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Abiotic Variables in Littoral-Limnetic Gradient of an Oxbow Lake of Mogi-Guaçu River Floodplain, Southeastern, Brazil

Glória Massae Taniguchi[1*], Denise de Campos Bicudo[2] and Pedro Américo Cabral Sennab[1]

[1] Departamento de Ecologia e Biologia Evolutiva; Universidade Federal de São Carlos; 13565-905; São Carlos - SP - Brazil. [2] Seção de Ecologia; Instituto de Botânica; 01061-970; São Paulo - SP - Brazil

ABSTRACT

The present study aimed to analyse the abiotic characteristics spatial variability in the littoral-limnetic gradient of the Diogo Pond, Mogi-Guaçu River floodplain, as well as evaluating the hydrological influence on the spatial gradient. During the hydrological cycle, four field trips (high water, flood, low water, and drought) were carried out at three sampling stations: littoral, interface, and limnetic region. Analysis of physical and chemical variables allowed to conclude that the time scale established by the hydrological cycle was the main forcing function over the limnological variability of the Diogo Pond. The relative spatial scale related to littoral-limnetic gradient contributed secondarily to the abiotic variability. Littoral was characterized as a distinct compartment from the other stations during the entire hydrological cycle.

Key words: Oxbow lake, littoral-limnetic gradient, physical and chemical features

INTRODUCTION

Floodplains along the great rivers constitute one of the most important types of flooding areas of tropics, having an important role on the balance of water and biogeochemical cycles in a continental scale (Sippel et al. 1992). The flooding areas, according to Mozeto and Albuquerque (1997), are key components of the river floodplain systems, as well as the central issue, in which matter and complex energy exchanges take place, between the local and the regional hydrographic compartments. Several studies in flooding areas have been carried out in an international level (Mozeto and Albuquerque, 1997). However, for tropic aquatic environment, these studies can be considered recent, especially for oxbow lakes (Huszar, 1994).

At Mogi-Guaçu River middle section, where the Jataí Ecologic Station is located, there is a reduced declivity in comparison to other sections, establishing a meandered floodplain during the raining season. According to Santos and Mozeto (1992), the flood pulse force of the Mogi Guaçu River causes an important embellishment of the local waters due to the influx of nutrients and particulate material, shaping the natural dominant mechanism of water quality control of these aquatic ecosystems. The dynamics of Mogi-Guaçu River surroundings lakes is a process not well known and very complex due to the occurrence of areas defined such as Aquatic/Terrestrial or ATTZ (Aquatical/ Terrestrial Transition Zone) (Junk et al., 1989).
Some of these limnological studies have been developed in these lakes, focusing taxonomic

[*]Author for correspondence

composition and biological diversity (Senna et al., 1998; Peres and Senna, 1998, 2000a; Güntzel et al., 2000; Magrin and Senna, 2000a, 2000b; Rocha et al.,2000; Taniguchi et al., 1998, 2003; Vieira and Verani, 2000; Wisniewski et al., 2000), the influence of hydrological cycle on biological communities, physical and chemical variables, and on chemical processes (Krushe, 1989; Lima, 1990; Melo, 1993; Feresin, 1994; Magrin and Senna, 1997; Albuquerque and Mozeto, 1997; Alves and Strixino, 2000; Ballester and Santos, 2000; Ferreira et al., 2000a, 2000b; Meschiatti et al., 2000; Peres and Senna, 2000b, 2000c; Taniguchi et al., 2000). The aim of this work was to study the spatial variability of abiotic characteristics in the littoral-limnetic gradient of the Diogo Pond, and to evaluate the influence of the hydrological regimen on the temporal variability of the considered characteristics.

MATERIALS AND METHODS

The Diogo Pond, an oxbow lake of the Mogi Guaçu River, is located in the conservation unit of the Jataí Ecological Station “Conde Joaquim Augusto Ribeiro do Vale” (21^{o}33´ to 21^{o}37´S; 47^{o}45´to 47^{o}51´W), in the Center East region of the State of São Paulo. The climate is classified as Aw by the Köppen system (mesothermic with dry winter and rainy summers), with significant higher precipitation from December to February (rainy season) than from June to August (dry season) (Nogueira 1989). The pond is characterized as a drainage system with area near to 4452 hectares. There is a main channel connected to the river throughout the year, and a permanent influx from the Cafundó Creek in its East portion. The pond’s morphometric characteristics were described by Krusche (1989).

Samples were taken at Site 1 (S1), located in open water (limnetic region); Site 2 (S2), located in the interface region (boundary of *Eichhornia azurea* Kunth stands and the open water) and Site 3 (S3), located at the littoral region (within the *E. azurea* banks) (Fig. 1). Samples were collected in four different periods to include a entire hydrological cycle: high water (HW) (11/28th/1996), flood (F) (02/18th/1997), low water (LW) (04/15th/1997) and the drought (D) (08/18th/1997). For each limnological variable analyzed twenty four samples were obtained, including twelve replicates (n=2). The Mogi-Guaçu River depth data (Porto Cunha Bueno Station) were obtained from the CTHRH - DAEE (Technological Center of Hydrology and Water Resources of São Paulo State Water and Electrical Energy Department).

The sampling sequence was from S1 to S3. The samples were collected on water surface and depth. Transparency, temperature, pH, conductivity, dissolved oxygen (DO), alkalinity, nitrite (NO_2), nitrate (NO_3), ammonium (NH_4), total nitrogen (TN), orthophosphate (PO_4), total dissolved phosphorus (TDP), total phosphorus (TP), orthossilicate (SiH_4O_4), TN/TP molar ratio, suspended inorganic matter (SIM) and suspended organic matter (SOM) were analyzed. Methods and equipment used for these analysis are presented in Table 1. For univariate statistical analysis (with a significance level of 0.05) of data it was applied (1) Two Way ANOVA (for water temperature, pH, dissolved oxygen, nitrate, total nitrogen and total phosphorus). Data presented normality and variance homogeneity; and (2) Kruskal-Wallis nonparametric test for the further variables (transparency, hydrometer level, alkalinity, conductivity, ammonium, total dissolved phosphorus, orthossilicate, and suspended matter). The Principal Components Analysis (correlation matrix) was used to ordinate sampling sites and hydrological periods in relation to physical and chemical variables. All the statistical analysis were done with the software “Statistics for Windows - version 5,5A” (Statsof Inc., 2000).

RESULTS AND DISCUSSION

Fig. 2 showed the daily variation of Mogi-Guaçu River depth from November/96 to August/97. DAEE did not provided data for June/97. Average values for abiotic variables are presented in Table 2. Diogo Pond was well oxygenated during three sampling periods (February, April and August). Results suggested nitrogen limitation during the rainy season (November/96 and February/97). The concentrations of nitrite (NO_2) during low water period (April/97), and of orthophosphate (PO_4) during all sampling periods were below detection limits.

Krusche (1989), Dias-Júnior (1990), Barroso (1994), Camargo and Steves (1995), Magrin and Senna (1997), Ballester and Santos (2000), and Taniguchi et al. (2000) have demonstrated the influence of the flood pulse over biological and abiotical variables of the oxbow lakes of Mogi-

Guaçu River floodplain. During the flooding peaks, water column chemistry and the biological communities altered as a consequence of water entry from the Mogi-Guaçu River, the flooding of marginal vegetation, and sediment turbulence of these lakes.

Higher levels of pH, total alkalinity, electrical conductivity, nitrite, ammonium, total phosphorus, and suspended matter (organic fraction) were observed during high water (November/96) but not during flood (February/97).

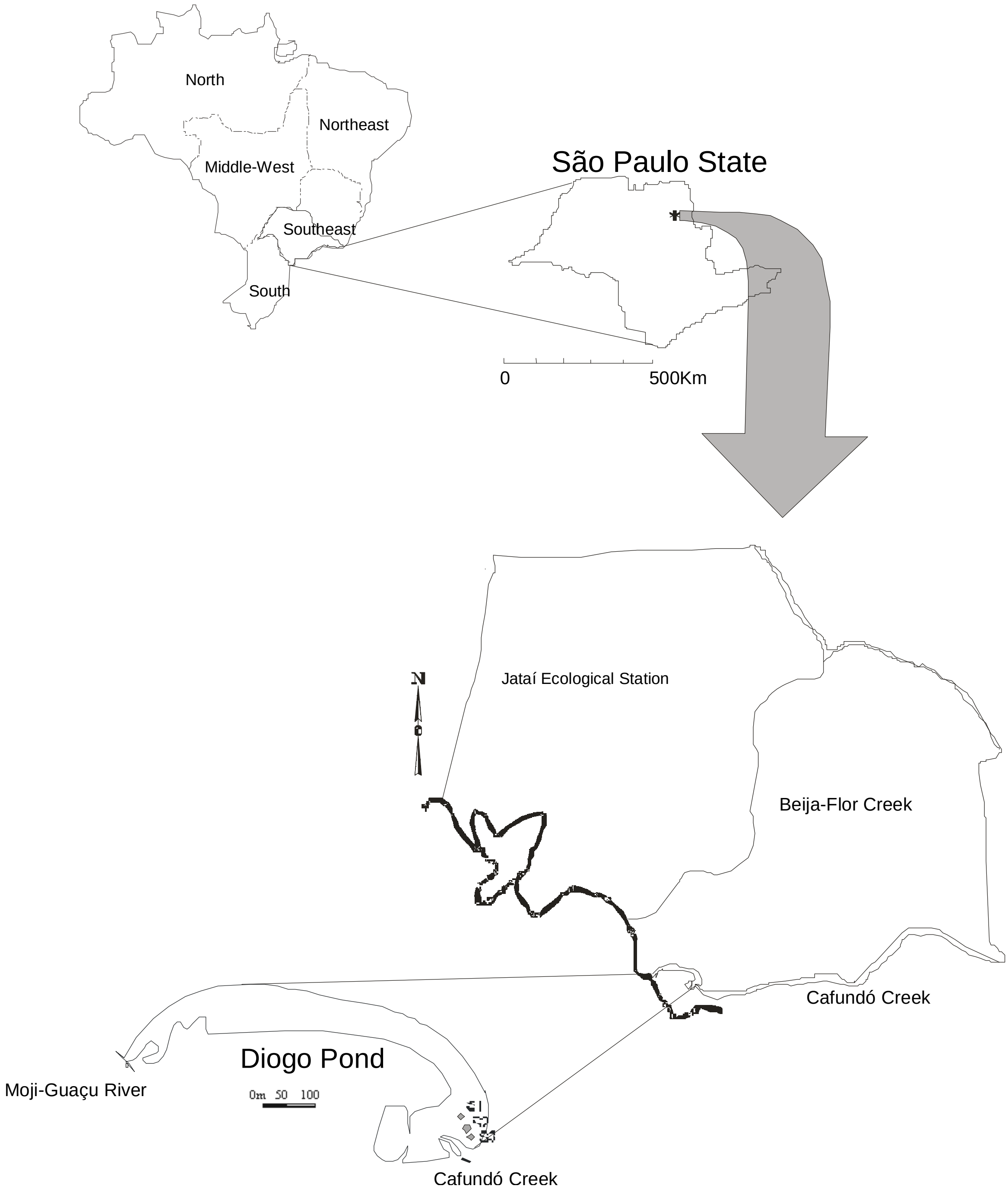

Figure 1 - Map of Brazil showing the São Paulo State, the location of Jataí Ecological Station, Diogo Pond, and sampling sites (S1, S2 and S3).

Table 1 - Methods and equipment used for abiotic variables measurements at the Diogo Pond.

Variable	Method or Equipment
Water transparency (m)	Secchi disk
Temperature (°C)	Horiba, model U-10
pH	Horiba, model U-10
Conductivity (μS/cm)	Horiba, model U-10
Dissolved Oxygen (mg/L)	Winkler method modified by Golterman et al. (1978)
Nitrite (μg/L)	Whatman GF/F filter, Mackereth et al. (1978)
Nitrate (μg/L)	Whatman GF/F filter, Mackereth et al. (1978)
Ammonium (μg/L)	Whatman GF/F filter, Koroleff (1976)
Total Nitrogen (μg/L)	Valderrama (1981)
Orthophosphate (μg/L)	Whatman GF/F filter, Strickland and Parsons (1960)
Total Dissolved Phosphorus (μg/L)	Whatman GF/F filter, Strickland and Parsons (1960)
Total Phosphorus (μg/L)	Valderrama (1981)
Orthossilicate (mg/L)	Whatman GF/F filter, Golterman et al. (1978)
Inorganic and Organic Suspended Matter (mg/L)	Whatman GF/F filter, Teixeira et al. (1965)

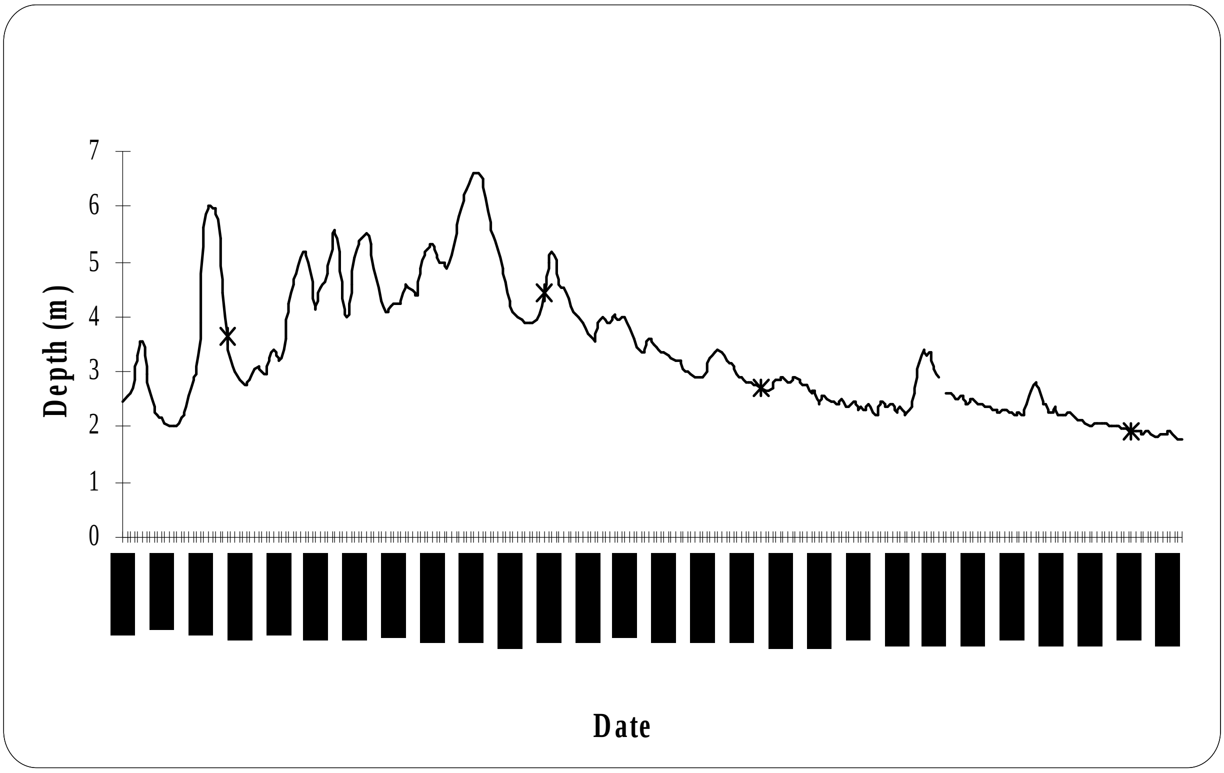

Figure 2 - Daily fluctuations of the Mogi-Guaçu River registered from November 1996 to August 1997 (* indicate sampling date).

As for the hydrological cycle during 96/97, the flood peak occurred at the end of January/97 and sampling was carried out during February/97. So the flood period data did not reflect entirely the influence of the Mogi-Guaçu waters on Diogo Pond during the highest pulse of the flood period, but after the pulse.

In spite of November/96 sampling period characterization as a high water period, it could be important to point out that the process of water entry from the Mogi-Guaçu river began a week before sampling. The River reached the water level of 6.02 m on 11/23rd/96. Therefore, the "flood pulse" effect (enrichment effect), usually expected for flood period, was observed during high water.

During low water and drought period, due to the low precipitation and consequently lack of contribution (or very little contribution) of the river influx, the oxbow lakes of the Mogi-Guaçu River usually show low concentrations of particulate materials, nutrients, conductivity and alkalinity (Krusche, 1989; Barroso, 1994; Magrin and Senna; 1997). As a consequence of the influx of solids in suspension by the influence of the rainy season (high water and flood periods), water transparency markedly decreased during these periods.

PCA analysis showed that Diogo Pond was strongly influenced by time scale or, in other words, by the hydrological cycle (rainy and drought seasons). The rainy periods (high water and flood) were associated with alkalinity, conductivity, pH, total phosphorus, temperature, river depth, ammonium and inorganic suspended matter. The drought periods (low water and drought) were associated with nitrate and dissolved oxygen. High water (November/96) was mainly separated from the flood (February/97) period according to total nitrogen (Table 3, Fig. 3A).

Moreover, univariate analysis (parametric and non-parametric) showed significant differences in most analyzed variables during periods of the hydrological cycle (Table 2). Results indicated that the hydrological regime was the main controlling force of abiotic factors variability in Diogo Pond.

According to Camargo (1991), there are two evident patterns related to nitrogen and phosphate forms and ions in the oxbow lakes: first, the rainy period and the consequent entry of the waters of the lotic systems, and the flooding promote the reduction of ion concentration in the lakes (dilution process), and second the enrichment of the water lake. The first pattern was observed by Silva (1990) for the Baía de Acurizal and Porto de Fora (Pantanal Mato Grossense), Hamilton and Lewis (1987) for the Tineo Lake (Venezuela), Bonetto et al. (1984) for a lake from the lower Paraná River and Thomaz et al. (1997) for lakes from the higher Paraná River. The second pattern was found for lakes in Mogi-Guaçu River such as Mato Pond (Camargo, 1991), Infernão Pond (Nogueira, 1989, Dias-Júnior, 1990; Schwarzbold, 1992; Barroso, 1994) and Diogo Pond (Krusche, 1989; Barroso, 1994; Magrin and Senna, 1997; Peres and Senna, 2000c), for lentic and semilotic environments of the higher Paraná River (Rodrigues and Bicudo, 2001) and for the Amazonian lakes (Forsberg et al., 1988; Silva, 1991; Furch and Junk, 1993; Huszar, 1994). In Diogo Pond the effect of water enrichment caused by the entry of the Mogi-Guaçu River was evident during the rainy period, like other lakes already studied in the same floodplain.

In relation to sampling sites, results of five variables were statistically different (pH, DO, TDP, orthossilicate, and SOM) (Table 3). In comparison to the others two sites, littoral region (S3) had higher concentrations for DO, TDP, orthossilicate and SOM.

Gradual increase of water temperature was observed from limnetic to littoral zone (0.5º to 1.6ºC), although not significant different. This might be attributed to the small turbulence within the bank of the E. azurea. Similar trends were also observed by Nogueira (1989) for the Infernão Pond, by Camargo (1991) for the Mato Pond and by Howard-Williams and Allanson (1981) for an African Lake, whose temperatures were 0.5º to 2.0ºC higher within littoral region.

Higher DO values were probably associated to higher densities of primary producers (macrophytes and phycoperiphyton) within the littoral region. Total dissolved phosphorus (TDP) also showed higher levels in this region. Pieczynska (1990) pointed out that aquatics macrophytes were an important source of phosphorus to the lake, due to its liberation mainly during the senescence period. Camargo (1991) also confirmed the occurrence of high liberation of dissolved phosphates by macrophytes. Higher concentrations of orthossilicate in S3 (littoral region) were possibly due to the influence of sediments (turbulence during flood and low water depth during drought period). The higher concentration of suspended organic matter in S3 could be attributed to the periphyton/aquatic macrophytes complex present in the littoral region that function as a particulate material filter in this compartment, as pointed out by Jørgensen (1990a).

The land-water interface can strongly influences the lakes, through the intense recycle of nutrients, the organic material production and the flux of energy that confer an important role on the metabolism regulation of the system as a whole (Howard-Williams and Lenton, 1975, Wetzel, 1990; 1992; 1996).

At Diogo Pond (component 3) there was a separation between littoral region and the remaining sampling sites during all periods of the hydrological cycle. This result was related mainly to the higher concentrations of orthossilicate, suspended organic matter, dissolved oxygen and total dissolved phosphorus, in littoral region (S3) (Table 3, Fig. 3B). The variability of abiotic factors in Diogo Pond was also due to spatial scale (littoral-limnetic gradient) and could be more or less accentuated by the influence of the hydrological cycle phases. This way, during drought period, littoral region differed the most from the others sites.

Table 2 - Depth, water transparency and mean values of abiotic variables in the sampling sites for the studied periods at Diogo Pond

	November/96 (high water)			**February/97 (flood)**			**April/97 (low water)**			**August/97 (drought)**		
	S1	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Depth (m)	2.20	2.20	2.10	3.20	2.60	2.40	1.10	1.70	1.10	1.00	0.30	0.30
Transparency (m)	0.30	0.30	0.25	0.60	0.50	0.50	0.80	0.70	0.60	0.75	0.30	0.30
Temperature (^oC)	25.1	25.1	25.1	27.6	27.8	28.4	20.0	20.0	20.5	17.3	17.6	18.6
pH	6.81	6.80	6.82	6.34	6.30	6.66	5.92	6.04	5.92	6.31	6.29	6.22
Alkalinity (mEq/L)	0.44	0.45	0.47	0.26	0.26	0.26	0.08	0.09	0.08	0.11	0.10	0.10
DO (mg/l)	3.00	2.55	3.40	7.28	7.16	7.22	6.13	5.74	7.62	7.46	7.28	8.03
Conductivity (µS/cm)	64.50	64.20	66.50	30.50	31.00	30.50	14.70	14.90	14.8	16.81	16.81	18.68
NO_2 (µg/L)												
NO_3 (µg/L)	16.93	11.97	11.74	5.13	6.07	5.12	45.73	40.30	28.97	58.25	55.18	61.08
NH_4 (µg/L)	91.63	106.02	102.7	8.66	8.30	15.30	19.73	14.19	10.50	30.42	31.16	37.80
TN (µg/L)	181.34	156.22	200.26	35.88	38.81	31.55	191.78	192.76	203.85	241.68	197.32	271.36
TDP (µg/L)	7.82	8.60	11.11	9.39	7.67	9.54	4.22	4.07	4.07	7.67	7.82	9.08
TP (µg/L)	57.73	59.35	64.67	29.33	27.71	30.29	19.97	20.61	30.13	18.03	30.78	29.00
TN/TP (molar ratio)	7.0	5.8	6.8	2.7	3.1	2.3	21.4	20.9	15.0	29.8	14.2	20.6
SiH_4 O_4 (mg/L)	2.26	2.38	3.02	2.63	3.71	3.02	2.29	2.49	2.38	2.13	2.14	2.72
SIM (mg/L)	14.25	15.50	18.50	2.83	2.25	2.37	3.12	1.83	4.33	3.12	4.31	10.37
SOM (mg/L)	8.12	8.75	10.29	5.37	9.31	9.25	5.34	5.79	8.54	5.34	5.72	9.90

Table 3 - Results (*p* values) of variance analysis for physical and chemical variables of Diogo Pond (* Kruscal Wallis Test, ** Two Way ANOVA analysis ◆ results statistically significant)

Variables	**Periods**	**Sites**
Transparency*	0.056500	0.064400
Depth*	0.000000◆	1.000000
Temperature**	0.00018◆	0.097779
pH**	0.000000◆	0.004515◆
Alkalinity*	0.000000◆	1.000000
Conductivity*	0.000000◆	1.000000
DO**	0.000000◆	0.000547◆
NO_3**	0.000000◆	0.051570
NH_4*	0.000000◆	1.000000
TN**	0.000000◆	0.066341
TDP*	0.056500	0.003830◆
TP**	0.000000◆	0.064633
SiH_4O_4*	0.261500	0.003020◆
SIM*	0.004000◆	0.135400
SOM*	0.445900	0.015000◆

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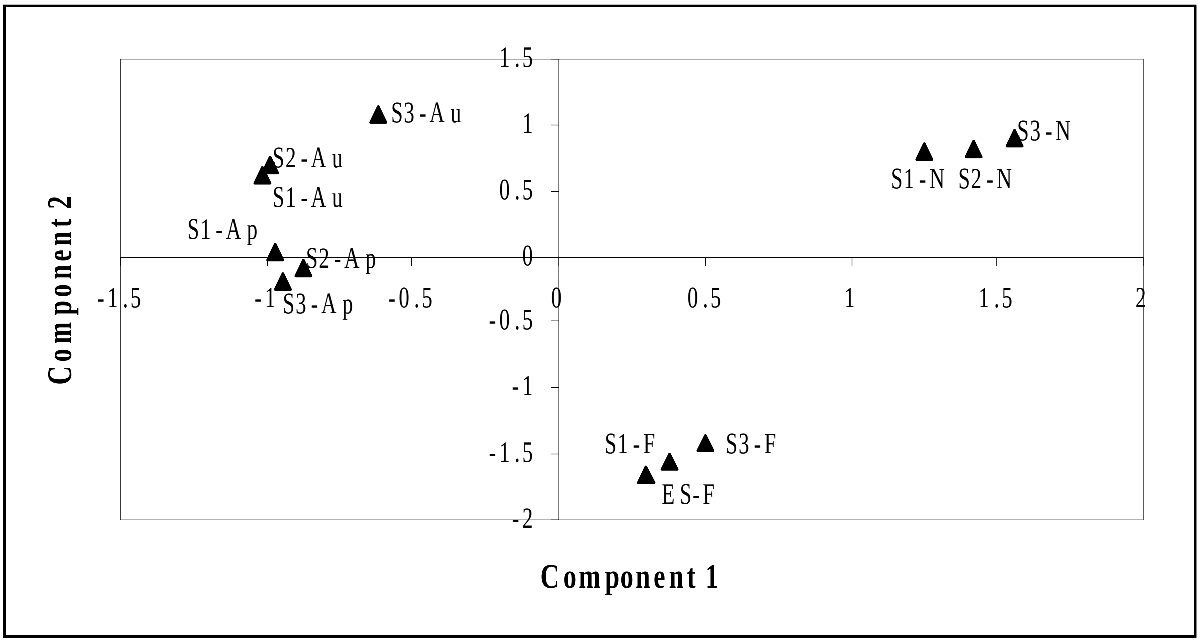

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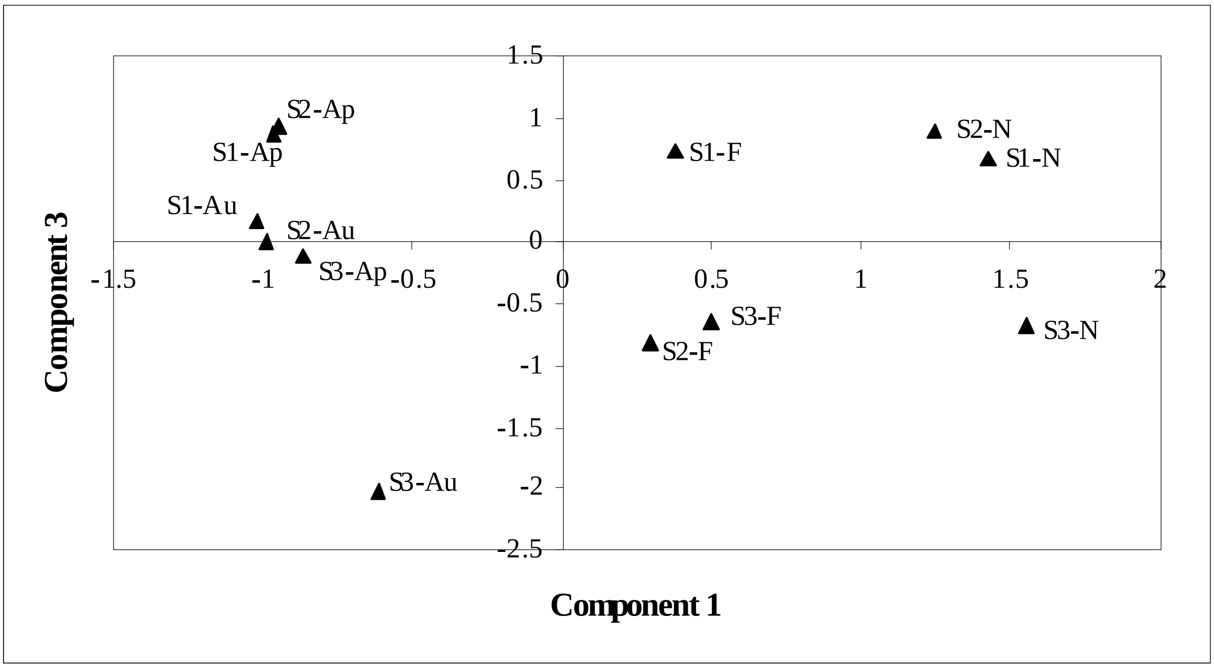

Figure 3 - PCA ordination of sampling sites and periods based on physical and chemical characteristics of Diogo Pond (N: November/96, F: February/97, Ap: April/97 and August/97).

Table 4 - Correlation of the physical and chemical variables with the principal components 1, 2, and 3 (*higher correlations).

Variables	Component 1	Component 2	Component 3
Temperature	0.825157	-0.548770	-0.008392
River depth	0.787447*	-0.585800	0.079549
Depth	0.696630	-0.644950	0.175628
Transparency	-0.609150	-0.048892	0.195731
pH	0.894651*	0.164937	-0.028901
Alkalinity	0.983878*	0.068045	0.133952
Conductivity	0.956384*	0.231660	0.163641
DO	-0.743361*	-0.386911	-0.455334
NO_3	-0.774142	0.578468	-0.100725
NH_4	0.737715*	0.638735	0.166119
TN	-0.360725	0.892745*	-0.025068
TDP	0.667581	0.052691	-0.502767
TP	0.859500*	0.397299	0.108601
SiH_4O_4	0.383689	-0.041049	-0.725437*
SIM	0.730689*	0.643960	-0.090603
SOM	0.569694	0.135418	-0.495843
% Variation explained Variation	55.35	21.45	8.82

Present results indicated for the littoral-limnetic gradient of the Diogo Pond that:

- temporal scale, established by the hydrological regime, was the main forcing function on the variability of abiotic factors. Three periods of hydrological cycle could be characterized: the high water period with higher values of alkalinity, conductivity, pH, total dissolved phosphorus, ammonium and inorganic suspended matter; the flood period with higher temperatures, river and pond depth, and the low water (drought period) mainly by the higher concentration of nitrate and dissolved oxygen;
- spatial scale in relation to the littoral-limnetic gradient also contributed to abiotic factors variability. The littoral region was characterized as a distinct compartment from the others regions (interface and open water) during all period of the hydrological cycle, mainly due to higher values of orthossilicate, suspended organic matter, dissolved oxygen and total dissolved phosphorus;
- the variability in the spatial gradient was influenced by the phases of hydrological cycle; and during the drought period littoral region differed the most from the others sites.

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RESUMO

O presente estudo visou analisar a variabilidade espacial de características limnológicas abióticas no gradiente litorâneo-limnético na lagoa do Diogo, planície de inundação do rio Mogi-Guaçu, bem como avaliar a influência do regime hidrológico no gradiente espacial. Quatro coletas foram realizadas durante o ciclo hidrológico (enchente, cheia, vazante e seca) e em três estações de amostragem: região litorânea, região limítrofe e região limnética. Através das análises de variáveis físicas e químicas pôde-se concluir que a escala temporal, determinada pelo regime hidrológico, foi a principal função de força sobre a variabilidade limnológica na lagoa do Diogo. A escala espacial relativa ao gradiente litorâneo-limnético contribuiu, secundariamente, com a variabilidade dos fatores limnológicos abióticos. A região litorânea foi caracterizada como um

compartimento separado das demais regiões em todas as épocas do ciclo hidrológico.

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