Implications of the flood pulse on morphometry of a Pantanal lake (Mato Grosso state, Central Brazil).

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ABSTRACT: Implications of the flood pulse on morphometry of a Pantanal lake (Mato Grosso state, Central Brazil). Floodplain lakes are the most common lentic water bodies in the tropics. They are typically shallow and submitted to a recurrent and predictable seasonal cycle. The effects of the flood pulse on the morphometry of a Pantanal lake, localized in Mato Grosso (Coqueiro lake - 16º 15' 12" S; 56º 22' 12" W), were analyzed. The air temperature, precipitation and hydrometrical level of Cuiabá River were measured monthly (April 2002 to May 2003). The batimetric survey of Coqueiro Lake was carried out during low (November 2002) and high (March 2003) water periods using a limnetic ruler and a GPS L1 Trimble (Pathfinder Pro XRS). Depth measurements were taken every 50 meters in 17 profiles perpendicular to the largest axis of the lake. This is an elongated system, which area ranged between 2.2 and 2.5 km^2, average depth varied from 0.7 to 1.5 m and the volume from 1.51 to 3.64x10^6 m^3 between low and high water, respectively. The rising and high water periods directly influence the variation in the volume and mean depth of lake. During the high water there is a strong connectivity between Coqueiro lake and the floodplain of the Cuiabá River. Based on the data of this study, it was possible to define that the Coqueiro Lake is connected to the rest of the floodplain when the hydrometric level of the Cuiabá River in at Porto Cercado reaches about 3.0 m. The morphometric variation of the lake indicates a strong interaction with the floodplain. Thus, the flood pulse played a fundamental role in the morphometric alterations of Coqueiro Lake.

Key-words: morphometry, hydrology, wetlands, floodplain lake.

RESUMO: Implicações do pulso de inundação sobre a morfometria de uma lagoa do Pantanal (Mato Grosso, Brazil Central). As lagoas nas planícies de inundação são os corpos d´água mais comuns nos trópicos. Elas são tipicamente rasas e submetidas a um recorrente e previsível ciclo sazonal. Foram analisados os efeitos do pulso de inundação na morfometria da lagoa do Coqueiro, localizada no Pantanal, Mato Grosso, Brasil Central (16º 15' 12"S; 56º 22' 12"W). A temperatura do ar, precipitação e nível hidrométrico do rio Cuiabá foram medidos mensalmente (abril 2002 a maio 2003). O levantamento batimétrico da lagoa do Coqueiro foi realizado durante as águas baixas (novembro 2002) e altas (março 2003) usando uma régua limnética e um GPS L1 Trimble (Pathfinder Pro XRS). As medidas de profundidade foram tomadas a cada 50 metros em 17 eixos perpendiculares ao maior eixo da lagoa. O sistema é alongado e os dados morfométricos variaram entre 2,2 e 2,5 km^2 de área; entre 0,7 e 1,5 m de profundidade média; e de 1,51 a 3,64x10^6 m^3 de volume nas águas baixas e altas, respectivamente. O período de enchente e águas altas influência diretamente a variação no volume e profundidade média da lagoa. Durante as águas altas há uma forte conectividade entre a lagoa do Coqueiro e o rio Cuiabá. Baseado nos dados deste estudo, é possível afirmar que a lagoa do Coqueiro conecta-se ao restante da planície de inundação quando o nível hidrométrico do rio Cuiabá em Porto Cercado atinge 3,0 m. A variação na morfometria da lagoa indica uma ampla interação entre este corpo de água e a planície de inundação, desta forma, o pulso de inundação teve papel definidor nas alterações morfométricas da lagoa do Coqueiro.

Palavras-chaves: morfometria, hidrologia, áreas úmidas, planície de inundação.

Introduction

Floodplain lakes are the most common lentic water bodies in the tropics (Lewis, 2000). They are typically shallow and submitted to a recurrent and predictable seasonal cycle (Hamilton et al., 2002). During floods, their dimensions can increase orders of magnitude in area and volume, becoming indistinguishable on the floodplain (Lesack & Melack, 1995). The Pantanal, located in the state of Mato Grosso, Central Brazil, is an extensive flooded area (140,000 km^2) of the (Paraguay river basin) recognized by UNESCO as a World Biosphere Reserve (www.mma.gov.br). It includes innumerable floodplain lakes, which are shallow and interconnected open systems with fluvial hydrodynamics typical of floodplains. They are submitted to fluctuations in the water level and to inflow and outflow of matter, including organisms from lotic systems, through channels that interconnect the main rivers of the drainage basin (Henry & Costa, 2003). Thus, hydraulic connectivity can convey matter and energy between the various floodplain systems.

Morphometrical aspects, although little evaluated in Pantanal region (Pinto-Silva, 1980; Nogueira et al., 2002), are important tools for management practices in aquatic ecosystems. In addition, environmental morphometry, by acting directly on the dynamic of the abiotic variables, including the hydrological processes of the system (Sperling, 1999), becomes fundamental for understanding the spatial and temporal distributions of the aquatic communities in general. As far as is known, the morphometry of floodplain lakes has seldom been evaluated in Brazil (Melack, 1984; Sippel et al., 1992; Panosso et al., 1995; Komatsu, 2003).

In the present study, we hypothesized that floods determine variation in morphometrical parameters of Coqueiro Lake. Thus, our goal is to analyze the effects of the flood pulse on the morphometry in a Pantanal lake.

Material and methods

Study site

Coqueiro Lake (Fig. 1) is located in "Pantanal de Poconé" region (15,800 km^2) state of Mato Grosso (16° 15' 12" S; 56° 22' 12" W) and belongs to the Cuiabá river (affluent of the Paraguay River) basin. During the rising and high water periods, it establishes a connection to the Piraim River, by which it connects to the Cuiabá River. The water overflow results in an extensive flooded area, with a water level ranging from 0.4 to 1.0 m, depending on the nearness to the body of water and the intensity of the floods. In this phase, there is an expansion of the marginal banks of emerged aquatic macrophyte Eichhornia azurea (Silva, 2002), in addition to other free-floating macrophyte species. The regional climate type is A_w (Köppen classification): hot and humid, with rains in the summer and drought in the winter (PCBAP, 1997). The range of the historical annual total precipitation is from 800 to 1600 mm and the annual mean temperature fluctuates between a maximum of 29 to 32°C and a minimum of 17 to 20°C (PCBAP, 1997).

Batimetry

The batimetric survey of Coqueiro Lake was carried out during low (November 2002) and high (March 2003) water periods using a limnetic ruler and a GPS L1 Trimble (Pathfinder Pro XRS). Depth measurements were taken every 50 meters in 17 profiles perpendicular to the largest axis of the lake using a map (scale: 1:250,000) as a reference. The batimetric map was made, and the lake area and volume were obtained using the software Surfer 7.0. The relative, mean and maximum (z_{max}) depths, shoreline and volume development index, lake cavity shape and hypsographic curve were calculated according to Hakänson (1981).

Climatology and hydrology

The monthly data of air temperature, wind and precipitation data were provided by the 9th Meteorological District, located at 80 km from the study area. The hydrometric level (HL) of the Cuiabá river in Porto Cercado was obtained through ANA (Agência Nacional de Águas - http://www.hidroweb.ana.gov/hidroweb/). Lake depth was monthly measured in the deepest area.

The elasticity coefficient was computed according to Neiff (1999). We considered elasticity as the ratio between, on one hand, the maximum area and volume at high water during an hydrological cycle, and, on the other hand, the surface area and volume of the lake, at the time it disconnected with the Cuiabá River (when the river stage drops below 3.0 m). The fluvial connectivity was estimated calculating the Fluvial Connectivity Quotient (FCQ) for one hydrological cycle (2002-2003), according to Neiff & Poi de Neiff (2003).

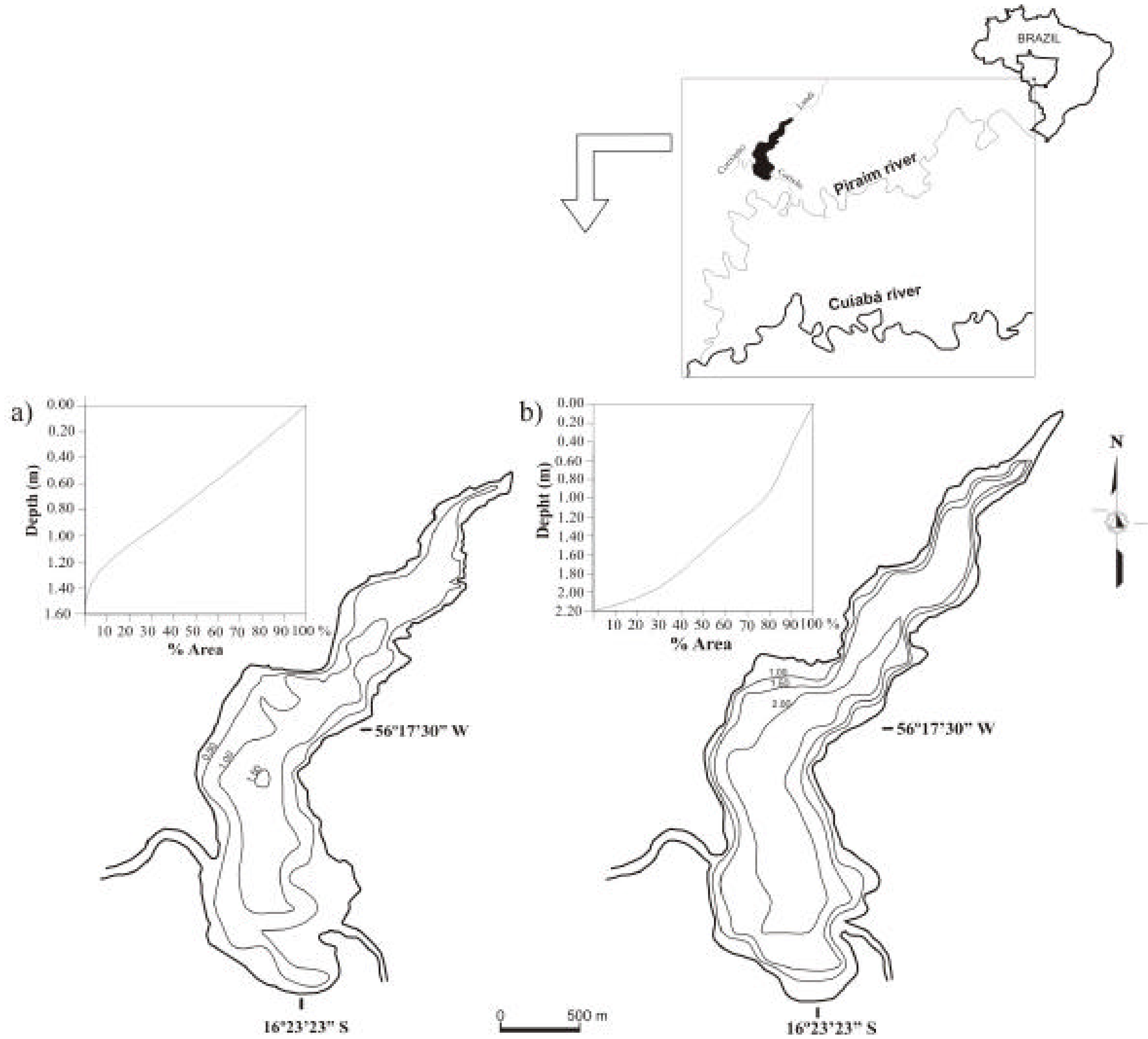

Figura 1: Location and batimetric maps of Coqueiro lake a) low water and b) high water, showing the respective hydrographic curves.

Results

Morphometry

Coqueiro lake has an elongated shape and is characterized as a permanently shallow (< 2.5 m) system, independent of the phase of the hydrological cycle. Drastic reduction in the water volume occurs during the falling and low water phases, leading to a maximum depth 35% lower than in the high water phase (Tab. I). The lake area was 2.5 km^2 in the high water period (HL = 4.3 m), which was 10% (2.3 km^2) larger than in the low water period (HL = 2.2 m; Tab. I). The flood process of the Pantanal resulted, during high water, in an increase on the morphometrical values, especially in the water volume (130%), mean depth (65%), maximum depth (30%) and development of the volume index (35%), if compared to the low water phase. The other parameters increases of about 10% (Tab. I).

The topography shows a gentle slope between the margin and its deepest part, which is shown by the small difference between the maximum and mean depth (Tab. I; Fig. 1). The littoral of the lake does not present great sinuosity, indicated by the reduced value of the shoreline development index, which did not present marked variability between the low and high water periods. The concave "U" shape of the accumulation basin is expressed by the volume development index and the small difference between z_{max} and z_{mean} (Tab. I). According to hypsographic curves, the shape of the cavity is linear in the low water phase and slightly concave in the high water phase (Fig. 1a and b).

Table I: Morphometrical parameters of Coqueiro Lake during low water (November 2002) and high water (March 2003) periods.

Parameters	Low water	High water
Area (km^2)	2,22	2,50
Volume (10^6 m^3)	1,51	3,64
Maximum lenght (km)	4,01	4,50
Maximum width (km)	0,98	1,10
Index of development volume	1,28	1,94
Index of development shoreline	1,95	1,97
Shoreline extension (km)	10,4	11,1
Maximum depth (m)	1,6	2,3
Mean depth (m)	0,7	1,5
Relative depth (%)	0,10	0,13

The morphometrical characteristics and the hydrological regime defined the occurrence of two well-defined compartments: one in the southern part of the lake, under the influence of the fluvial flow during the rising and high water periods, where the greatest depths of the system are observed, and one in the northern part of the lake with lower mean depths. Although this region is not directly connected to the Piraim River, during the high water phase, a temporary channel drains the water from the adjacent fields.

Climatological and hydrological variables

During the study period, both the annual total precipitation (1,259 mm) and the annual mean temperature (27° C) were within the climatological patterns of the region, if compared to the historical means (800-1,600 mm and 26° C, respectively). The monthly mean of the air temperature fluctuated from 10.9° C in July 2002 to 39.8° C in August 2002 (Fig. 2a). The monthly mean precipitation variation in the Cuiabá region, referring to the period April 2002 to May 2003 (Fig. 2a), followed the regional pattern, with maximum precipitation in December 2002 and January 2003 (203 and 298 mm, respectively) and minimum in June and July 2002 (0.5 and 7.7 mm, respectively). The monthly means of the maximum wind velocities in the region varied from 1.7 to 5.7 m s^{-1}. The predominant direction was north, except in August 2002, April and May 2003 when it was the opposite. Both directions coincided with the longitudinal axis of the lake. The period of higher maximum wind velocities was coincident with the lowest lake depths (November and December 2002).

Even though the highest precipitation had occurred between October 2002 and January 2003 (period II, characterized by reduced depths in Coqueiro Lake), the elevation in the hydrometric level of the Cuiabá river in this region began only in December 2002. However, the effects on the lake depth occurred only after about one month (January 2003), reaching maximum values in April 2003 (Fig. 2b). Thus, the variability in the depth of Coqueiro Lake was significantly related ($p < 0.0001$) to the hydrometric level of the Cuiabá river ($r^2 = 0.64$), but not to rainfall ($p = 0.798$).

Thus, the elevation in the hydrometric level of the Cuiabá river is the main factor in the reestablishment of the connectivity between the lake and the other environments of the drainage basin. Based on the data of this study, it was possible to define that Coqueiro Lake is connected to the rest of the floodplain (Fig. 3 - regression line hydrometric level vs lake depth), when the hydrometric level of the Cuiabá river in Porto Cercado reaches about 3.0 m.

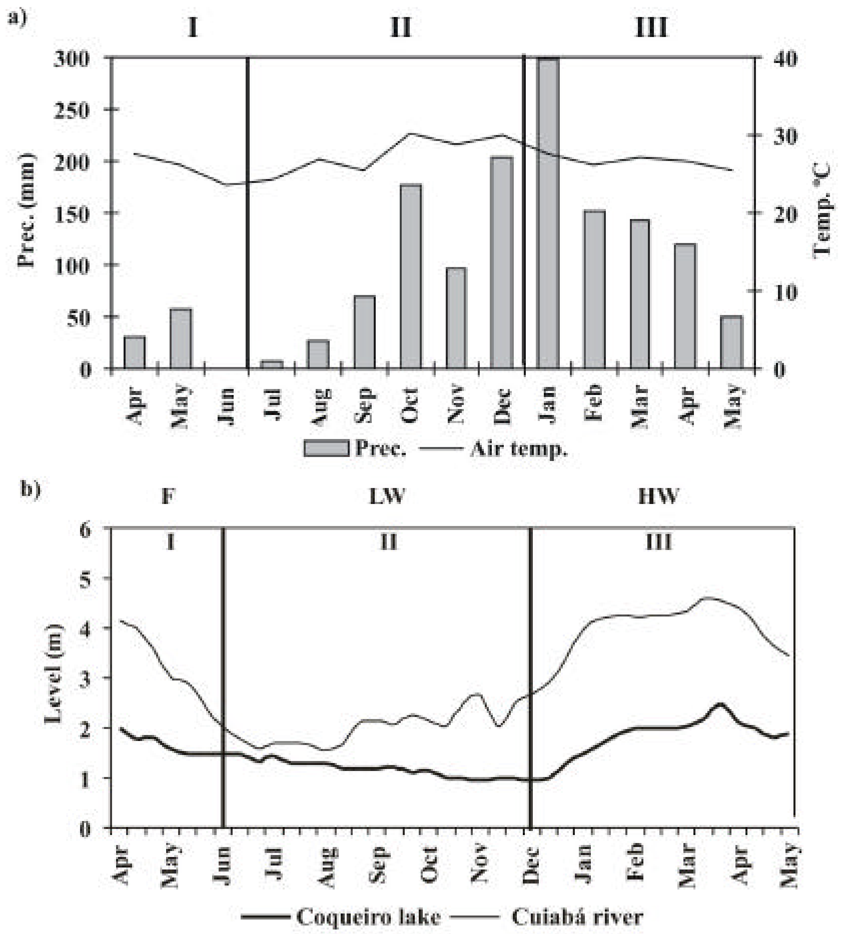

Figure 2: Variation in a) monthly total precipitation (prec.) and monthly average air temperature (temp); b) hydrometrical level in Cuiabá river and maximum depth in Coqueiro lake. (Period I=falling, F; period II = low water and the beginning of the rising phase, LW; period III= high water, which includes also the end of the rising phase and the beginning of the second falling phase, HW).

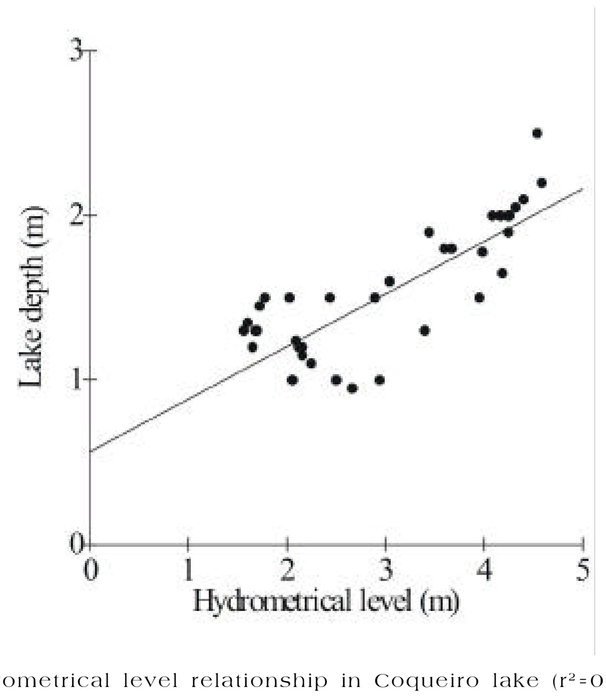

Figure 3: Lake depth – hydrometrical level relationship in Coqueiro lake ($r^2=0.64$; $p < 0.0001$; $n=40$).

The elasticity coefficient of the Coqueiro Lake was 1.13 for surface and 2.41 for volume. The lake remained disconnected for 240 days (from 20/05/2002 to 13/01/2003) and was connected to the Cuiabá River for 152 days (14/01/2003 a 14/06/2003). The Fluvial Connectivity Quotient (FCQ) yielded a value of 1.58.

The historical variability in the monthly mean of the hydrometric level of the Cuiabá river (1970-2003, interrupted from 1989 to 1992) showed that the period studied corresponded to intermediate hydrometric levels averaging 2.3 and 2.5 in 2002 and 2003, respectively (Fig. 4). A higher monthly mean (4.5 m) occurred in April 2003 (Fig. 4). It should also be emphasized that the study period followed two years of very low mean levels (1.5 and 2.6 m), similar to 1998. It was coincident with the filling period of Manso Reservoir, which is located upstream of Cuiabá river drainage basin (1999-2001).

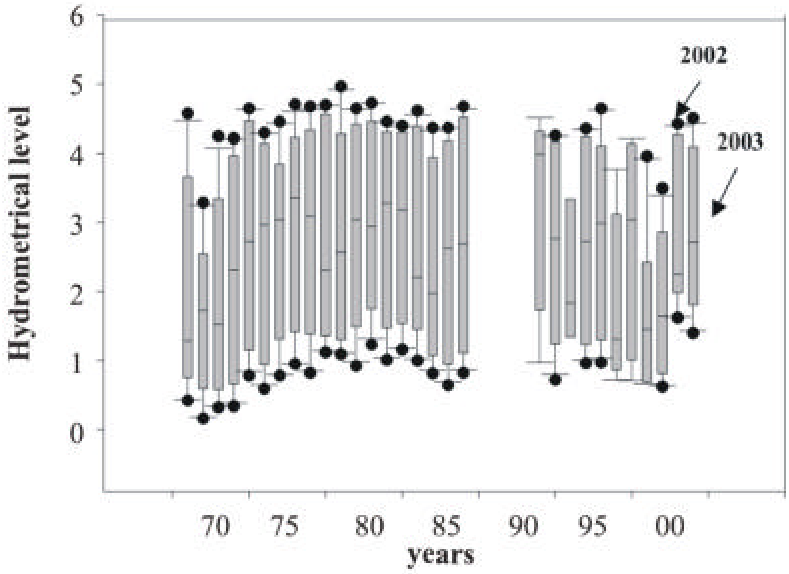

Figura 4: Annual variation in hydrometrical level of Cuiabá River in Porto Cercado, Poconé during 1970 to 2003 showing the sampling years of this study. (Line within boxes is the median, boxes, whiskers and dots encompass 75, 90 and 95% of the data, respectively).

Discussion

The influence of the hydrological pulse on the dynamics of the structure and metabolism of tropical aquatic floodplain ecosystems overlaps the seasonality of the conditions defined by the annual cycle of solar radiation and temperature, the main regulator of the processes in high latitude lakes. The periodic innundation of the extensive area of the Pantanal, resulting from the flooding of the main rivers that integrate the hydrographic basin, is responsible for the formation of lakes through the filling of depressions (Esteves, 1988), forming shallow systems (‹ 10 m, Barbanti, 1985), which are directly or indirectly interconnected among themselves and the main river (Pinto-Silva, 1980; Nogueira et al., 2002).

The elevation in the hydrometric level of the Cuiabá River is the main factor responsible for the reestablishment of connectivity between Coqueiro lake and other environments of the drainage basin. When the hydrometric level reaches about 3.0 m, it coincides with the entrance of water into the lake. Thus, only part of the variability in the depth of the lake was explained by the variations in the hydrometric level of the Cuiabá River, because the lake remained disconnected from the river during most of the phases of the annual hydrological cycle. During the low water period, the relationship between the hydrometric level and the depth of the lake is inverse and significant because both systems are disconnected. Other factors may also play a role, for example: i) the deepening of the water table, as demonstrated for the Coqueiro lake region by Corrêa-Neto (2000) and ii) more recently, the handling of Manso reservoir (built in the Manso river, affluent of the Cuiabá river upstream from the Pantanal), whose filling occurred between 1999 and 2001. Positive and significant relationship (r^2 = 0.30; p = 0.0003) between the outflow of the reservoir (FURNAS, unpublished data) and the level of the Cuiabá River was verified during the study period (April 2002 to May 2003). Historical data (1970-2003) of the hydrometric level of the Cuiabá River (http://www.hidroweb.ana.gov/hidroweb/) demonstrated that during the filling phase of the reservoir, the hydrometric levels of the Cuiabá river reached very low values (1.73 m), near the minimum recorded during El Niño years (e.g. 1998 - 1.83 m). However, two years later they stabilized at mean levels near historical intermediate levels.

Precipitation is similar in the entire floodplain, with higher values usually recorded during the rising and high water phases (Oliveira, 1999; Silva, 2002; Nunes, 2003). However, the local rains have little influence on the variation in the lake depth. Indeed, the increase in the hydrometric level of the Cuiabá River in the region of this study occurs about two months after the beginning of more intense local precipitation. Because of the reduced slope of the terrain and the sinuosity of the river course, water accumulates and floods the plain and its bodies of water. In Coqueiro Lake, this effect is delayed about one month, compared to other upstream systems connected directly to Cuiabá River, like Sinhá Mariana and Chacororé lakes (Da Silva & Figueiredo, 1999).

The variation in water volume and mean depth of the water bodies during rising and high water phases is determined by the amplitude of the flood and by the connection to lotic environments (Henry & Costa, 2003; Henry, 2005). The establishment of this river-lake connectivity implies alterations in the physical regime, promoting acceleration of the processes of sedimentation in more shallow areas and increasing the concentrations of suspended material and water turbidity. This pattern is comparable to other inundation lakes in South America (Carvalho et al., 2001; Abdo & Da Silva, 2004; Loverde-Oliveira & Huszar, 2007). Although this connection is reestablished cyclically, the quite regular contour of the lake margin demonstrates the wide interaction between this body of water and the floodplain. The configuration of the bottom relief of Coqueiro lake, due to it being linear (low water) to slightly concave (high water), contributes to the weak influence of the processes of erosion and sedimentation, which are more active in lakes which have convex bottoms (Barbanti, 1985). The Development Volume Index (>1) recorded to Coqueiro lake confirms the high susceptibility of the system to the action of the winds as categorized by Sperling (1999). The North-South wind direction (dominant in the region) coincident with the longitudinal axis of Coqueiro lake and greater intensity when the lake is shallower, added to the reduced mean depth of the lake, act as the main driving factors of the mixing regime of the system.

The elasticity coefficient for the area of the Coqueiro Lake (1.3) are smaller than those of the Pantanal (11.9) or the Paraná River floodplain. However it is similar to those found for the Iberá floodplain (1.54) and with Camargo marginal lake (1.07) e Coqueiral (2.02) both in the Paranapanema River floodplain (Neiff, 1999; Henry, 2005). The value of the elasticity coefficient for volume (2.41) is similar to what is found for the Camargo lake (1.8; Henry, 2005). The Fluvial Connectivity Quotient (>1) confirmed that Coqueiro lake remained only 40% of the time connected to the main river, allowing then the flux of matter and energy between these sub-system of floodplain.

The rising of the Cuiabá River water level is the prime factor to explain the re-establishment of connectivity between Coqueiro Lake and the other environments of the drainage basin. During high waters, the variation in morphometry of the lake, especially volume and depth, indicate a strong relation between this water body and the floodplain. During floods, environments similar to Coqueiro Lake (Panosso et al., 1995; Lesack & Melack, 1995) showed an increase in their dimensions (surface and volume) by orders of magnitudes, becoming indistinguishable on the floodplain. Thus, the flood pulse played a crucial role in the morphometric alterations of Coqueiro Lake.

Acknowledgements

We thank Dr. Pierre Girard for the revision of the text and Osmar Amaral Filho, topographer for its help with field work. We also thank FAPEMAT, NEPA/UFMT, CNPq and CAPES for financial support.

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Received: 19 October 2007
Accepted: 28 January 2008