The connectivity of the Paranapanema River with two lateral lakes in its mouth zone into the Jurumirim Reservoir.

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ABSTRACT: The connectivity of the Paranapanema River with two lateral lakes in its mouth zone into the Jurumirim Reservoir. The pattern of hydrological interactions of the Paranapanema River with two lateral lakes in its mouth zone into the Jurumirim Reservoir was examined during a four-year period (from January 1, 1998 to December 31, 2001). Measurements of water level and precipitation were obtained. The volume and surface area variability of the two lateral lakes was described for the study period. Except during a prolonged period of drought (from October 1999 to December 2000), the lakes were connected with the Paranapanema River, and the annual range of water level was around 2.4-3.0m. The variability of the lateral hydrologic pulse produced highest variation in surface area than volume in the two lakes (except during the drought period). However, the area elasticity coefficient of one of the lakes (Camargo Lake) was around 50% smaller than the other (Coqueiral Lake). The volume elasticity coefficient of the Camargo Lake was around five times smaller than of the Coqueiral Lake. The differences on elasticity coefficients were attributed to the morphometry of the lakes. Except during the drought, the lateral environments are maintained permanently in a potamophase. This type of behavior is not a characteristic of a floodplain. Thus, the stored water in the Jurumirim Reservoir acts as a buffer system of hydrological pulses, in the riverine zone of reservoir.
Key-words: connectivity, water level, river mouth, reservoir.

RESUMO: A conectividade do Rio Paranapanema com dois lagos laterais na zona de sua desembocadura na Represa de Jurumirim. O padrão de interações hidrológicas entre o Rio Paranapanema e duas lagoas laterais na zona de sua desembocadura na represa de Jurumirim foi examinado durante um período de 4 anos (de 1 janeiro de 1998 a 31 de dezembro de 2001). Medidas de nível de água e de precipitação foram obtidas. A variabilidade em volume e área de superfície das duas lagoas laterais ao rio foi descrita para o período. Exceto durante um período prolongado de seca (de outubro de 1999 a dezembro de 2000), as lagoas mantiveram-se conectadas com o Rio Paranapanema apresentando amplitude de variação anual no nível de água de cerca de 2.4-3.0m. A variabilidade do pulso hidrológico lateral produziu maior variação na área de superfície do que no volume para os dois lagos (exceto durante o período de seca). Entretando, o coeficiente elasticidade de área em uma das lagoas (Lagoa do Camargo) foi cerca de 50% menor do que na outra (Lagoa do Coqueiral). O coeficiente de elasticidade de volume da Lagoa do Camargo foi cerca de cinco vezes menor que para a Lagoa do Coqueiral. As diferenças nos coeficientes de elasticidade foram atribuídas à morfometria das lagoas. Exceto durante o período de seca, os ambientes laterais mantiveram-se em potamofase permanente. Este tipo de comportamento não é característico de uma planície de inundação. Portanto, a água acumulada no reservatório age como sistema de amortecedor dos pulsos hidrológicos na zona de transição rio-represa.
Palavras-chave: conectividade, nível de água, desembocadura de rio, represa.

Introduction

In floodplains, a great diversity of aquatic environments can be identified. Besides the main channel and secondary arms of the river, several lentic ecosystems with temporary or permanent connection with the river occur in the wetland. The lacustrine environments are located near (parapotamon) or distant (paleopotamon) from the lotic ecosystem (Henry, 2003). The floodplains are submitted to flood pulses (Junk et al., 1989) that during the year present unimodal frequency, as in the Matogrossense Pantanal (Hamilton et al., 1998), or multiple short-time pulses of flooding, as in the Medium Mogi-Guaçu floodplain (Krusche & Mozeto, 1999).

The connection between the main channel of the river and marginal lakes occurs when a water overflowing and an inundation of the lateral plain are observed. When the water level exceeds this stage, the potamophase starts (Neiff, 1999). In the inundation phase, an exchange of water, biota, nutrients dissolved or adsorved to sediment is observed between the main channel of the river and the lateral aquatic environments. According to Galat et al. (1997), five metric attributes can be used to quantify the relative connectivity of water bodies: distance, duration, timing, exchange and type. The disconnectivity or disconnection of river with lateral lakes occurs when the water discharge is restricted to its main channel, and the lacustrine environments are isolated, a phase called "limnophase" (sensu Neiff, 1999). Because of the disconnection period duration, the lakes can be maintained as water bodies or can disappear completely due to water evaporation, to infiltration to groundwater and to lateral flux to another lentic ecosystem or river by the hyporheos. The connectivity along the year can vary in magnitude according to the variability of the hydrological pulse of the river. The temporary connection could explain the species richness of benthic fauna (Castella et al., 1984) and aquatic macrophytes (Bornette et al., 1998). In lateral lakes submitted to disturbance with intermediary magnitude and with a mean amount of resources, maximum biodiversity can theoretically be found (Ward et al., 1999). Thus, the nearest lacustrine enviroments (parapotamon) would present a higher species richness than the most distant ones (paleopotamon) from the river due to different connectivities.

A lot of information about floodplains were introduced after an analysis in macro-scale level, for instance in Amazon (Junk et al., 1997), in the Medium (Neiff, 1999), Low (Villar et al., 1998) and High Paraná River (Vazzoler et al., 1997), and in a regional scale in the medium Mogi-Guaçu (Krusche & Mozeto, 1999) and the Pantanal (Hamilton & Lewis, 1987). Few investigations refer to wetlands in the mouth zone of tributaries into reservoirs (Luciano & Henry, 1998).

The aim of this paper was to examine the variability pattern of the water level of a river and its influence in lateral waterbodies in a transition river-reservoir zone and to determine the attributes of the connectivity between lotic and lentic ecosystems.

Study Area

In order to show the pattern of hydrological interactions of the river with lateral aquatic environments, the mouth zone of the Paranapanema River into Jurumirim Reservoir was selected (Fig.1). The site is a zone with current velocity reduction (Casanova & Henry, 2004) and with high sedimentation of allochthonous matter introduced by the Paranapanema River into the reservoir (Henry & Maricato, 1996). The two selected lakes (Coqueiral and Camargo Lakes) apparently present different degrees of connection with the river.

Material and methods

The pattern of water level variability (stage in meters) of the Paranapanema River, and of rainfall was determined for a four–year period (from January 1, 1998 to December 31, 2001). The stage data came from the water levels in the dam zone of the Jurumirim Reservoir. An early study showed that the variation of the water level measured at the mouth zone of the Paranapanema River into the reservoir presented the same pattern of values of the dam, despite the distance (ca., 100km) between the two sites (Pompêo et al., 1999). The precipitation data came from the pluviometric E5-061-R station in

Paranapanema (closed in December 2000) and were provided by the Water and Electric Power Department (DAEE). Last-year study data came from DAEE E5-117 station in Angatuba, around 20 km from the study site, the same distance from the pluviometric station of Paranapanema.

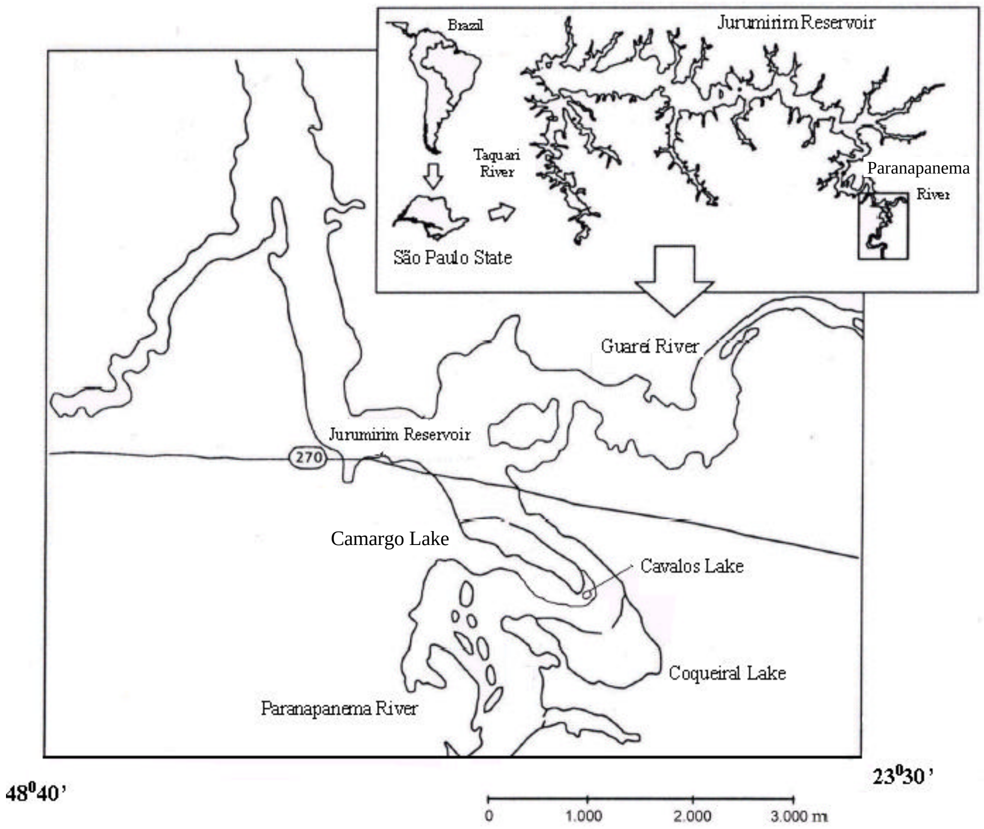


Figure 1: The study site: the Coqueiral and the Camargo Lakes in the mouth zone of Paranapanema River into the Jurumirim Reservoir.

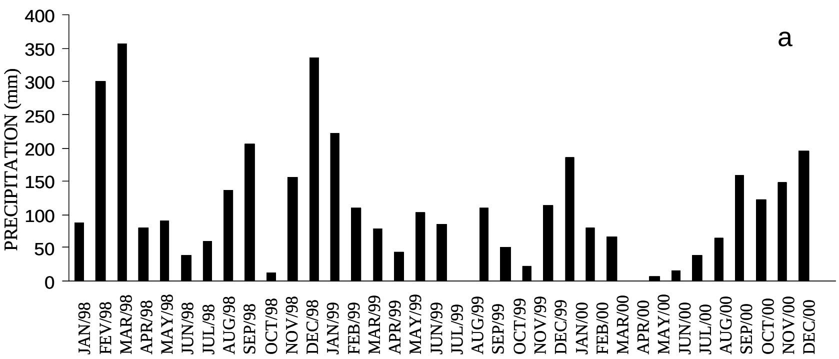
Using the daily water levels, the attributes of the flood pulse of the Paranapanema River, such as frequency, intensity, duration and, timing were described. Frequency is the number of times that the flood pulse occurred during a year. Inundation occurs when the river water level overflows to the lateral plain. Intensity is the inundation magnitude that can be evaluated through the difference between the maximum and the over flow water levels. Duration is the amount of time (days) of a flood pulse year and timing refers to the season of similar periods of inundation in successive years.

The influence of the flood pulse into the Camargo and Coqueiral Lakes was evidenced through the description of area and volume increases and reductions of the lacustrine environments. In order to evaluate these two morphometric parameters, batimetric maps of the lakes were developed. Using an Ocean echosound (Mod. Bathy-500m), a study of the bottom topography was made in 13 transects perpendicular to maximum length of the Camargo Lake during the potamophase (sensu Neiff, 1999) with the water level at 566.67m stage (April 18, 2001). The echosound utilization at the Coqueiral Lake was not possible because the high density of aquatic macrophytes interfered with the equipment readings. Thus, manual soundings were carried out during the boat movement in 18 transects perpendicular to maximum length of the lake on June 14, 2001 (565.65m stage). Hypsographic curves of area and volume were outlined, and the primary and secondary morphometric parameters were computed (Von Sperling, 1999).

In order to evaluate the increase/decrease of volume and area of lentic ecosystems having connectivity with the Paranapanema River, the changes in these morphometric parameters were estimated from the water levels (the stages) and an extrapolation of respective hypsographic curves. The absolute area and volume data were transformed in relative data (absolute value-mean/mean) and were used for an intra-lake and inter-lakes comparison. The elasticity coefficients of both lentic ecosystems were computed. According to Neiff (1999), the elasticity coefficient of a floodplain is the ratio between the occupied area during the maximum of inundation, and the corresponding area during the drought time. We considered elasticity as the ratio between the maximum area found during the four-year period, and the surface area of the lakes, corresponding to the disconnection day with the Paranapanema River (at 563.60m stage).

Results

Rainfall variability during the four-year period is shown in Fig. 2. The annual precipitation was 1,544.3mm and 1,273.8mm from January to December 1998, and 1999, respectively. In the third year (from January to December, 2000) the annual pluviosity (1,080.2mm) was around 20-30% lower the than the two previous years. In the fourth year (from January to December, 2001) the annual precipitation, measured in Angatuba-SP was 1,438.7mm. Comparing the value of the year 2000 (1,073.4mm), the annual precipitation was very similar to the Paranapanema data.



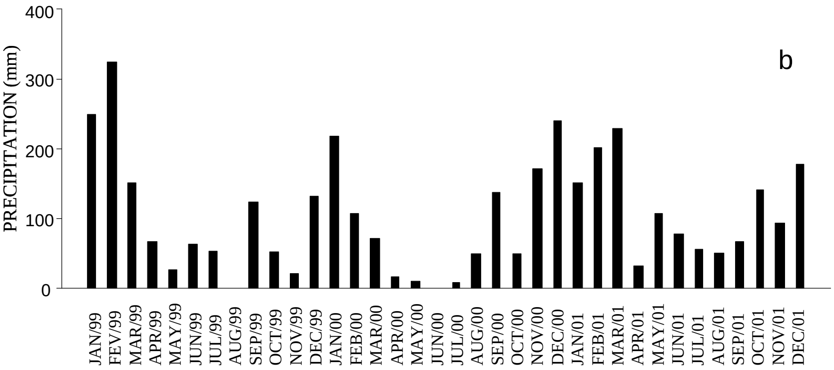


Figure 2: Monthly precipitation (mm) a) from January 1998 to December 2000(at Paranapanema town, São Paulo State); b)From January 1999 to December 2001 (at Angatuba town, São Paulo State).

The stages variability pattern (water level) measured daily at the dam of Jurumirim Reservoir from January 1, 1998 to December 31, 2001 is presented in Fig.3.

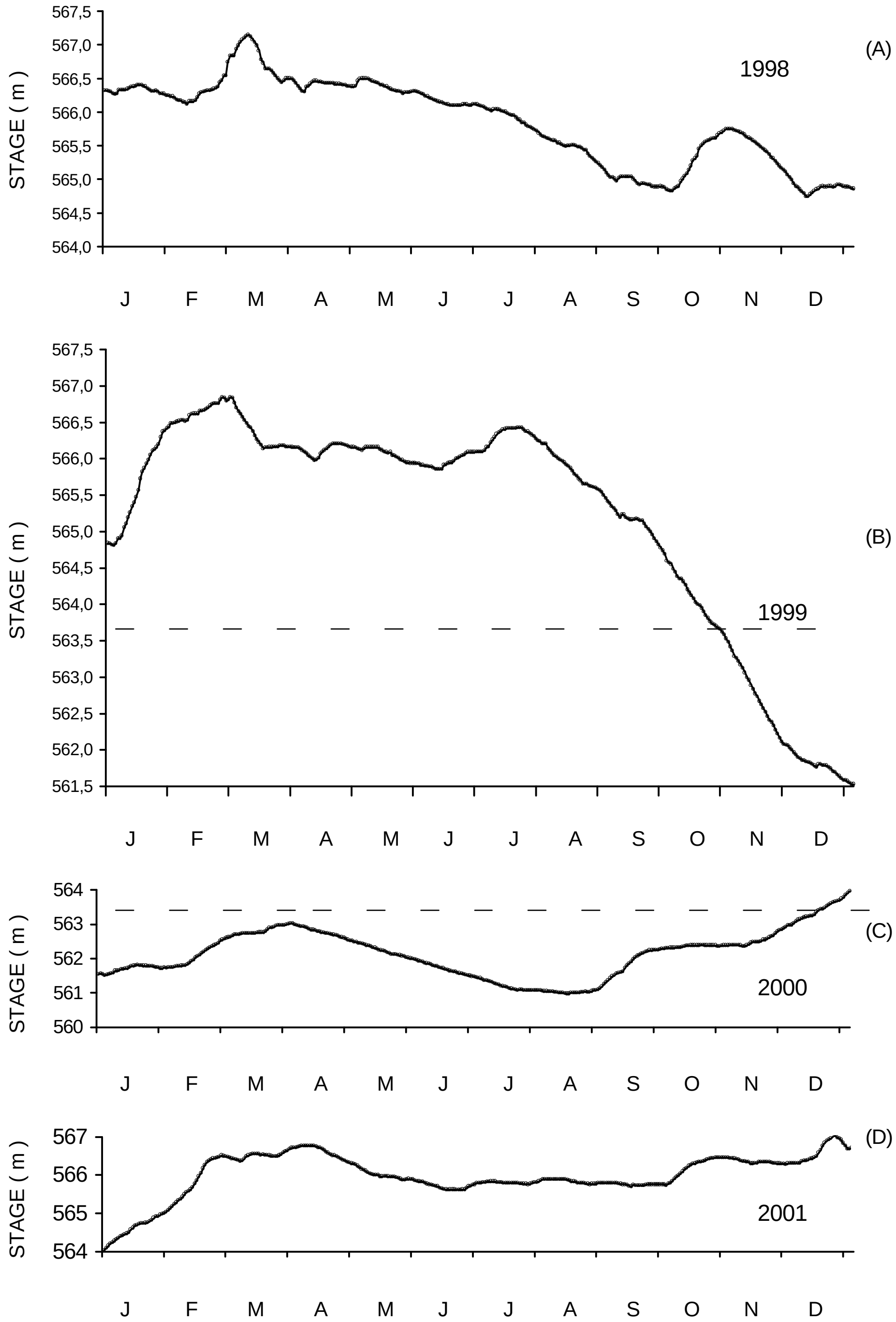


Figure 3: Daily water level variations (stage in m) at the dam of the Jurumirim Reservoir from January 01 to December 31 in 1998 (A), 1999 (B), 2000 (C) and 2001 (D). Dashed line represents the water overflow (when›563.60 m) between potamophase and limnophase.

In the first year, the amplitude of variation was 2.40m (from 567.15m to 564.75m). These values were recorded on March, 12 and December 08-09, respectively (Fig. 3A). In the second year, the amplitude of variation (5.35m) was higher, considering the difference between the maximum (566.85m on February, 26) and minimum stages (561.50m on December, 31) (Fig. 3B). In the third year, the amplitude of variation (2.39m) was lower than the previous year, in spite of the extreme stage values (563.91m on December, 31 and 560.98m on August 17) (Fig.3C). In the last year of the four-year period, the amplitude of variation (2.99m) was similar to the previous year considering the difference between maximum (567.02m on December, 22) and minimum (564.03m on January, 1) stages (Fig.3D). In 1999, a year of severe drought, the pronounced water level reduction produced the disconnection of the Coqueiral and the Camargo Lakes with the Paranapanema River (at 563.60m stage). The disconnection lasted around 14 months (from October 29, 1999 to December 22, 2000). This period would be the limnnophase, if the study site were a "true" floodplain, as observed at the Amazon Varzea, the Pantanal and the Medium Paraná. As a consequence, the potamophase would include the major part of the four-year period. In Fig.3B and C, the draw line reproduces the stage (563.60m) of frontier between the limnophase (‹ 563.60m) and potamophase (› 563.60m) periods.

Disconnection records of the lateral lacustrine environments with the Paranapanema River are infrequent since the formation of Jurumirim Reservoir lake (in 1962). According to the operation division of CESP-Energetic Company of São Paulo (presently Duke Energy-Paranapanema), only in three episodes (in 1969, 1976 and 1986), stages ‹ 563.60m were recorded.

Although no flood pulse was detected as in floodplains, we identified, during three of the four-year period, alterations on water level corresponding to river water introduction in the lateral wetland (the Coqueiral and the Camargo Lakes). In the first year (Fig. 3 A), two "pulses" can be clearly recognized. The first extends from February 18 to April 08 (50 days duration). A second "pulse" was detected in a period from October, 03 to december 06 (63 days duration). In the second year (Fig. 3B), the pulse produced an increase of 2.05m in water level from January 04 to March 02 .

Another pulse reached the highest value (566.43 m) on July 22. From July 22, a continuous decrease on water level of the Paranapanema River could be seen and, on October 29, a disconnection with lateral lakes was recorded. In the third year (Fig.3 C), the water level remained below 563.60m (the overflow level), and the lateral lakes in the limnophase. A small increase on water level was observed in the year 2000 in February and reached a "peak" on April 04. From April 04 to August 17 (560.98m stage), a reduction in water level occurred in the river. Then, a small level increase was observed (Fig.3 C). On December 22, the lateral lakes (Coqueiral and Camargo) changed from limnophase to potamophase, through the water introduction from the Paranapanema River. From the end of February to the beginning of December 2001, water level stability was an evident feature (Fig.3 D) and no characteristic hydrologic "pulse" was evidenced. From December 05, an increase in water level was observed and a "peak" was attained on December 22 (Fig.3 D).

The batimetric maps and the hypsografic curves (area and volume) are shown on Fig. 4 (Coqueiral Lake) and Fig.5 (Camargo Lake). The primary and secondary morphometric parameters computed for the two lentic ecosystems are presented in Tab.I.

Fig 6. shows the variability of expansion/reduction of the surface area (above) and volume (below) of the Coqueiral Lake during the four-year period. The line interruption of the corresponds to the period without information during the limnophase, when the lacustrine environment presented some fragments of isolated water bodies (the shallowest water) that became completely extinct in the drought period (from October 29,1999 to December, 22, 2000) and others were undamaged, despite the continuous reduction in area and volume. During the potamophase (almost the first two years-up to October 1999, and the last of the four-year period), there were evident modifications in volume (from a maximum of 1,833,453m^3 in March, 1998 to a minimum of 709,070m^3 in September 1999, during the first two years; and, from a minimum of 374,794m^3 in January 2001 to a

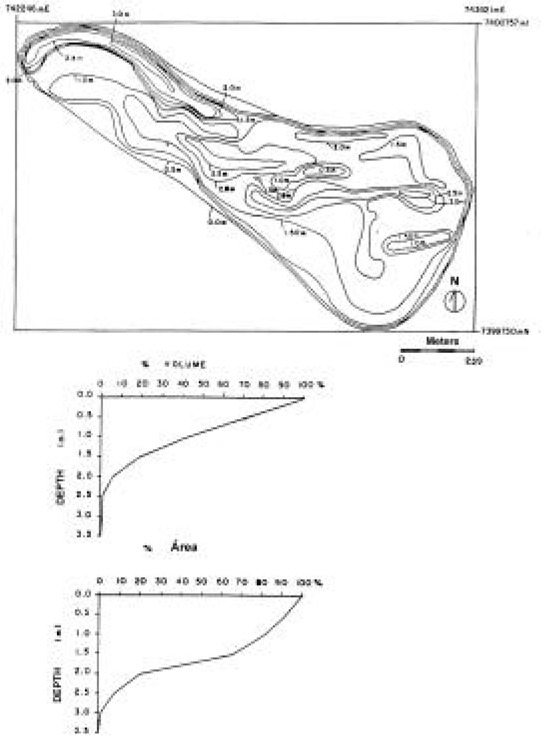


Figure 4: Batimetric map (above) and hypsographic curves (below) of volume and area of the Coqueiral Lake.

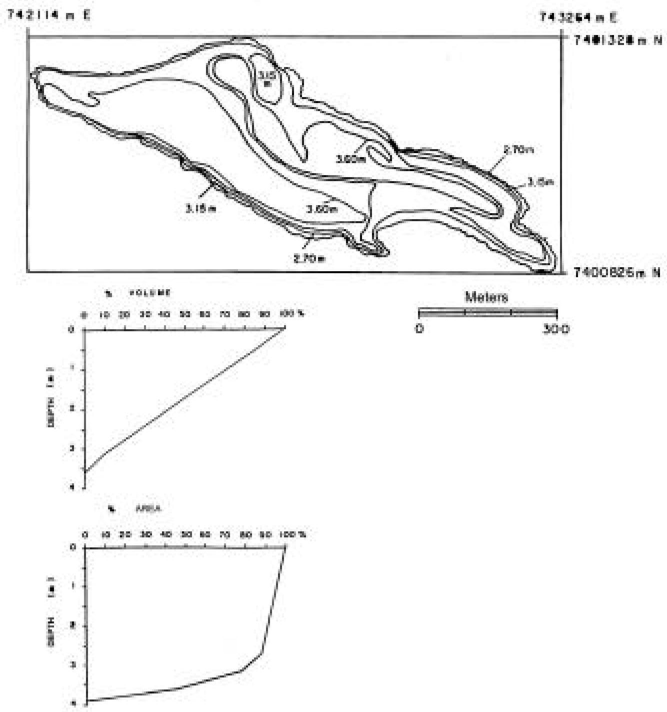


Figure 5: Batimetric map (above) and hypsographic curves (below) of volume and area of the Camargo Lake.

Figure 6: Variability on surface area and volume of the Coqueiral Lake during the four-year period.

Table I: Primary and secondary morphometric parameters of two lateral lakes in the mouth zone of the Paranapanema River into Jurumirim Reservoir.

Morphometric Parameters	Camargo Lake	Coqueiral Lake
Primary Parameters		
Maximum Length (m)	1,220.0	1,576.1
Maximum Depth (m)	3.90	3.50
Maxium Width (m)	307.0	665.3
Perimeter (m)	3,100.0	4,063.5
Surface Area (m^2)	224,465.0	641,263.2
Volume (m^3)	719,867.0	1,012,957.4
Secondary Parameters		
Mean Depth	3.20	1.58
Mean Width	184.0	406.9
Shore Development	1.85	1.43
Volume Development	2.46	1.35
Relative Depth (%)	0.73	0.48
Mean Slope (%)	0.60	2.72

maximum of 1,671,380m³ in the last year) and in surface area (from a maximum of 795,166m² to a minimum of 557,899m² in the two first years, and from a minimum of 500,185m² to a maximum of 801,579m² in the fourth year).

In relation to the Camargo Lake (Fig.7), the volume ranged from 323,940m³ (December 1998) to 719,867m³ (February, 1999) during the first two years, and from 266,351m³ (January, 2001) to 719,867m³ (December, 2001) in the fourth year. For surface area, the minimum and maximum values were, respectively, 196,407m² (September, 1998) and 224,465m² (February, 1999) in the first two years and, 202,019m² (January, 2001) and 224,465 (December 2001) in the last year.

The lowest relative values variability was observed for area rather than for volume in both lakes (Fig. 8). Also, the variability of relative values for area was higher for the Coqueiral lake (range:0.19 to-0.26) than for the Camargo Lake (range: 0.04 to-0.08). In relation to volume, the highest variability of relative values was found for the Coqueiral Lake (range: 0.55 to-0.70) than for the Camargo Lake (range; 0.30 to-0.67).

The area elasticity coefficient of the Camargo Lake (1.07) was around 50% of the value (2.02) for Coqueiral Lake. Thus, Camargo Lake presents higher stability for area than Coqueiral Lake. The volume elasticity coefficient (ratio between maximum volume and estimated volume of lakes when it occurs the disconnection with Paranapanema River occurs) corresponded to 1.8 (for Camargo Lake), around five times smaller than for the Coqueiral Lake (8.68).

Figure 7: Variability of surface area and volume of the Camargo Lake during the four-year period.

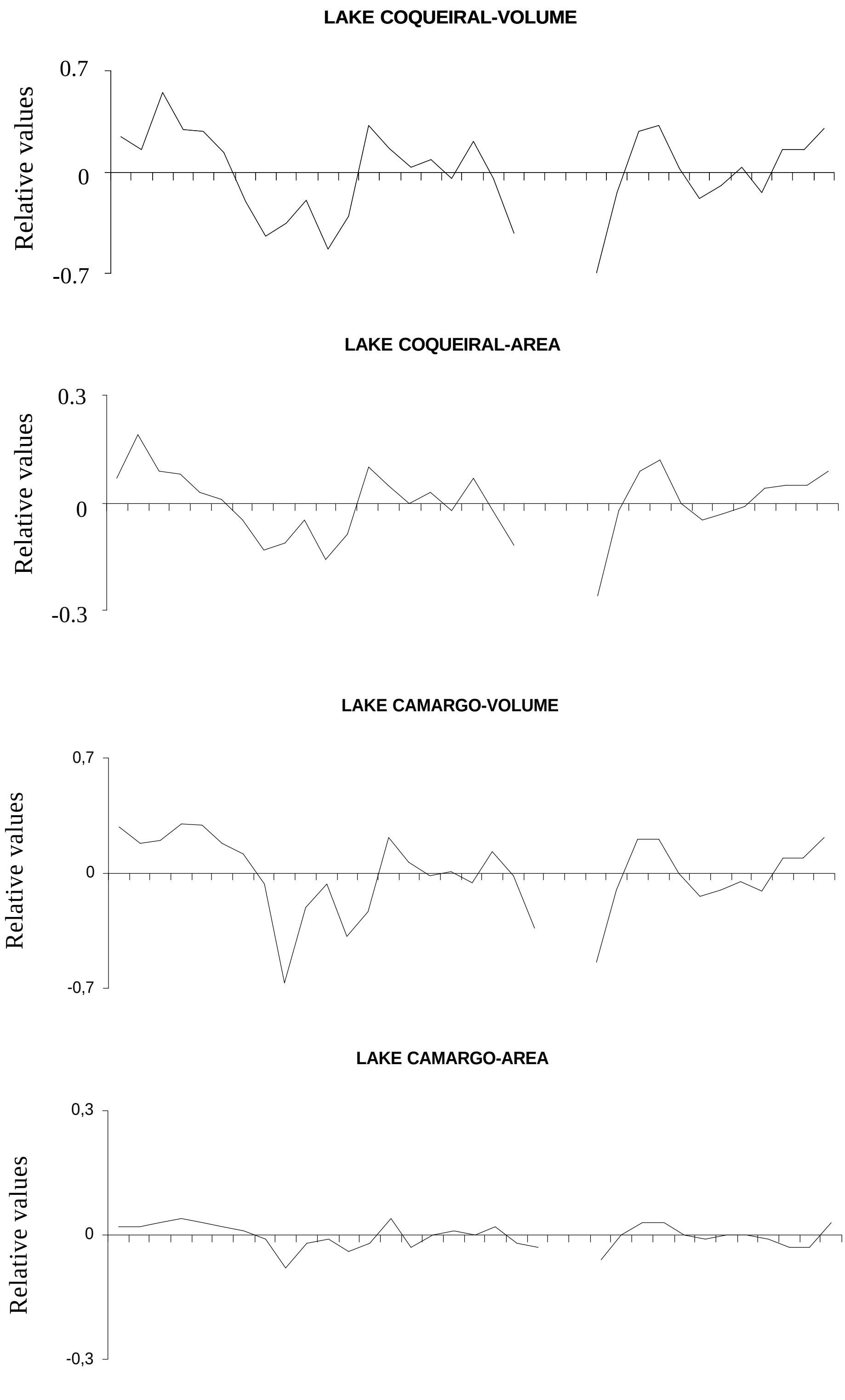


Figure 8: Variability of the relative values of volume and area of the Coqueiral and Camargo lakes during the four-year period.

Discussion

The mouth site of the Paranapanema River into the Jurumirim cannot be considered as having a similar behavior of a floodplain. Connectivity is permanently maintained between river and lateral lakes, except during all the period of severe drought (from October 29, 1999 to December 22, 2000). According to Neiff (1999), the elasticity area coefficient measured in Oriental Chaco, Matogrossense Pantanal and in Medium Paraná was ›7.0 for floodplains, while the values of the Paranapanema River mouth zone were ‹ 2.0. Lowest indexes were found when an evaluation of elasticity was made for Jurumirim Reservoir (1.14 and 0.997, for area and volume, respectively). The low elasticity variability of the reservoirs is an index of high hydrological stability of the artificial lake during the year and, probably, of small number of habitats in the water-land interface.

Floodplains are known for being submitted to hydrological pulse having a amplitude of variation of about 10m, as in the Amazon (Junk et al., 1997). During the year, the lateral lakes are connected to the river (after an overflow of water from the river channel, in the high water period) or disconnected (in the low water time) from the river. The first case (linkage river-lakes) characterizes the potamophase, while the isolation period is the limnophase (Neiff, 1999). During the potamophase, an increase on the seeds transport and deposition by the floodplain pulse, on decomposition of terrestrial organic matter, detritus storage and bacterial activity on sediments, and a reduction on invertebrate abundance linked to plants are observed (Neiff & Poi de Neiff, 2003). During the disconnection period of lentic ecosystems (the limnophase), an increase on nutrient content in water, and on primary production by plants is evidenced (Neiff & Poi de Neiff, 2003).

Except during the period of severe drought, the lateral lakes and the Paranapanema River presented characteristics of permanent potamophase during the four-year period. Thus, the connectivity between the river channel and the Coqueiral and the Camargo Lakes was maintained during all the year, and only a temporal variability on the magnitude of association (measured in terms of water level) was observed between the lotic environment and the lentic ecosystems. The temporal variation caused an expansion during the high water time, and an area and volume reduction of the lakes during the low water period. Despite the low magnitude on water level of Paranapanema River during the year (c.a. 2-3m), Pompêo et al. (2001) showed that Echinochloa polystachya, a dominant grass plant in study site, can double the biomass from low to high water periods. Costa & Henry (2002) evidenced that, for Eichhornia azurea, no significant variations on the plant biomass were found in the two lakes. The hydrological pulse effect was related to the expansion of covering area of the E. azurea stands, being larger in lake with the highest connection with the Paranapanema River.

Neiff & Poi de Neiff (2003) proposed a ratio between the number of days of inundation, and the number of days with a disconnection between lateral lakes and the river to estimate the fluvial connectivity. Since the association between the lateral lakes (the Coqueiral and the Camargo Lakes) with the Paranapanema River was persistent each year in most part of the studied period, it was impossible to evaluate the fluvial connectivity between lotic and lentic ecosystems. Similary, the flood pulse estimated attributes in our study differ significantly from the characteristic values of floodplains (Neiff,1999). The great volume of stored water in the Jurumirim Reservoir (7.9Hm^3) acts as a "buffer" system of hydrological pulses in the mouth zone of its main tributary. Henry et al. (1999) showed that, at Campina do Monte Alegre (around 60 km upstream of the study site), multiple "peaks" of water discharge of the Paranapanema River were recorded during each one of the two years of measurements (1992 and 1993). The records are evidences of probable oscillation of association/disconnection of lateral lakes with the Paranapanema River during the year, in the previous shaping period of Jurumirim Reservoir lake (before 1962). The lateral water pulses to the Coqueiral and the Camargo Lakes, with an intensity reduced by the "buffer" system of the reservoir cannot act as disturbances. These characteristics, observed in the mouth zone of the Paranapanema River, can explain the lowest species richness of phytoplankton and zooplankton in lateral lakes when compared with river reservoir transition zone (Henry, 2003).

The episode of prolonged drought (around 14 months) can be considered as a disturbance, since the habitats fragmentation led to multiple isolated low water bodies because of the peculiar bottom topography in the Coqueiral Lake. The exposed sediment also caused the colonization of terrestrial plants in accelerated succession. Considering the Camargo Lake, the high bottom declivity in the littoral zone originated a volume reduction without a similar decrease of lake surface area during the severe drought period. Thus, the terrestrialization process, well evidenced in the Coqueiral Lake, presented low amplitude in the Camargo Lake.

The connection of both the lakes with the Paranapanema River in December 2000 produced significant effects on the structure of planktonic and benthic communities, and on the water chemistry that will be described in other papers.

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