environments.

Conclusion

This study demonstrates that regional factors were the main responsible for the limnological dynamics of the study environments, indicated by significant seasonal changes in the limnology of river and lagoons, mainly due to the contribution of tributaries located upstream. This fact evidences the need to consider these distinct habitats in regional conservation strategy, presently focused on terrestrial habitats.

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