Seasonal and diel limnological differences in a tropical floodplain lake (Pantanal of Mato Grosso, Brazil).

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ABSTRACT: Seasonal and diel limnological differences in a tropical floodplain lake (Pantanal of Mato Grosso, Brazil). The present study supplies information on the structure and function of the Baía das Pedras, a floodplain lake at the Pantanal of Mato Grosso, emphasizing the role of the water level variation on its annual functioning and the internal ecological processes on its 24 hours functioning. The fieldwork was accomplished from September 1998 to April 2000. In the central area of the lake, limnological variables were monthly determined and the water was collected for chemical analysis. The same procedure was repeated during a 24 hours period, at the same station inside the lake, during the low and high water periods. To estimate the role of the caiman in the nutrient cycle in the lake, a controlled experiment was conducted, aiming to quantify the water enrichment by the feces. In the field, the population was numerically estimated by direct counting. The floodwater increases the depth of the lake and dilutes the suspended particulate, but introduces dissolved ions that increase the electric conductivity and the water pH. Along the day, changes of oxygen saturation are more intense than along the flood phases. The nutrient concentrations are higher at the drought than during the wet season, possibly due to the excretion of phosphorus by the animals, like caimans. The flood prevents the permanent eutrophication.
Key-words: floodplain lake, nutrients, eutrophication, caimans.

RESUMO: Variações limnológicas sazonais e diárias em um lago tropical de planície inundável (Pantanal de Mato Grosso, Brasil). O presente estudo apresenta um modelo de funcionamento do lago "Baía das Pedras", localizado em uma planície de inundação no Pantanal de Mato Grosso. O trabalho de campo se desenvolveu de setembro de 1998 a abril de 2000. Na área central do lago, foram determinadas algumas variáveis limnológicas e a água foi coletada para análises químicas. O mesmo procedimento foi repetido durante períodos de 24 horas, em dias típicos de estiagem e cheia. Para estimar o papel de *Caiman crocodilus yacare* na ciclagem de nutrientes na lagoa, um experimento foi realizado em condições controladas, visando estimar a velocidade de enriquecimento da água pelas fezes. Em campo, a população foi numericamente estimada por contagem direta. Os resultados mostraram que a água de inundação aumenta a profundidade do lago e dilui os sedimentos em suspensão, mas introduz íons dissolvidos que elevam a condutividade elétrica da água e o pH. Ao longo do dia, mudanças relacionadas à disponibilidade de oxigênio são mais intensas do que ao longo do ano. A elevada concentração de nutrientes, possivelmente influenciada pela concentração de animais como o jacaré na lagoa indica eutrofização, mas a inundação evita que este processo ocorra de forma permanente.
Palavras-chave: lago em planície inundável, nutrientes, eutrofização, jacaré.

Introduction

The Pantanal of Mato Grosso is generally defined as the floodplain of the upper Paraguay River (Hamilton et al., 1997). In the floodplain, there are many lakes locally called as "baías" that constitute dynamic aquatic ecosystems, whose seasonality is determined by the water level fluctuations. These small and shallow lakes are important refuge sites to animals such as caimans during the low water period, when the floodplain is drought and the water is permanent only in some sites of the landscape.

The ability of wetlands to cleanse water has received much attention in research and development (see Mitsch 1996 and Mitsch & Gosselink 2000 for a review). However, the natural eutrophication observed at some tropical lakes and the role of the flood controlling this process have been less described. Putz & Junk (1997) summarized results obtained at many Amazon floodplain lakes and concluded that at low water period transparency decreases, but the high levels of nutrients (about 0.15 $mg.L^{-1}$, total phosphorus) and low water depths (2-3m) result in maximum values of primary production per unit volume. When the river invades the floodplain at the rising water, transparency is slighting increased but the production is lower because of the dilution of the existing plankton community.

We postulate that this process is much more intense at the Pantanal floodplains, as a consequence of its wet-and-drought extreme climatic condition (Heckmann, 1996). In this context, the present study provides information on the structure and function of the Baía das Pedras, a typical floodplain lake in Pantanal, emphasizing the role of the water level variation on its annual functioning. We also evaluated the trophic state of the lake during the low water period by studying its internal limnological processes on its 24 hours functioning at both extreme climatic conditions (drought and wet period, what means low and high water levels in the lake). To the drought period, we discussed some preliminary results about the role of the caiman population by the feces production.

Study area

The Pantanal of Mato Grosso is located at Central Brazil, between the parallels 16° to 22° S and 55° to 58° W. It occupies an area around 140.000 km^2, representing 35% of the total Paraguay River Basin surface. During the drought period (May to September) the precipitation is low (less than 100mm by month) and the water levels decrease (low water period). During the wet period (October to April), the rains are very frequent and the precipitation is around 300mm by month (Carvalho, 1986) (high water period). Air temperature is high all year round (25.1°C, annual average), ranging from 27.4°C (average in December) to 21.4°C (average in July) (Tarifa, 1986). The highest values, observed from August to November, can exceed 40°C.

During the wet period, the lake receives the river water indirectly throughout the floodplain. Different aquatic plants can be observed in this period: *Eichhornia*, *Polygonum*, *Ludwigia*, *Xyris*, and *Nymphoides*, among others. During the drought period, the lake is used as habitat for many animals like caiman, capybara, giant fish otter, and different bird and fish species. Machado (pers. com.) registered 46 fish species at the lake during the low water period, representing almost 18% of the total fish species of the whole Pantanal. Like other sites in Pantanal, the landscape changes completely during the wet period; when the water level is higher most of those terrestrial animals migrate to drier places and the fishes start their migration to the rivers.

Methods

Annual evaluation

The fieldwork was accomplished monthly from September 1998 to August 1999 at around 8:00 a.m. In the central area of the lake, in the surface, middle and bottom layer, some limnological variables were determined: temperature, dissolved oxygen, pH and electric conductivity of the water with specific electrodes (Mettler Toledo); depth and transparency (by a graduate rope and Secchi Disk). We also measured the air temperature. Water samples in triplicate were collected with a van Dorn bottle, at the same layers. The samples were filtered (Millipore 0.45µm) for the determination of the suspended particulate concentration (Teixeira et al., 1965). Total phosphorus

(P_{total}) and orthophosphate (PO_4^{3-}) (Allem, 1989) were performed only for the surface samples. Differences among the average values were tested (One Way ANOVA/Tukey, significance level=0.05, SPSS 9.0).

24 hours evaluation

In September 1999 and April 2000 observations were accomplished along 24 serial hours at the water column (surface, 0.70 , 1.40 , 2.20 m in September and surface, 1.20, 2.40 , 4.50 m in April), in the central station of the lake. The same variables (temperature, dissolved oxygen, pH and electric conductivity of the water, depth and transparency) were observed at the water column every two hours, and the water was sampled for the chemical analyses (P_{total} and PO_4^{3-}) in a four hours interval.

The role of the caymans during the drought season

To evaluate the contribution of *Cayman crocodilus yacare* regarding nutrient enrichment by feces in the water at Baía das Pedras, we accomplish an experiment in controlled conditions at the Federal University of Mato Grosso State's Zoo (UFMT Zoo). To extrapolate the results for field conditions, an individuals' direct counting was made in September 1999. The lake was divided at bits of 20 m of width with stakes, totalizing 20 bits. We tied phosphorescent ribbons plastic at the stakes, so the bits were visualized at night with common lights. We organized five groups of two people each, remaining each group in a bit. The groups stayed in the lake margins and did the direct counting in intervals of five minutes, time enough for each component of a group to count twice. So, each group counted four times inside a same bit. After each counting the groups took new positions quickly for the next bits counting, until all of the groups had gone through all the bits. This procedure resulted on a total of 80 counting by each group, totalizing 400 countings.

At the UFMT Zoo, a tank of 8 X 6 m^2 (1,680 L), protected against the sun and the rain, was filled with tap water and daily determinations of conductivity were made. One single caiman was kept in the tank for 25 days. The caiman (2.15 m and 51.5kg), was fed every day with fresh fish (around 300g, including the viscera). The fish species were *Predoradoras granulosus*, *Pimelodus maculatus*, *Prochilodus lineatus* and *Hypostomus* sp, following the normal procedure in the Zoo. The food was supplied to the animal at the drought part of the area to avoid the contamination of the tank water.

Six water samplings (in triplicate), three before and three after the caiman's introduction in the tank, were carried out for total phosphorus (P_{total}) and orthophosphate (PO_4^{3-}) determinations. To estimate the phosphorus daily liberation, the difference between the stocks on the subsequent days was computed. The number of caimans estimated in the field multiplied the daily average value.

Results and discussion

During the year, significant differences between depths were not observed for temperature (p=0.507), pH (p=0.658), conductivity (p=0.996) and suspended particulate (p=0.382), but differences were significant among months (p=0.001). Regarding the dissolved oxygen significant differences were detected between depths and among months (p=0.001 and p=0.009 respectively). The highest (168% sat.) and the lowest (zero) oxygen concentrations occurred during the low water period at the surface and at the bottom layer, respectively.

Baía das Pedras was characterized as a tropical shallow lake, controlled by the regional water level variation along the year (Fig. 2). Low transparency occurs during the low water period (r^2 = 0.89); conductivity and pH values are higher during the beginning of the flood period, as the suspended particulate concentration presented a dilution effect.

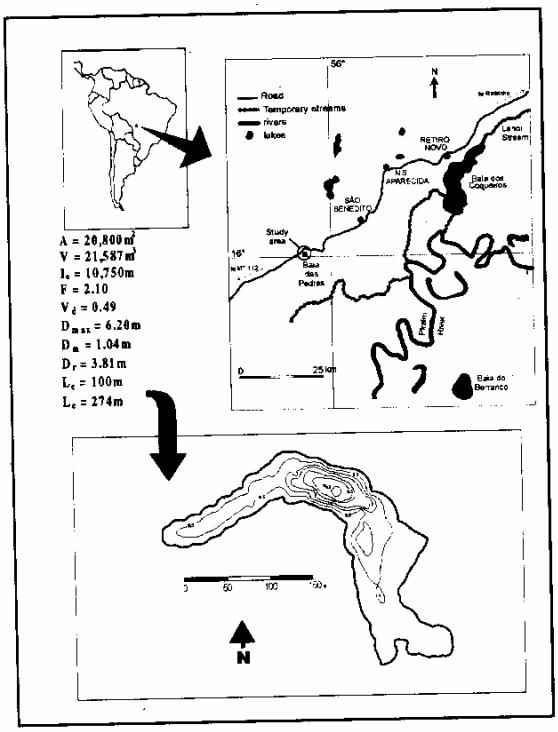

Figure 1: Baía das Pedras lake, Pantanal of Mato Grosso, Brazil. A = surface area (m^2), V = volume (m^3), l_o = shoreline (m), V_d = volume development, F = shoreline development, D_{max} = maximum depth (m), D_m = mean depth (m), D_r = relative depth (m), L_c = maximum effective width (m), L_e = maximum effective lenght (m).

Cooper et al. (1998) studied small and turbid ponds in East Africa and observed the same pattern, with conductivity and total nitrogen and phosphorus increasing during the drought season. Mitsch & Gosselink (2000) pointed that summer algal blooms can actually cause nutrient concentration to be higher under the low-flow conditions typical of late summer in many streams in the Midwestern United States. At the Baía das Pedras lake, the patterns are also similar to the ones described in other aquatic systems in Pantanal (Heckman 1996; 1998) and in the Paraná River floodplain (Pagioro, 1996). However, in other tropical systems like the oxbow lakes at the Mogi-Guaçu River, there is an input of solid particulates and ions from the floodplain during the flood that result in lower transparency and higher oxygen consumption (Nogueira et al., 1996).

The chemical variations along the year in respect to phosphorus concentrations in the surface water are also showed in Fig.2. Significant differences between months ($p=0.000$ regarding to P_{total} and PO_4^{3-}) were observed, indicating different conditions between the low and the high water periods. Baía das Pedras is a hypereutrophic lake during the low water period, when compared to other lakes, as in Africa or Europe, for instance. Total phosphorus are almost ten times higher than that observed by Yusoff et al. (1997) in a shallow eutrophic lake in Africa (0.2 ± 0.008 mg.L^{-1}) and by Gervais et al. (1999) in Germany (0.12 mg.L^{-1}).

An evident input of phosphorus ions during the beginning of the wet season was recorded, and along the drought season the total phosphorus concentration becomes higher. During this period, there are no direct connections among the lake and other water bodies, no expressive agricultural activities on the base that could contaminate

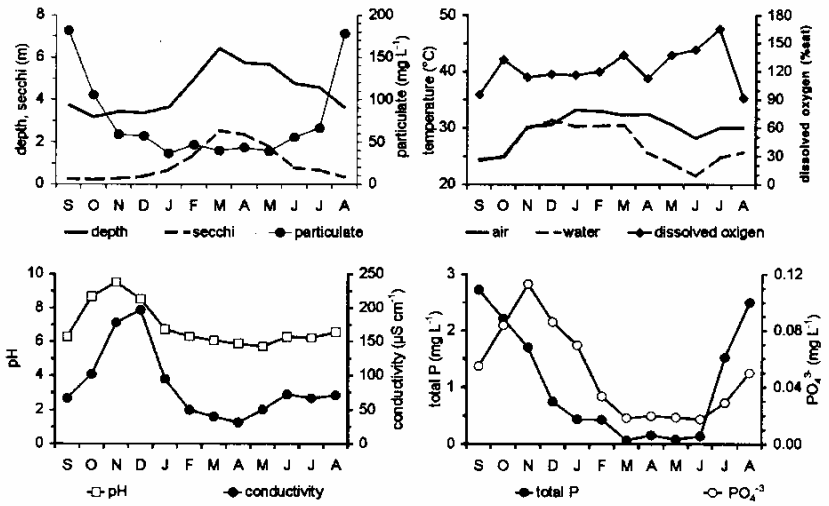

Figure 2: Seasonal variations of particulate solids, pH and conductivity (from surface, middle and bottom layers) and dissolved oxygen and phosphorus (total P and PO_4^{-3}) at Baía das Pedras lake.

the aboveground water and the rains are uncommon. Two processes may promote an increase in P_{total}: the evaporative concentration and the input of animal feces. Taking into account the high temperature values (around 35°C) during the day and the lack of rains, the evaporation is an important process to the Baía das Pedras, as also showed by Melack (1988) for a shallow equatorial lake in Kenya. The input of animal feces seems also to be an important contribution to water nutrient concentration.

The night and day extreme variations on typical low and high water periods were observed at 2:00 a.m. and 2:00 p.m. (Figs. 3 and 4). As in other tropical and equatorial lakes (Petterson & Wilson, 1995; Esteves, 1998), the changes in a diel cycle were more intense for some variables, such as oxygen, than in a seasonal limnological cycle, mainly during the low water period. Esteves et al. (1994) studied two Amazonian lakes and observed that the distinct daily thermal patterns determine the behavior of the other limnological variables. At Baía das Pedras, the temperature is almost constant at the bottom layer along the 24 hours interval during the drought period (26.5 ± 0.2 °C), but the lake is thermally stratified between 12:00 and 8:00 p.m., with a gradient up to 5.1°C between the top and the bottom layer. Stratification is also observed for pH (9.6 to 7.2 at the top and bottom layer, respectively, at 10:00 a.m.) and water conductivity between 10:00 a.m. and 10:00 p.m. (86.0 to 63.5 at the top and bottom layer, respectively, at 4:00 p.m.). However, the changes of the dissolved oxygen are more intensive than to the other variables. The water column is completely oxidized between 4:00 and 10:00 p.m. (120.8 ± 34.3 % sat. on average), but during the dawn (0:00 to 6:00 a.m.) the concentrations are very low. As the bottom layer is anoxic for more than 50% of the 24 hours period (between 0:00 a.m. and 2:00 p.m.), it is common to observe fishes coming to the surface to breath. At the early morning (around 6:00 a.m.), the fishes are completely stressed by the low oxygen concentrations and are easily captured by the alligators (*Caiman crocodilus yacare*). The total phosphorus and orthophosphate concentrations did not present linear correlation to any other variables during the both 24 hours periods.

No stratification was observed regarding température and pH during the diel interval at the high water period. For temperature, the highest difference between the

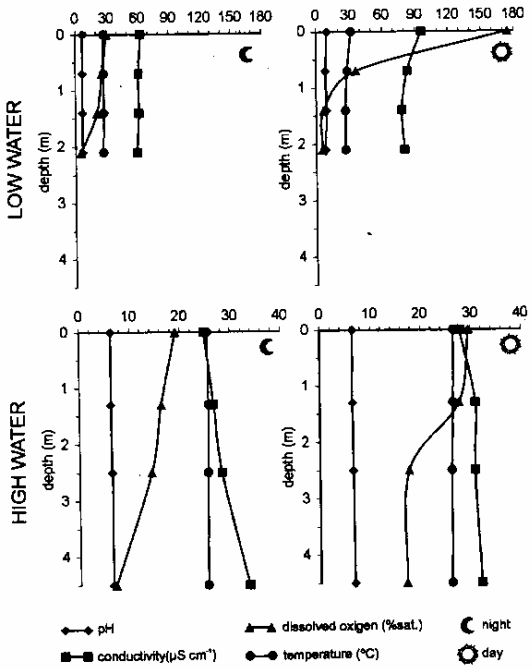

Figure 3: Diel variations on limnological characteristics during the low and high water periods at Baía das Pedras lake

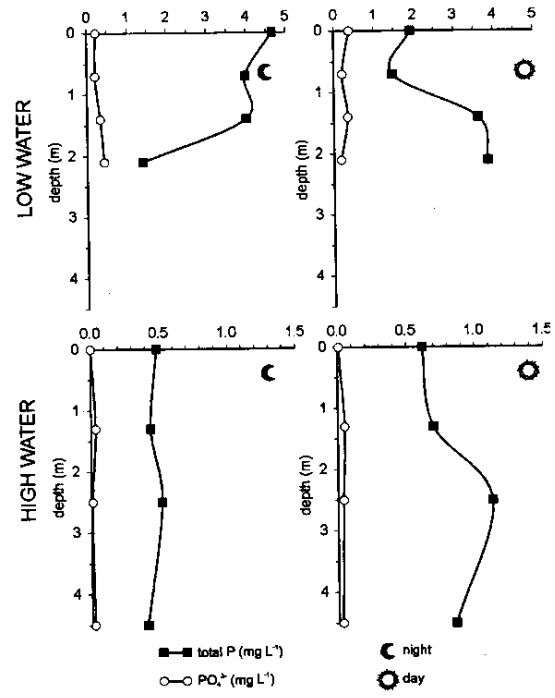

Figure 4: Diel variations on P_{total} and PO_4^{3-} concentrations ($mg.L^{-1}$) during the low and high water periods at Baía das Pedras lake.

top and the bottom layer was only 0.7°C at 12:00 p.m. The conductivity values, however, were slightly higher at the bottom layer along all the diel cycle, with differences around 4 to 11 µS.cm^{-1} from the top to the bottom layer, at 2:00 p.m. and 0:00 a.m. respectively. Lower values detected for conductivity during the diel cycle at the high water period confirm the dilution effect by the water that comes from the floodplain. The oxygen stress seems is constant along the year during the dawn, because even with "new water" from the floodplain, the saturation was lower than that observed during the low water period. The bottom layer presented values lower than 10% saturation during more than 30% of the 24 hours period (between 2:00 and 10:00 a.m.). Lower values also occur at the top layer, mainly during the early morning (6:00 to 8:00 a.m.).

Water enrichment, based a single animal and in controlled conditions, showed that caiman released c.a. 1.32 g P_{total}.day^{-1} (Fig. 5). The caiman population was estimated in about 983 individuals (n=400), and thus excreted c.a. 1.27 kg.day^{-1} of total phosphorus to the lake.

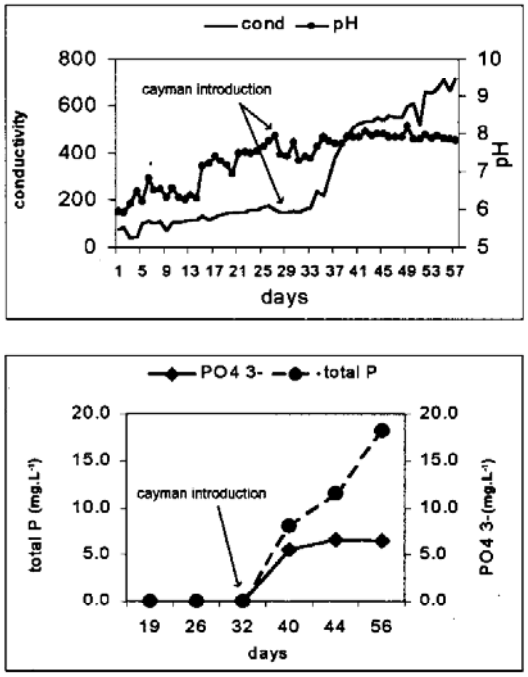

Figure 5: Electric conductivity (µS.cm^{-1}) and pH, P_{total} and PO_4^{3-} concentrations (mg.L^{-1}) during the controlled experiment with *Caiman crocodiles yacare*.

Fittkau (1973) performed similar experiments and estimated an increase of about 1.5 mg.L^{-1} of phosphorus in the water from an hypothetical lake containing around 4,000 (c.a. 50 kg each) Amazonian caimans, in 10 days. This kind of input could be enough to elevate the primary production of the Amazon lakes. Cooper et al. (1998) also emphasized the animal contribution to the nutrient cycle of small lakes. Adding planktivorous fishes to the lakes, they observed a very fast increase in phosphorous concentration. The same pattern seems to occur in the Baía das Pedras lake. The high animal density (caiman and fishes) in a small water body produces a high feces liberation. After the feces decomposition in the water, the dissolved nutrients are

able to support a high primary production level, since the strong greenish color of the water was observed in this period.

The pulse of annual flood controls the functionning of Baía das Pedras lake. The flood increases the depth and dilutes the suspended particulate, but introduces dissolved ions that increase the water electric conductivity and pH. Along the day, changes in oxygen saturation are more intense than along the flood phases. During the low water period, the floodplain is drought and the high density of terrestrial animals near the lake cause transient eutrophication. The flood dilutes nutrients and avoids permanent eutrophication. As the pulse is periodic and previsible, the predictability of seasonal and diel events is high. In this context, any conservation strategy must guarantee the water exchange between the river and other aquatic systems for maintain the natural hydrological and nutrient regimes of the small lakes in the floodplain.

Acknowledgments

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