Limnological characteristics comparison in three systems with different hydrodynamic regime in the upper Paraná river floodplain

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RESUMO: Comparação das características limnológicas de três sistemas com diferentes regimes hidrodinâmicos da planície de inundação do alto rio Paraná. O papel do regime hidrológico sobre as variáveis físicas e químicas em regiões litorais da planície de inundação do alto Rio Paraná foi avaliado através de estudo comparativo de três sistemas com distintos regimes hidrodinâmicos (ambientes lêntico, semilótico e lótico) e em dois períodos hidrológicos (águas altas e baixas). Três amostras foram coletadas próximo a estandes de *Eichhornia azurea* para cada período e local de estudo. A análise dos componentes principais discriminou os sistemas com base nos períodos hidrológicos e nos regimes hidrodinâmicos. O ambiente semilótico foi caracterizado como um sistema intermediário, aproximando-se da lagoa no período de águas altas pelos maiores teores de fósforo, e do ambiente lótico no período de águas baixas pelos maiores valores de nitrogênio total, pH e alcalinidade. As razões N/P evidenciaram o fósforo como fator limitante no período de águas baixas. Maiores oscilações temporais ocorreram do sistema lótico para o lêntico, indicando maior estabilidade das variáveis abióticas no rio. Os resultados indicam o regime hidrológico como a principal função de força sobre a dinâmica e o funcionamento dos três sistemas da planície de inundação do alto Rio Paraná. Todavia, apontam o regime hidrodinâmico e o grau de conexão dos sistemas com o Rio Paraná como fatores controladores da magnitude de influência do regime hidrológico.

Palavras-chave: variáveis limnológicas, regime hidrodinâmico, nível fluviométrico, planície de inundação, rio Paraná.

ABSTRACT: Limnological characteristics comparison in three systems with different hydrodynamic regime in the upper Paraná river floodplain. Physical and chemical variables of littoral region in the upper Paraná River floodplain was evaluated in a comparative study of a lentic, semilotic and lotic systems, during high and low water levels. Principal component analyses grouped the systems according to water level periods and hydrodynamic regimes. The semilotic system had intermediate limnological conditions, approaching the oxbow lake during high water due to higher phosphorous concentration and the river at low water due to high values of total nitrogen, pH, and alkalinity. Phosphorous enrichment occurred in the lentic and semilotic systems during the flood period. Although the main functioning force of the upper Paraná River floodplain was the hydrological regime, the influence of the flood pulses was moderated by the degree of connection of the environments with the main river channel, as well as the hydrodynamics and morfometry of the associated systems.

Key words: limnological parameters, hydrodynamic regime, water level, tropical floodplain, Paraná River

Introduction

Floodplains are present along almost all rivers of the world. Some are small and some have been modified or even eliminated by man, particularly in temperate zones. The largest and the most important floodplains occur along large tropical lotic systems (Bonetto, 1993; Neiff, 1996). In the tropical and subtropical regions of South America where large river systems occur, almost all are accompanied by extensive floodplains (Junk & Da Silva, 1995). Floodplains are important in the regulation of water balance and the biogeochemical cycles on a continental scale (Sippel *et al.*, 1992). These systems, because of their high organic matter production and accumulation of detritus, offer a variety of habitats and food for zooplankton, invertebrates, vertebrates, amphibians and birds, as well as providing refuge and spawning grounds for many species of fish (Wetzel, 1990). The floodplains are among the most productive ecosystems of the globe and are also important centers of biological diversification (Junk, 1996). As a consequence, understanding how these ecosystems work is fundamental for establishing environmental protection measures, and procedures for sustainable use and preserving biodiversity.

Ecological studies of floodplains began about 20 years ago (Junk & Da Silva, 1995). In Brazil, four floodplain systems have received the greatest attention: that of the Amazon basin (e.g. Sioli, 1984, Melack & Fisher, 1990, Esteves *et al.*, 1994), of the Pantanal of Mato Grosso (e.g. Da Silva & Esteves, 1995, Hamilton *et al.*, 1996), of the Mogi-Guaçu River (e.g. Camargo & Esteves, 1995), and of the Paraná River. The Paraná River, has the second largest drainage system in South America. The floodplains of the middle and lower Paraná River have been studied since the early 1970's (e.g. Bonetto, 1975; Bonetto *et al.*, 1984; Garcia de Emiliani, 1993; Neiff, 1990). The literature on the limnology of the floodplain of the upper Paraná River currently includes almost 100 publications. Of these, about ten papers deal with physical and chemical parameters (Thomaz, 1991; Thomaz *et al.*, 1991, 1992a, 1992b, 1992c, 1997; Roberto *et al.*, 1992; Rauber *et al.*, 1992; Pagioro *et al.*, 1994, 1997; Paes da Silva & Thomaz, 1997).

The flood pulse is one of the main factors regulating the physical, chemical and biological processes on floodplains, and the analysis of the hydrological regime of the rivers associated with the floodplains occupies a central role in the interpretation of their ecological processes (Junk *et al.*, 1989; Agostinho *et al.*, 1995; Junk, 1996; Neiff, 1996; Thomaz *et al.*, 1997).

In the upper Paraná River, the variations in water level determine the occurrence of many flood pulses. At low water, oscillations on a weekly scale occur because of the operation of various dams situated upstream of the floodplain. Thomaz *et al.* (1997) characterized the flood pulse as irregular compared to that of other large South American rivers. Flood pulses occur during the high water period and minor pulses occur during the low water period which does not allow for the exact delimitation of the flood and drought periods.

This study provides a limnological analysis comparison of three systems with distinct hydrodynamic regimes in the upper Paraná River floodplain. It aims to evaluate the influence of the water level variation and hydrodynamic regimes on the limnological characteristics of the littoral regions in the floodplain.

Study area

The upper Paraná River flows generally from north to south/southwest through a region with tropical to subtropical climate, with mean monthly air temperatures above 15 °C and precipitation over 1,500 mm/year (Agostinho & Zalewski, 1996). The work was undertaken near the municipality of Porto Rico, state of Paraná, at border with the State of Mato Grosso do Sul, between coordinates 22°40'- 22°45'S and 53°15'-53°25'W (Fig. 1). Three environments with distinct hydrodynamic regimes were chosen:

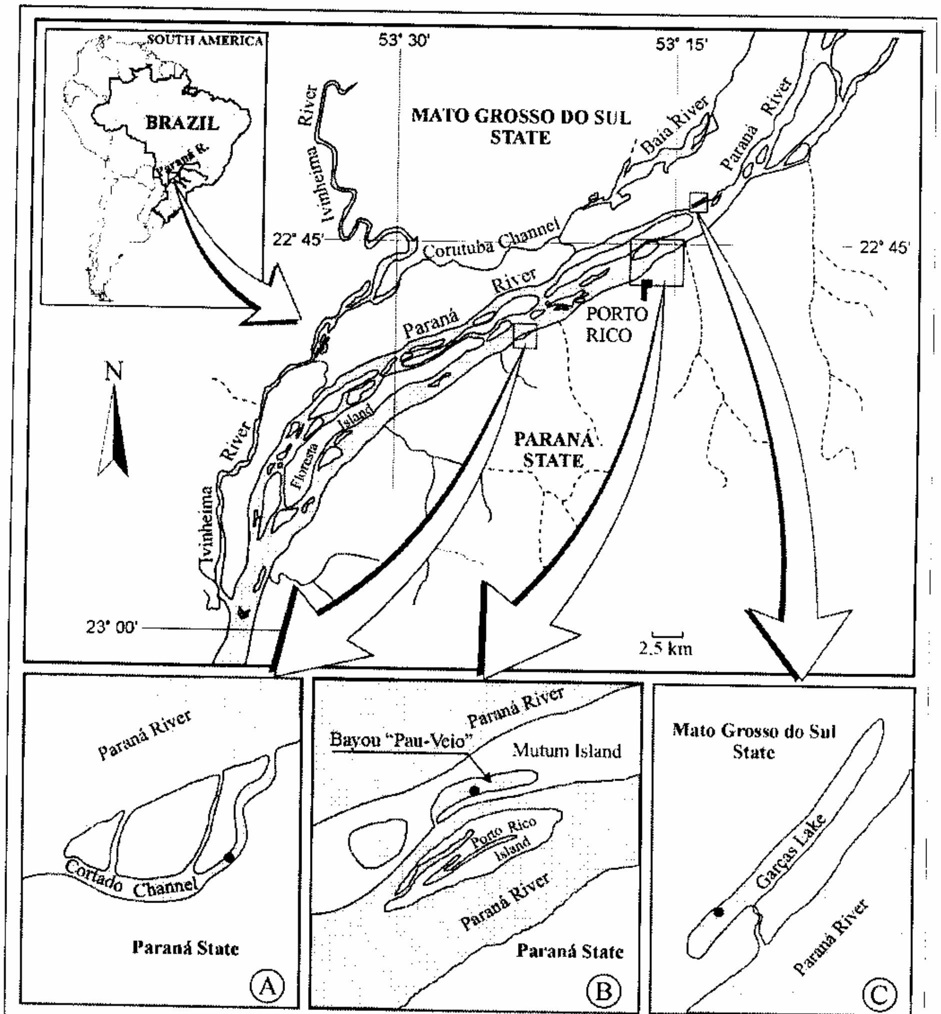

Figura 1: Locations of the three environments sampled on the Upper Paraná River floodplain (Garças Lake (C); Pau Véio (B); Cortado Channel (A)).

(a) Garças Lake is connected all year round to the Paraná River by a narrow canal. It is approximately 2 km long and 150 m wide. Macrophytes are abundant in the littoral zone and *Eichhornia azurea* is dominant. Margins are colonized by arboreal riparian vegetation; (b) Pau Véio Bayou, is situated on Mutum Island in the Paraná River. It is about 1.2 km long and 50 m wide and there is no water current. The eastern bank is formed by a natural dike which separates it from the Paraná River. On the dike the vegetation grades from aquatic to terrestrial systems and is composed of macrophytes, mainly *E. azurea*, and herbaceous and shrubby riparian vegetation. The western bank is mainly pasture; and (c) Cortado Channel is located on the eastern bank of the Paraná River. It is about 2 km long, 80 m wide and mean water current of 50 and 30 $cm.s^{-1}$ in high and low water, respectively. It has arboreal riparian vegetation along both margins and stands of macrophytes, with a dominance of *E. azurea*.

Material and methods

The study was conducted between March 12 - April 1, 1994 (high water period) and July 18 - August 5, 1994 (low water period). Water level and rainfall data were provided by the "Departamento Nacional de Água e Energia Elétrica" (DNAEE) and obtained at the meteorological stations of Porto São José and São Pedro do Paraná situated approximately 17 km from the sampling sites. Water transparency was measured with Secchi disk and temperature of the water measured with digital thermistor. Samples were collected in the littoral zone, at the surface, with a Van Dorn water sampler and immediately transported to the laboratory. The non-filtered portion of the samples was used to measure pH and electrical conductivity with portable, digital meters; alkalinity (Mackereth *et al.*, 1978) and dissolved oxygen (Winkler method, according to Golterman *et al.*, 1978). Part of these samples were preserved with sulfuric acid for determination of the total fractions of nitrogen and phosphorous according to Mackereth *et al.* (1978) and Golterman *et al.*, (1978), respectively. Another part of these samples were immediately filtered through Whatman GF/F filters and held in a freezer at -20°C for a maximum of 30 days for later analysis of dissolved nutrients. Ammonium (Koroleff, 1976), nitrite and nitrate (FIA, according to Zagatto *et al.*, 1981), total dissolved phosphorus and orthophosphorus (Mackereth *et al.*, 1978) and reactive silicates (Golterman *et al.*, 1978) were measured. Part of each sample was also filtered through Whatman GF/F filters to determine chlorophyll-*a* (Wetzel & Linkens, 1991) and suspended material (Schwarzbold, 1990). A Principal Component Analysis (Manly, 1994), based on the variables obtained (correlation matrix), was used to ordinate the sampling dates and sites.

Results and discussion

Despite the annual variability and the anthropogenic impacts, the floodplain of the upper Paraná River is characterized by two distinct periods on a seasonal cycle, a high water period between November and May, and a low water period between June and October (Thomaz *et al.*, 1997). During the study period, mean precipitation values were 4.4 mm/day during the high water period and 2.4 mm/day during the low water period. Water levels varied between 4.1 m and 4.7 m during high water, and 2.2 m and 3.1 m during low water (Fig. 2). On one occasion (July 26, 1994), in less than 24 hours there was a water level fluctuation of 0.9 m, showing the marked influence of the outflow of the upstream dams during low water period.

Based on 21 years of data, Thomaz (1991) calculated a mean annual oscillation in water level for the Paraná River of the range of 2.9 m. Junk & Da Silva (1995) mention fluctuations in the range of 2 to 5 m for the Pantanal of Mato Grosso and in the range of 5 to 15 m for the Amazon basin. Camargo & Esteves (1995) observed a

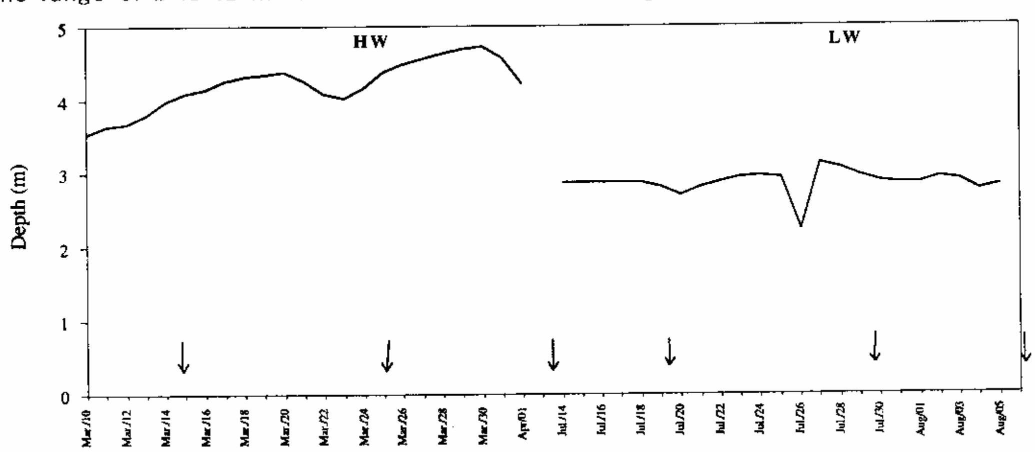

Figura 2: Daily water levels recorded in the Paraná River from March 10 through April 1, 1994 and from July 14 through August 5, 1994 (HW= high water; LW= low water). The arrows indicate sampling dates.

variation of 2.5 to 5 m in Mato oxbow lake, situated on the Mogi-Guaçu River floodplain, Grande River basin, that empties in the Paraná River.

Mean air temperature was 29.8 °C during high water and 20.2 °C during low water period. During the high water period, the water temperature was between 25.8 °C and 27.2 °C, without great differences between the sampling sites and dates. During low water period, temperature ranged from 14.0 to 22.4°C (Table I).

During high water, mean values of water transparency reached 61% of the maximum depth in Garças Lake, 48% in the Pau Véio system, and 38% in Cortado Channel. During low water, total water transparency (100%) was observed in the littoral region of all three systems (Table I), although suspended material were actually higher in this water phase, except for the lotic system (Fig. 3). Suspended inorganic material in lotic and semilotic environments were generally higher than in the lagoon during both sampling periods (Fig. 3). So, water transparency was influenced by allochthonous material as well as the resuspension of bottom sediments.

The values of conductivity, total alkalinity and pH usually increased from the lentic to the lotic environment during the two hydrological periods (Table I), which

Table I: Limnological parameters measured in the littoral region of three systems of the Upper Paraná River floodplain during high and low water periods; minimum, maximum values and in parenthesis the mean and standard error (n=3).

Periods	**High Water**			**Low Water**		
Variable	**Lake**	**Bayou**	**Channel**	**Lake**	**Bayou**	**Channel**
Depth (m)	1.9-2.0 (1.9±0.01)	1.7-1.8 (1.7±0.01)	1.3-1.6 (1.4±0.02)	1.0-1.5 (1.2±0.02)	0.4-0.8 (0.6±0.02)	0.7-1.0 (0.8±0.02)
Transparency (Secchi disk)	0.9-1.6 (1.2±0.03)	0.7-0.9 (0.8±0.01)	0.4-0.6 (0.5±0.01)	1.0-1.5 (1.2±0.02)	0.4-0.8 (0.6±0.02)	0.7-1.0 (0.8±0.02)
Water temperature (°C)	25.9-27.0 (26.6±0.6)	25.8-27.1 (26.5±0.7)	26.0-27.2 (26.6±0.6)	16.2-19.3 (17.5±1.6)	14.0-22.4 (18.7±4.3)	18.6-20.1 (19.5±0.8)
pH	6.1-6.4 (6.3±0.2)	6.3-6.6 (6.4±0.2)	6.9-7.0 (7.0±0.03)	6.7-6.8 (6.7±0.1)	6.9-7.1 (7.0±0.1)	7.4-7.6 (7.5±0.1)
Alkalinity (mEq/l)	0.29-0.32 (0.31±0.01)	0.30-0.33 (0.31±0.01)	0.33-0.34 (0.34±0.01)	0.35-0.39 (0.37±0.02)	0.38-0.42 (0.40±0.001)	0.40-0.42 (0.41±0.001)
Conductivity (µS/cm)	48-49 (48.3±0.6)	48-51 (49.7±1.5)	56-58 (57.0±1.0)	46-53 (50.0±3.6)	51-54 (52.0±1.7)	58-62 (60.0±2.0)
Dissolved oxygen (mg/l)	0.63-4.63 (3.18±2.2)	3.81-5.47 (4.40±0.9)	7.8-8.5 (8.22±0.3)	3.9-6.14 (4.77±1.2)	7.3-9.66 (8.60±1.2)	9.2-9.9 (9.61±0.4)
PDT (µg/l)	5.8-15.4 (11.1±4.9)	7.4-8.9 (8.3±0.8)	4.4-7.2 (5.6±1.4)	4.9-5.7 (5.3±0.4)	3.0-3.6 (3.3±0.3)	2.3-4.9 (2.6±0.4)
PT (µg/l)	18.3-36.5 (30.1±10.2)	30.5-31.9 (31.1±0.7)	36.7-49.2 (43.5±6.3)	14.4-15.2 (14.8±0.4)	45.3-55.3 (48.6±5.8)	51.8-72.2 (65.0±11.4)
$P\text{-}PO_4$ (µg/l)	5.4-13.3 (10.1±4.1)	5.4-8.0 (6.5±1.3)	3.5-7.1 (5.2±1.8)	1.1-2.2 (1.8±0.6)	2.9-3.5 (3.2±0.3)	2.0-2.2 (2.1±0.1)
NT (µg/l)	336-384 (362.7±24)	336-400 (362.7±33)	272-416 (341.3±72)	458-615 (539±78)	1818-2018 (1894±108)	1489-1703 (1593.7±107)
$N\text{-}NO_3$ (µg/l)	19-37 (26.7±9.3)	62-105 (86.0±21.9)	120-232 (173.3±56.2)	16.6-80 (48.2±31.7)	10-80 (49.5±35.9)	175-200 (186.3±12.7)
Ammonium (µg/l)	21.1-72.4 (39.0±28.9)	14.8-27.6 (19.1±7.4)	16.2-37.0 (29.2±11.4)	23.6-32.7 (27.1±4.6)	13.8-58.9 (38.6±22.9)	23.6-34.0 (28.6±5.2)
Orthosilicate (mg/l)	4.3-5.6 (4.9±0.7)	4.8-5.7 (5.3±0.5)	5.5-6.1 (5.8±0.3)	3.3-3.8 (3.5±0.2)	4.4-5.4 (5.0±0.5)	5.3-6.2 (5.6±0.5)
Inorganic N:P (atomic ratio)	6.7-24.8 (16.7±2.0)	27.7-48.5 (36.5±1.8)	57.2-121.4 (92.0±3.2)	81.5-114.0 (93.2±2.7)	49.3-72.4 (61.9±2.4)	222-230.2 (226±0.8)
NT:PT (atomic ratio)	22.3-40.6 (28.9±1.2)	24.4-28.5 (26.0±0.8)	16.4-18.7 (17.1±0.3)	68.7-89.4 (80.5±1.2)	80.8-90.4 (86.7±1.2)	46.4-72.8 (56±2.6)
Chlorophyll-a phytoplankton (µg/l)	2.2-5.5 (3.6±0.6)	0.6-2.2 (1.2±0.1)	0.2-2.0 (1.1±0.1)	1.9-3.6 (3.0±0.1)	10.6-28.2 (16.6±0.2)	1.64-4.1 (2.82±0.3)

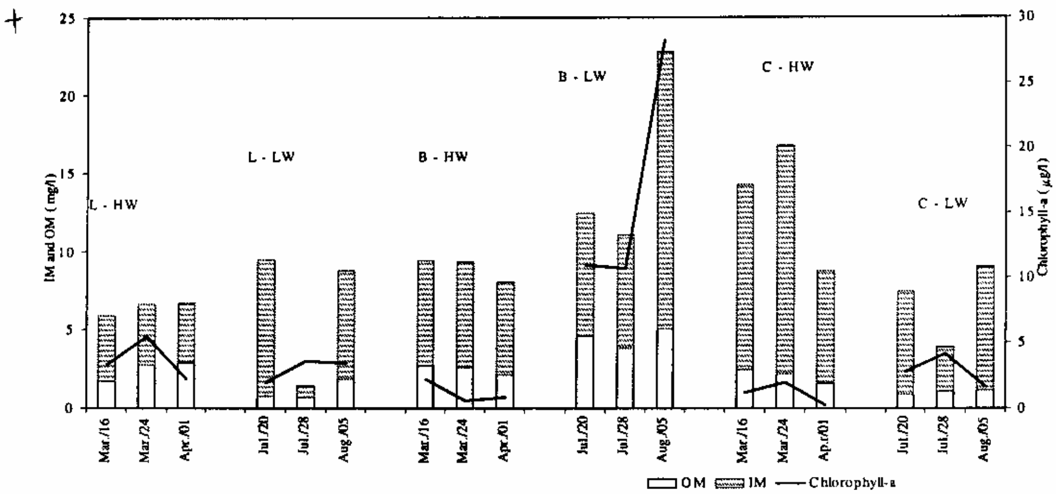

Figura 3: Suspended organic (OM) and inorganic material (IM) and phytoplanktonic chlorophyll-*a* at the surface of the littoral regions of three environments during both study periods (L = Garças Lake, B = Pau Véio Bayou, C = Cortado Channel, HW= high water period, LW= low water period).

can be related to the greater buffering capacity of the river. The same tendency was observed by Magrin & Senna (1997) in an oxbow lake of the Mogi-Guaçu River floodplain, which was attributed to the entrance of the river water into the lagoon. The greater values of free CO_2 during high water in all systems were related to the relatively lower pH, also observed by Pagioro *et al.* (1994) for another marginal lagoon of the upper Paraná River floodplain, as well as to a greater decomposition processes at this time of the year (Paes da Silva & Thomaz, 1997). Accordingly, lower values of dissolved oxygen were found during this hydrological phase. In the lagoon this was evident, with oxygen levels decreasing to 0.63 mg/l (April 1, 1994). Paes da Silva & Thomaz (1997) also observed a dissolved oxygen concentration of less than 2 mg/l for Garças Lake soon after the increase in water level, and Thomaz *et al.* (1997) found an inverse correlation between water level and this variable for other lentic and semilotic systems of this floodplain.

Reactive silicate values usually increased from lentic to lotic systems and also during high water period, particularly in the lagoon. Agostinho & Zalewski (1996) reported high concentrations of reactive silicate all year round in the Paraná River. During high water phase, when connection with the Paraná River is greater, there most probably is an input of silicates from the River to the other system.

Total dissolved phosphorus (PDT) and orthophosphate presented similar trend of variation pattern during high water period, that is, increasing values from the lotic to the semilotic and lastly to the lentic system. Total phosphorus values, instead, were lower in the lagoon during the two hydrological periods, increasing towards the lotic environment especially during the low water period. Present results do not agree with available data for the upper Paraná River floodplain. Thomaz (1991), Thomaz *et al.* (1992c), Agostinho *et al.* (1995), Paes da Silva & Thomaz (1997), and Thomaz *et al.* (1997) observed a decrease in phosphorus in pelagic region of marginal lagoons during the high water period due to a dilution effect brought by the entrance of river water.

Total nitrogen values were higher during low water, particularly in the semilotic and lotic systems. Nitrate concentrations were much higher in the lotic system during both periods and had in high water period, increasing values from the lentic to the lotic system. Ammonium did not show differences between the two study periods.

The Paraná River water has generally high nitrate concentrations and low phosphorous levels. According to Agostinho *et al.* (1995) this can be attributed to phosphorus sedimentation in the upstream reservoirs, also verified by Henry (1992). Based on the inorganic fractions of these nutrients one can consider the Paraná River as a source of inorganic nitrogen for the lentic and semilotic environments, as also suggested by Thomaz *et al.* (1997). Concerning phosphorus, the lentic and semilotic environments would function as stock areas for the upper Paraná River.

The atomic ratios for nitrogen and total phosphorus (NT:PT) and for inorganic forms (N:P) have different values, among the systems and hydrological periods (Table I). Considering the inorganic ratio, lower values were always observed during the high water period, and higher values were always found in the lotic system. Except for the lagoon (high water period), all values were well above the range 10-20. Considering the total ratio, the three systems had values near this range in high water. These data indicate phosphorus as a limiting nutrient in the floodplain systems of the upper Paraná River even more so during the low water period, when ambient N:P ratios are well above 20:1, indicative of P-limited condition (Schanz & Juon, 1983).

Phytoplankton biomass (chlorophyll-*a*) was greater during high water period in the littoral region of Garças Lake (Table I, Fig. 3). Paes da Silva & Thomaz (1997), however, detected lower values of chlorophyll-*a* in the pelagic region of this lake and suggested a dilution effect on phytoplankton during this water phase. Present results, based on littoral region characteristics, indicate the influence of P-enrichment, as well as contribution of periphyton detachment from substrata due to physical disturbances (flood pulses) during high water phase (Rodrigues, 1998). In the other two systems chlorophyll-*a* was greater during low water period than the high water period (Table I, Fig. 3), despite lower phosphorus concentrations. In those cases most probably physical characteristics such as lower current were determinant. Hence, although hydrological regime plays its role in controlling phytoplankton biomass, the response is also influenced by the hydrodynamic characteristics and the internal processes of each system.

Table II presents the correlations between variables with principal components I and II, which together explain 64.7% of total variation. Figure 4a shows the ordination by principal components of sampling dates and systems, with four groups identifiable along the first two components.

The first component (43.2%) was negatively associated with water level, depth, total dissolved phosphorus and orthophosphate, and positively associated with total nitrogen, pH, dissolved oxygen and alkalinity. In this component two groups are readily identifiable: (a) a group including the lentic and semilotic environments during the high water period basically due to the greater phosphorus concentrations, and (b) a second group with semilotic and lotic environments during the low water period, which presented higher total nitrogen concentrations and greater buffering capacity, based on alkalinity and pH. The second component (21.5%) separated the lagoon in low water from the lotic system during high water in association to greater values of orthosilicate, nitrate, free CO_2 in the river and greater transparency in the lagoon (Tab. II).

The semilotic system was characterized as an intermediate system, approaching the lagoon during the high water period due to phosphorous (Fig. 4b), and nearing the lotic system during the low water period due to high values of total nitrogen, pH, and alkalinity (Fig. 4c).

The hypothesis put forth by Thomaz *et al.* (1997) referring to the homogenizing effect of the floods on the aquatic environments influenced by the upper Paraná River is presently reinforced. During low water, the abiotic limnological characteristics in the littoral regions of the floodplain systems differed mostly among themselves, and the semilotic system variables were more similar to the river's variables. During this phase, the environments presented limnological characteristics more associated to autochthonous processes and thus more individualized. During the high water phase lentic and semilotic systems become more similar. Present data clearly demonstrate that Pau Véio Bayou is as a transition system between the lagoon and the river and should be considered a semilotic system.

The dilution effect brought about by the input of river water in the lagoon observed by previous authors (Thomaz *et al.*, 1997) was not supported by this

Table II: Correlation of the variables with principal components I and II.

Variables	Principal Component	
	I	II
water level	-0.773	0.562
conductivity	0.667	0.469
alkalinity	0.899	-0.273
transparency	-0.487	-0.532
depth	-0.931	0.205
pH	0.905	0.224
temperature	-0.664	0.589
O_2	0.866	0.361
Orthosilicate	0.203	0.905
CO_2	-0.526	0.722
PDT	-0.850	0.162
$P\text{-}PO_4$	-0.777	0.348
PT	0.666	0.552
NT	0.843	-0.160
$N\text{-}NO_3$	0.467	0.649
Ammonium	0.006	-0.201
% variation explained	43.2	21.5

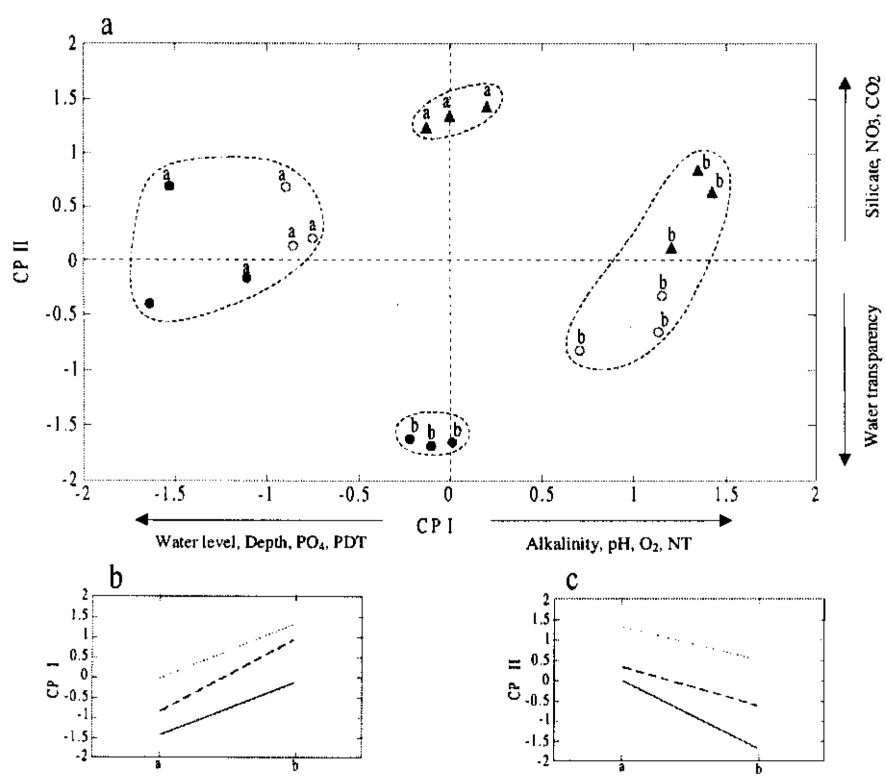

Figura 4a,b,c.: Principal component analysis of the sampling dates for three systems and two hydrological periods (a= high water period; b= low water period): a) ● = Garças Lake; O = Pau Véio Bayou; ▲ = Cortado Channel; 4b-c. continuous line = Garças Lake; dashed line = Pau Véio Bayou; dotted line = Cortado Channel study. P-enrichment was clearly observed in the lentic and semilotic systems during the flood pulses. It is presently suggested two controlling factors for the fertilization processes during the flood pulses (high water period) in littoral zones, that are, the greater input of phosphorus in the lentic and semilotic systems due to the marginal vegetation decomposition and the sediment resuspension, caused by turbulence. During low water, total transparency (absence of aphotic zone) and high oxygen content found in littoral zones probably reduce nutrient release from the sediments. Moreover during low water phase, the oxbow lakes may represent a stock of nutrients as also suggested by Camargo & Esteves (1995) for a marginal lagoon in the Mogi-Guaçu River (São Paulo State). Hence, the autofertilization process found in other lagoons of the floodplain of the upper Paraná River (Pagioro *et al.*, 1994) and the pantanal in Mato Grosso (Da Silva & Esteves, 1995) during low waters may not be a general trend.

The apparently contradictory data can reflect the limnological conditions in the different compartments of the systems, since pelagic regions have traditionally received greater attention, as well as the size representativeness of the littoral region within the system studied. The interface regions of aquatic systems present distinct characteristics, representing areas of high assimilation, nutrient cycling especially phosphorus and the synthesis of organic material, carrying out an important controlling role on the ecosystem (Wetzel, 1990, 1996). Hence, there is a need for a better understanding of the functioning of the littoral regions and the role of this compartment in the metabolism of the aquatic system.

Finally, although the main functioning force of the upper Paraná River floodplain is the hydrological regime, present results indicate that the magnitude of the influence of the flood pulses is moderated by the degree of connection of the environments with the main river channel, the hydrodynamics, and morphometry of the associated systems.

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References

Agostinho, A. A. & Zalewski, M. 1996. A planície Alagável do Alto Rio Paraná: Importância e Preservação. Editora da Universidade Estadual de Maringá, Maringá. 100p.

Agostinho, A. A., Vazzoler, A. E. A. M. & Thomaz, S. M. 1995. The high River Paraná Basin: limnological and ichtyological aspects. In: Tundisi, J. G., Bicudo, C. E. M. & Matsumura-Tundisi, T. (eds.) Limnology in Brazil. ABC/SBL, Rio de Janeiro. p.59-103.

Bonetto, A. A. 1975. Hydrologic regime of the Paraná River and its influence on ecosystems. In: Hasler, A. D. (ed.) Coupling of land and water systems. Springer Verlag, New York. p.175-197.

Bonetto, A. A. 1993. Structure and functioning of large river floodplains of neotropical America: The Parana-Paraguay System. In: Gopal, B., Hillbricht-Ilkowska, A. & Wetzel, R. G. (eds.) Wetlands and ecotones: studies on land-Water Interactions. National Institute of Ecology and International Scientific Publications, New Delhi. p.123-138.

Bonetto, A. A., Zalocar, Y. & Lancelle, H. G. 1984. A limnological study of oxbow lake covered by *Eichhornia crassipes* in the Paraná River. Verh. Int. Verein. Limnol., 22:1315-1318.

Camargo, A. F. M. & Esteves, F. A. 1995. Influence of water level variation on fertilization of an oxbow lake of Rio Mogi-Guaçu, state of São Paulo, Brazil. Hydrobiologia, 299:185-193.

Da Silva, C. J. & Esteves, F. A. 1995. Dinâmica das características limnológicas das baías Porto de Fora e Acurizal (Pantanal de Mato Grosso) em função da variação do nível de água. Oecol. Bras., 1:47-60.

Esteves, F. A., Thomaz, S. M. & Roland, F. 1994. Comparison of the metabolism of two floodplain lakes of the Trombetas River (Pará, Brazil) based on a study of diurnal variation. Amazoniana, 13:33-46.

Garcia de Emiliani, M. O. 1993. Seasonal succession of phytoplankton in a lake of the Parana River floodplain, Argentina. Hydrobiologia, 264:101-114.

Golterman, H. L., Clymo, R. S. & Ohmstad, M. A. M. 1978. Methods for physical and chemical analysis of freshwaters. Blackwell Scientific Publication, Oxford. 214p.

Hamilton, S. K., Sippel, S. J. & Melack, J. M. 1996. Inundation patterns in the Pantanal wetland of South America determined from passive microwave remote sensing. Arch. Hydrobiol., 137:1-23.

Henry, R. 1992. A exportação de nutrientes e material em suspensão em alguns cursos de água na bacia do alto Paranapanema (Estado de São Paulo). Acta Limnol. Bras., 4:67-80.

Junk, W. J. 1996. Ecology of floodplains - a challenge for tropical limnology. In: Schiemer, F. & Boland, K. T. (eds.) Perspectives in Tropical Limnology. Academic Publishing, Amsterdam. p.255-265.

Junk, W. J. & Da Silva, C. J. 1995. Neotropical floodplains: A comparison between the Pantanal of Mato Grosso and the large Amazonian river floodplain. In: Tundisi, J. G., Bicudo, C. E .M. & Matsumura-Tundisi, T. (eds.) Limnology in Brazil. ABC/SBL, Rio de Janeiro. p.195-218.

Junk, W. J., Bayley, P. B. & Sparks, R. S. 1989. The flood pulse concept in River Floodplain systems. Can. Spec. Publ. Fish. Aquat. Sci., 106:110-127.

Koroleff, K. 1976. Determination of ammonia. In: Grasshoff, E. & Kremling, E. (eds.) Methods of seawater analysis. Verlag Chemie Weinhein, New York. p.117-181.

Mackereth, F. J. H., Heron, J. G. & Talling, J. F. 1978. Water analysis: some revised methods for limnologists. Freshwater Biological Association, London. 121p. (Scientific Publications, 36)

Magrin, A. G. E., & Senna, P. A. C. 1997. Composição e dinâmica de diatomáceas planctônicas em uma lagoa da planície de inundação do médio Mogi-Guaçu, Estado de São Paulo, Brasil. In: Anais do VII Seminário Regional de Ecologia. Universidade Federal de São Carlos, São Carlos. p. 247-276.

Manly, B. F. J. 1994. Multivariate estatistical methods. 2 ed. Chapman & Hall, London. 215p.

Melack, J. M. & Fisher, T. R. 1990. Comparative limnology of tropical floodplain lakes with an emphasis on the Central Amazon. Acta Limnol. Bras., 3:1-48.

Neiff, J. J. 1990. Ideas for the ecological interpretation of the Paraná River. Interciência, 15:424-441.

Neiff, J. J. 1996. Large rivers of South America: toward the new approach. Verh. Int. Verein. Limnol., 26:167-180.

Paes da Silva, L. & Thomaz, S. M. 1997. Diel variation of some limnological parameters and metabolism of a lagoon of the high Paraná river floodplain, MS. In: Anais do VII Seminário Regional de Ecologia. Universidade Federal de São Carlos, São Carlos. p.169-189.

Pagioro, T. A., Roberto, M. C., Lansac-Tôha, F. A. & Veríssimo, S. 1994. Caracterização limnológica de uma lagoa (Lagoa Figueira) da planície de inundação do alto rio Paraná. Rev. Unimar, 16:203-215.

Pagioro, T. A., Roberto, M. C. & Lansac-Tôha, F. A. 1997. Comparative Limnological Analysis of two Lagoons on the Upper Paraná River, Brazil. Int. J. Ecol. Environ. Sci., 23:229-239.

Rauber, T., Luchese, E. B., Lenzi, E., Oliveira, M. A. & Palácio, S. M. 1992. Níveis de concentração dos macronutrientes N, P e K que aportam nos rios Paraná e Baía, na região de Porto Rico-PR. Acta Limnol. Bras., 4:239-246.

Roberto, M. C., Thomaz, S. M., Lansac-Tôha, F. A. & Lima, A. F. 1992. Caracterização limnológica do canal Corutuba, planície de inundação do alto rio Paraná - MS. Rev. Unimar, 14:139-152.

Rodrigues, L. 1998. Sucessão do perifíton na planície de inundação do alto rio Paraná: interação entre nível hicrológico e regime hidrodinâmico. Maringá, UEM, 208p. (Tese).

Schanz, F. & Juon, H. 1983. Two different methods of evaluating nutrient limitations of periphyton bioassays using water from the River Rhine and eight of its tributaries. Hydrobiologia, 102:187-195.

Schwarzbold, A. 1990. Métodos ecológicos aplicados ao estudo do perifíton. Acta Limnol. Bras., 3:545-592.

Sippel, S. J., Hamilton, K. & Melack, J. M. 1992. Inundation area of lakes on the Amazon river floodplain, Brazil. Arch. Hydrobiol., 123:385-400.

Sioli, H. 1984. The Amazon; limnology and landscape ecology of a mighty tropical river and its basin. Dr. W. Junk Publications, Netherlands. 763p.

Thomaz, S. M. 1991. Influência do regime hidrológico (pulsos) sobre algumas variáveis limnológicas de diferentes ambientes aquáticos da planície de inundação do alto rio Paraná, MS, Brasil. São Carlos, Universidade Federal de São Carlos, 294p. (Dissertação)

Thomaz, S. M., Roberto, M. C., Lansac-Tôha, F. A., Esteves, F. A. & Lima, A. F. 1991. Dinâmica temporal dos principais fatores limnológicos do rio Baía - planície de inundação do Alto rio Paraná - MS, Brasil. Rev. Unimar, 13:299-312.

Thomaz, S. M., Lansac-Tôha, F. A., Roberto, M. C., Esteves, F. A. & Lima, A. F. 1992a. Características limnológicas de uma estação de amostragem do alto rio Paraná e outra do Baixo rio Ivinheima - (PR, MS-Brasil). Acta Limnol. Bras., 4:32-52.

Thomaz, S. M., Lansac-Tôha, F.A., Roberto, M. C., Esteves, F. A. & Lima, A. F. 1992b. Seasonal variation of some limnological factors of lagoa do Guaraná, a varzea lake of the high Paraná river, State of Mato Grosso do Sul, Brazil. Hydrobiol. Trop., 25:269-276.

Thomaz, S. M., Roberto, M. C., Lansac-Tôha, F. A., Lima, A. F. & Esteves, F. A. 1992c. Influência do regime hidrológico do rio Paraná sobre os valores da transparência, oxigênio dissolvido e clorofila *a* de três lagoas de sua várzea. Rev. Unimar, 14:153-162.

Thomaz, S. M., Roberto, M. C. & Bini, L. M. 1997. Caracterização limnológica dos ambientes aquáticos e influência dos níveis fluviométricos. In: Vazzoler, A. E. A. M., Agostinho, A. A. & Hanh, N. S. (eds.) A planície de inundação do alto Rio Paraná. Editora da Universidade Estadual de Maringá, Maringá. p.73-102.

Wetzel, R. G. 1990. Land-water interfaces: metabolic and limnological regulators. Ver. Int. Verein. Limnol., 24:6-24.

Wetzel, R. G. 1996. Benthic algae and nutrient cycling in lentic freshwater ecosystems. In: Stevenson, R. J., Bothwell, M. L. & Lowe, R. L. (eds.) Algal ecology: freshwater benthic ecosystems. Academic Press, San Diego. p.641-667.

Wetzel, R. G. & Linkens, G. E. 1991. Limnological analyses. Springer-Verlag, New York. 391p.

Zagatto, E. A. G., Jacintho, A. O., Reis, B. F., Krug, F. J., Bergamin, H., Pessenda, L. C. R., Mortatti, J. & Giné, M. F. 1981. Manual de análises de plantas empregando sistemas de injeção em fluxo. Editora da Universidade de São Paulo, São Paulo. 45p.

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