Limnological features after a flushing event in Paranoá Reservoir, central Brazil

Características limnológicas após um "flushing" no Reservatório Paranoá, Brasil central

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Abstract: Aim: Paranoá Reservoir was subjected to an intense eutrophication during at least three decades (1968 to 1998) due to higher human occupation of the catchment area and nutrients inflow derived to inadequate sewage treatment. The occurrence of large blooms of *Microcystis aeruginosa*, extended areas of aquatic macrophytes (*Eichhornia crassipes*), and frequent fish kills were observed during this period. Nutrient loading in Paranoá Reservoir has been reduced since 1993, but a water quality improvement was identified only after a major *flushing* occurred at the end of 1998. **Methods:** In order to evaluate limnological features of the reservoir after *flushing*, this study was developed during a year (2005), with monthly and weekly samplings in pelagic zone of an early eutrophicated region of the reservoir (Riacho Fundo arm). **Results:** During this study, this arm had higher water transparency (0.6 m until 1998 to 1.9 m), due to lower values of suspended material (2.5-7.3 $mg.L^{-1}$) and lower content of chlorophyll-*a* (mean 35 $\mu g.L^{-1}$ until 1998 to 17.4 $\mu g.L^{-1}$), and well oxygenate (above 70%) and pH neutral. Nevertheless, some limnological features have indicated higher trophic state, as water electric conductivity (above 90 $\mu S.cm^{-1}$) and high content of inorganic nutrients, as ammonium (above 1,000 $\mu g.L^{-1}$), nitrate (145-405 $\mu g.L^{-1)}$ and total nitrogen (above 1,600 $\mu g.L^{-1}$). The seasonal course of limnological variables tended to exhibit a temporal pattern associated to precipitation regime and related to wind and precipitation effects as well as dam operation. **Conclusion:** A major flushing event of Lake Paranoá (sudden release of water on November/98) was an abrupt intervention on water quality. This intervention may have being a permanent impact to reach a new level of equilibrium, since has an effective control mechanism feedback (between nutrients and phytoplankton biomass) to avoid the course of eutrophication. A further efficient lake management is necessary to maintain a lower trophic degree and adequate water quality.

Keywords: tropical urban reservoir, physical and chemical features, restoration, seasonal cycle.

Resumo: Objetivo: O Reservatório do Paranoá foi submetido à intensa eutrofização durante três décadas (1968 a 1998), decorrente de ocupação desordenada da bacia, além da entrada de nutrientes provenientes de tratamento inadequado de esgoto urbano. Foram observados florescimentos de cianobactérias (*Microcystis aeruginosa*), bancos de plantas aquáticas (*Eichhornia crassipes*) e mortandades de peixes. Desde 1993, as cargas de nutrientes para o lago estão sendo reduzidas, mas somente após o *flushing* ocorrido em 1998 foi observada uma melhoria de qualidade de água. **Resultados:** Com o objetivo de avaliar as características limnológicas após o *flushing*, este estudo foi desenvolvido durante um ano, com amostras mensais e semanais em área pelágica de uma parte do lago anteriormente mais eutrofizada (braço do Riacho Fundo). **Métodos:** Neste estudo, este braço ficou mais transparente (de 0,6 m até 1998, para 1,9 m) devido aos menores valores de materiais suspensos (2,5-7,3 $mg.L^{-1}$) além de baixos níveis de clorofila-*a* (média de 35 $\mu g.L^{-1}$ até 1998 para 17,4 $\mu g.L^{-1}$), bem oxigenado (acima de 70%) e pH neutro. Entretanto, algumas variáveis limnológicas indicaram grau de trofia mais elevado, como condutividade elétrica (acima de 90 $S.cm^{-1}$) e elevada concentração de nutrientes, como íon amônio (acima de 1.000 $\mu g.L^{-1}$), nitrato (145-405 $\mu g.L^{-1}$) e nitrogênio total (acima de 1.600 $\mu g.L^{-1}$). A flutuação sazonal das variáveis limnológicas mostrou um padrão temporal associado ao regime de chuvas, além dos efeitos do vento bem como devido às vazões da barragem. **Conclusão:** A ocorrência do *flushing* do reservatório (repentina saída de grande volume de água em Novembro/98) foi uma abrupta intervenção na qualidade de água. Esta intervenção pode ter sido um impacto permanente para alcançar um novo nível de equilíbrio, desde que haja um efetivo controle no mecanismo de resposta (entre nutrientes e fitoplâncton) para evitar o retorno à eutrofização. É necessário um manejo eficiente do lago para a manutenção de grau de trofia mais baixo e da qualidade de água.

Palavras-chave: reservatório tropical urbano, características físicas e químicas, oligotrofização, ciclo sazonal.

1. Introduction

Anthropogenic activities in catchments may alter the water quality of reservoirs, notably in urban regions. In Brazil, man-made lakes have been used for multiple purposes like power generation, irrigation, potable water supply, tourism and they were also built up with the purpose of enhancing the regional development. The ecological features of reservoirs involve a set of innumerous factors, as their spatial and temporal variability, community structure of the aquatic biota and watershed uses (Matsumura-Tundisi and Tundisi, 2005).

As a consequence, many reservoirs became eutrophicated, which has interfered with the uses of these water bodies. Limnological characterization is a fundamental tool for designing the conservation and management policies of lakes and reservoirs as discussed by González et al. (2004).

Paranoá Reservoir was subjected to intense eutrophication during at least three decades due to higher human occupation of the catchment area and nutrients inflow derived to inadequate sewage treatment (Mattos et al., 1997; Fellizato et al., 2000). Since 1970 phytoplankton biomass was dominated by *Cylindrospermospsis raciborskii*, which remained dominant in subsequent decades (Cronberg, 1976; Pinto-Coelho and Giani, 1985; Branco and Senna, 1996), with the periodic occurrence of *Microcystis aeruginosa* blooms during the end of the dry season (Branco and Senna, 1996).

Eutrophic conditions were also indicated by a dominance of detritivorous microzooplankton (mainly rotifers and small cladocerans, such as *Diaphanosoma birgei* and *Bosmina* spp.), low Secchi depth (<50 cm) and high levels of nutrients and chlorophyll-*a* (Branco and Senna, 1996; Branco and Cavalcanti, 1999; Padovesi-Fonseca et al., 2002).

Extended areas of aquatic macrophytes were observed in some parts of the reservoir, especially near the effluents from the sewage treatment plants, mainly formed by free floating *Eichhornia crassipes* and *Pistia stratiotes* (Padovesi-Fonseca et al., 2001a).

The ichthyofauna of the reservoir is composed by eleven fish species from the catchment, in addition of exotic fish species, such as bluegill sunfish (*Lepomis macrochirus*), black-bass (*Micropterus salmoides*), carp (*Cyprinus carpio*), Congo (*Tilapia rendalli*) and Nile (*Oreochromis niloticus*) tilapias, and the piscivorous tucunaré (*Cichla ocellaris*) from the Amazon Basin (Ribeiro et al., 2001). In the late 1980s, tilapia dominated and accounted for 50% of total fish biomass. In subsequent years, the lake was stocked with tambaqui (*Colossoma macropomum*) and tamoatá (*Callychthys callychthys*), both from the Amazon Basin and with high commercial value.

Since 1993 nutrient loading in Paranoá Reservoir has been reduced, as a result of a new sewage treatment system (Fellizato et al., 2000). Resultant decrease in external point-source of TP loading was observed (Branco and Cavalcanti, 1999; Burnett et al., 2001). However, limnological studies revealed the maintenance of early conditions, as the dominance of *C. raciborskii* and blooms of *M. aeruginosa* (Padovesi-Fonseca and Philomeno, 2004), high phytoplankton biomass and a dominance of detritivorous microzooplankton (Padovesi-Fonseca et al., 2001b), with low water transparency (<60 cm), high water electric conductivity (above 85 $\mu S.cm^{-1}$), low oxygen concentration, and anoxic condition in 1997 and 1998 (Padovesi-Fonseca and Philomeno, 2004).

Also, in 1998 a fish population management was evaluated by an echo-sounding campaign and revealed a fish stock of 1,500 ton, with tilapia constituting up to 90% of fish biomass. Laboratory studies concerning to fish feeding rates on lake plankton and P excretion rates, plus an assessment of planktivorous fish impacts in enclosures, indicated that tilapia overpopulation control would prevent accumulated P from being available to primary production, especially due to bottom feeding *(*Starling, 1993a, b; Starling and Rocha, 1990). Tilapia control was initiated in the most eutrophicated region by legalizing commercial cast-net fisheries (Starling and Lazzaro, 2001).

Nevertheless, the recovery process has intensified with a consequent water quality improvement only after an intentional flushing occurred at the end of 1998. During this year, after an increase of residence time of the reservoir (from 321 to 721 days), there was a further abrupt reduction of residence time to 192 days in December 1998 (Souto Maior et al., 2001).

After this event, abiotic and biological changes were observed: (1) decreased cyanobacteria dominance and replacement of *C. raciborskii* by green algae and diatoms (Philomeno and Padovesi-Fonseca, *in preparation*); (2) reappearance of *Ceriodaphnia cornuta*, *Daphnia gessneri*, other small cladocerans, such as *Moina micrura* and *Bosminopsis deitersi* (Elmoor-Loureiro et al., 2004), and *Notodiaptomus cearensis*, an oligotrophic calanoid copepod species (Padovesi-Fonseca et al., 2001b); (3) Chlorophyll-*a* values decreased (from 50 to 25 $\mu g.L^{-1}$) (Burnett et al., 2001), and Secchi depth attained 2.4 m (Pereira and Padovesi-Fonseca, *in preparation*).

The present study aimed to investigate limnological features in pelagic zone of the reservoir over a year, with monthly and weekly sampling, after the intentional flushing occurred in the reservoir.

2.Material and Methods

2.1 Study area

Lake Paranoá (15° 48' S and 47° 47' W) is a reservoir (area 38.1 km^2, volume 498.6 × 106 m^3, max. depth 40 m, mean depth 13 m, max. length 40 km, max. width 5 km) situated in the urban region of Brasília, at an altitude of

1,000 m. The regional climate is characterized by two seasons: the cool-dry (May-September) and the warm-rainy (October-April). Four main tributaries feed the reservoir: Ribeirão do Torto and Córrego do Bananal (northern part), and Ribeirão do Gama and Riacho Fundo (southern part). Lake Paranoá has an irregular form, with a central area and four extended branches, corresponding to former valleys of the tributaries (Figure 1). The Riacho Fundo branch has been the more eutrophic part of the reservoir because it received the effluents from the sewage treatment plant in the southern part of Brasília as well as the loads transported from the Riacho Fundo tributary. This branch has a 4.6 km^2 area, 39.3×10^6 m^3 volume, 19 m maximum depth, and 8.6 m mean depth (Mattos et al., 1992).

Lake Paranoá was constructed in 1959 and rapidly become eutrophic, with the ocurrence of large blooms of *Microcystis aeruginosa*, extended areas of aquatic macrophytes (*Eichhornia crassipes*), and frequent fish kills (Altafin et al., 1995; Padovesi-Fonseca and Philomeno, 2004).

This progressive eutrophication has been related to high inorganic nutrient input mainly deriving from sewage effluent, as point-source of TP loading (Fellizato et al., 2000). Several factors have contributed to water quality deterioration, including the rapid growth of Brasília within the lake catchment area and the installation of two sewage plants with no adequate treatment processes. After flushing event studies point out a water quality improvement and biodiversity changes in Lake Paranoá (Padovesi-Fonseca et al., 2001a,b; Elmoor-Loureiro et al., 2004).

2.2. Sampling and procedures

This study was carried out at a fixed station located in the Riacho Fundo arm of the reservoir (15° 49' 81' S and 47° 53' 18" W) (Figure 1). Samples were taken monthly from January to December/05 and weekly during two months in the rainy (February-March/05) and two months in the dry (August-September/05) seasons. The depth of the water column was measured using a weighted and graduated cable. Water transparency (m) was measured with a 30 cm Secchi disk. The euphotic zone was estimated as 2.7 times the depth disappearance of the Secchi disk (Wetzel and Likens, 2000). Water temperature profile

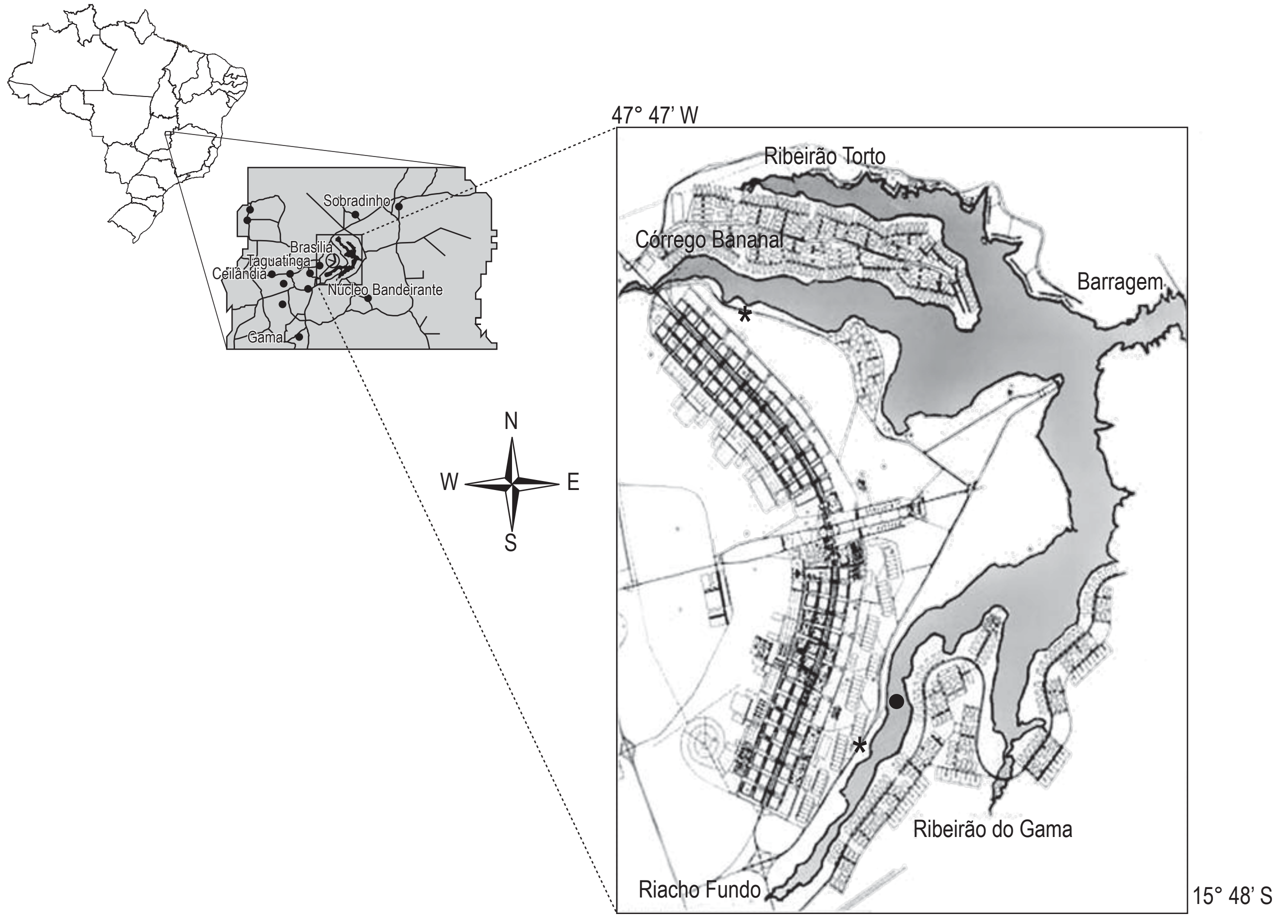

Figure 1. Study area: Paranoá Reservoir and the main tributaries, sewage treatment stations (*), dam and sampling point (•). Brasília, DF, central Brazil.

(°C) was measured using a sensor probe YSI 30. The response of the interface to wind forcing was done using a simplified Wedderburn analysis by numerical simulation ($W = (h_1^2 g')/u_*^2 L$, Stevens and Lawrence 1997), with low wind values obtained for this region. Wind data were provided by a meteorological station (INMET, National Institute of Meteorology; 15° 78' S and 47° 93' W). Rainfall data were provided by the meteorological station from the CAESB (Company of Environmental Sanitation of Federal District), (15° 50' 29" S and 47° 54' 31" W).

Water samples were taken at one meter with a Van-Dorn bottle (5 L) for further laboratory analysis to: pH (Micronal pHmeter), water electric conductivity (Digimed conductivimeter), dissolved oxygen (Winkler method modified by Golterman et al., 1978), water suspended material (gravimetry technique, Wetzel and Likens, 2000).

For chlorophyll-*a* determinations 500 to 1,000 mL non-fractionated whole water were filtered through Whatman 47 mm GF/F glass fiber filters (0.7 µm) under vacuum (<120 mmHg). Sampling filtration was performed in duplicate and immediately following sampling to minimize any potential grazing effects. The filters were placed in dark test tubes pre-filled by 10 mL extraction solution (acetone 90%, Wetzel and Likens, 2000). After storage for 12 hours in a refrigerator, the absorbance of the acetonic extract was measured at specific wavelengths (750 and 665 nm) with a Hitachi model 100-60 double beam spectrophotometer using 1 cm glass cuvettes.

Also, samples were taken for inorganic nutrients analyses to: total phosphorus (TP), total nitrogen (TN), ammonium ($N\text{-}NH_4$), nitrate ($N\text{-}NO_3^{-2}$) and nitrite ($N\text{-}NO_2^{-3}$) according to standard methods recommended by APHA (1998).

Studies of the primary production in many parts in Paranoá Reservoir (Pinto-Coelho and Giani, 1985) considered one meter the most productive of the euphotic layer. This study stated this depth for further comparisons with previous studies.

Non-parametric Wilcoxon Z-Test was used to test differences in values of limnological variables between rainy (February-March/05) and dry (August-September/05) periods with weekly intervals.

The limnological variables were synthesized through a principal components analysis (PCA). This procedure was done for seasonal and weekly periods. The PCA is based on correlations among variables, and all variables (except pH) were transformed to natural logarithms prior to analysis. Axes were considered important for data ordination when eingenvalues were >1.0 (Jackson, 1993) and variables with structural coefficients >0.5, using PC-ORD 4.0 (McCure and Mefford, 1999).

It's also worth of mention that, water samples were taken at one, three and six meters with a Van-Dorn bottle (5 L) for pH, water electric conductivity and dissolved oxygen. In order to verify differences among these depths, the data were logarithmically transformed (except pH) and analyzed using analyses of variance (ANOVA). Variable that showed F*s* significant for $p < 0.05$, the Turkey method was applied to compare two mean values between two depths.

3. Results

Seasonal precipitation during 2005 showed a typical variation for this region, although the dry period extended to October (Figure 2). March was the rainiest month (294.8 mm) and September attained 53.5 mm during the dry period, with annual total precipitation of 1,301.9 mm. For shorter periods, the rainy season (February-March/05) had 32 days of rainfall (maximum value day, 83.8 mm; total precipitation, 471.4 mm). Along the dry season (August-September/05) there were six precipitation days (maximum value day, 26.2 mm; total precipitation, 78.9 mm) and concentrated at end September (Figure 2b).

During 2005, Riacho Fundo arm did not develop persistent thermal stratification and there were micro-

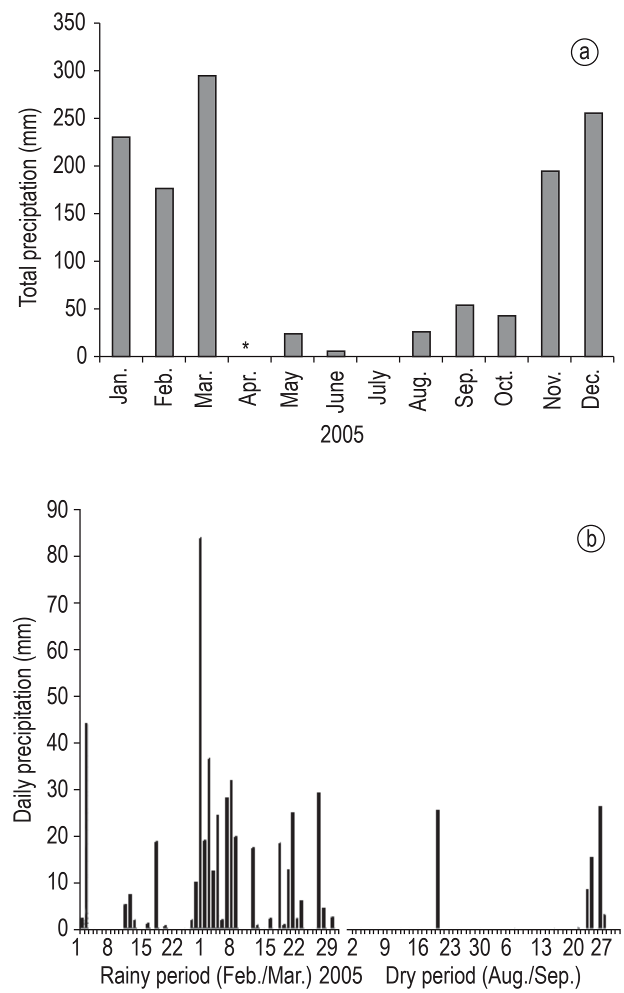

Figure 2. Temporal variation on precipitation in Lake Paranoá region. a) Monthly data 2005; b) rainy (Feb.-Mar./05) and dry (Aug.-Sep./05) periods.

stratifications during dry and rainy seasons (Figure 3). During weekly intervals the alternating periods of turbulence and short-term stratification were evidenced, as observed in February-March/05 and in August-September/05 (Figures 3b, c).

These results were demonstrated by temperature-depth profiles and confirmed by the Wedderburn number (W). If W is much greater than one, then mixing due to wind forcing will not occur. Conversely, if W is much smaller than one, then mixing is very likely to occur. In this study, W computed by numerical simulation using low values of wind velocity showed that weak winds would be sufficient to break the thermal stratifications.

During the hottest period (January-March/05), water temperature varied from 26.5 to 29 °C with micro-stratifications. During the intermediate period (April-August/05) values of water temperature were between 23 and 26 °C with homogeneous profiles. The remainder months (September-December/05) showed a progressive increase of water temperatures, from 24 to 26 °C with micro-stratifications too.

Descriptive statistics of limnological variables are presented in Table 1. During this study, water transparency fluctuated from 0.9 to 2.4 m and the euphotic zone varied between 2.4 and 6.5 m, with a maximum depth in the sampling station between 10.0 and 12.4 m. Total suspended

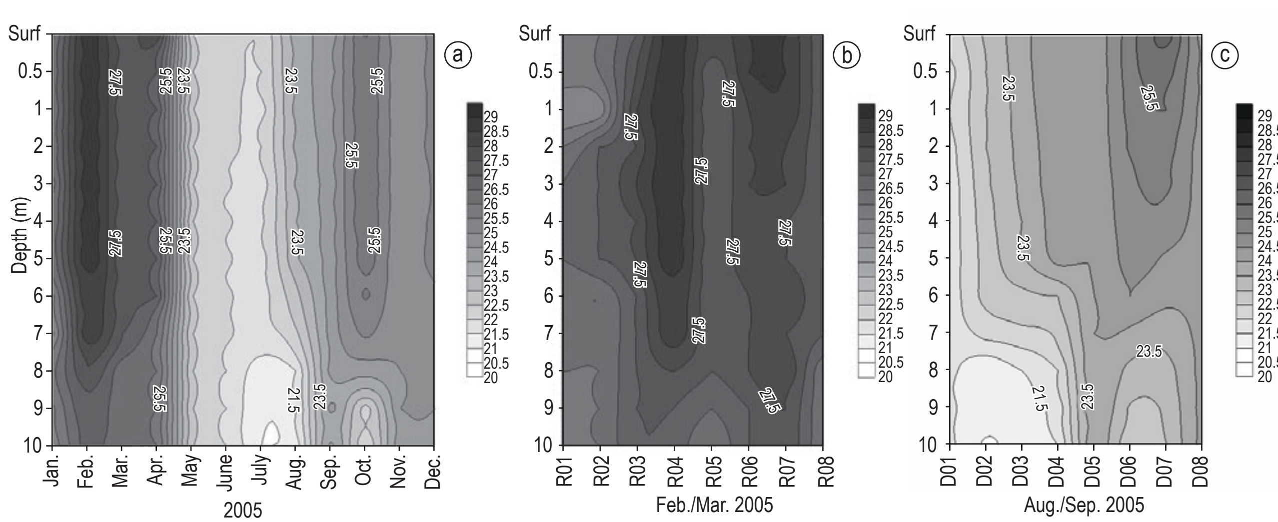

Figure 3. Thermal structure of the water column during 2005 in the Riacho Fundo branch, Paranoá Reservoir, DF, central Brazil. a) Monthly; b) Rainy period: February and March; c) Dry period: August and September.

Table 1. Average, standard deviation, minimum and maximum values of limnological variables from monthly and rainy (Feb.-Mar.) and dry (Aug.-Sep.) periods data during 2005 in Paranoá Reservoir, Riacho Fundo branch, DF, central Brazil. X ± SD = Average value ± Standard Deviation; (Min-Max) = (Minimum-Maximum Values).

Variable	Monthly data (year 2005)	Rainy (Feb.-Mar./05) data	Dry (Aug.-Sep./05) data
	X ± SD (Min-Max)	X ± SD (Min-Max)	X ± SD (Min-Max)
Transparency (m)	1.5 ± 0.3 (1.1-1.9)	1.6 ± 0.5 (0.9 -2.4)	1.7 ± 0.4 (1.1 -2.1)
Euphotic zone (m)	4.0 ± 0.8 (2.9-5.1)	4.3 ± 1.2 (2.4-6.5)	4.5 ± 1.0 (3.1- 5.6)
Local depth (m)	11.1 ± 0.7 (10.1-12.0)	11.1 ± 0.8 (10.0-12.4)	10.8 ± 0.6 (10.3 -11.9)
Temperature (°C)	24.9 ± 2.2 (29.0-21.8)	27.2 ± 1.5 (25.0-29.0)	24.0 ± 1.1 (22.0-25.5)
Total suspended solids (mg.L^{-1})	5.0 ± 1.4 (2.5-7.3)	4.8 ± 0.9 (3.4-5.5)	4.7 ± 2.2 (1.7-8.3)
Organic suspended solids (mg.L^{-1})	2.9 ± 1.6 (1.5-6.4)	1.7 ± 0.2 (1.5-2.0)	3.4 ± 1.9 (0.6-6.2)
Inorganic suspended solids (mgL^{-1})	2.0 ± 1.1 (0.8-3.4)	3.0 ± 0.7 (1.8-3.6)	1.3 ± 1.0 (0.3-3.4)
Chlorophyll-*a* (µg.L^{-1})	6.9 ± 4.5 (2.2-17.4)	2.9 ± 0.9 (1.5-4.2)	10.6 ± 3.8 (4.5-14.2)
pH	7.2 ± 0.2 (6.8-7.6)	7.1 ± 0.2 (6.8-7.5)	7.2 ± 0.2 (7.0-7.6)
Electric conductivity (µS.cm^{-1})	114.7 ± 13.4 (98.1-134.7)	101.2 ± 3.6 (94.6-105.8)	121.4 ± 10.4 (100.0-135.0)
Dissolved oxygen (mg.L^{-1})	6.3 ± 0.8 (5.3-7.7)	6.3 ± 1.2 (4.7-7.9)	7.5 ± 0.8 (6.2-8.6)
N-NO3 (µg.L^{-1})	290.1 ± 70.0 (143.0-404.0)	215.5 ± 50.2 (110.0-282.0)	415.0 ± 135.0 (328.0-743.0)
N-NO2 (µg.L^{-1})	52.5 ± 45.1 (3.0-183.0)	19.8 ± 17.5 (3.0 -58.0)	90.8 ± 42.1 (44.0 -183.0)
N-NH4 (µg.L^{-1})	1,969.4 ± 1,084.8 (1,97.0-3,638.0)	2,837.5 ± 625.5 (2,200.0-3,700.0)	1,623.6 ± 402.0 (948.0-2,315.0)
Total Nitrogen (µg.L^{-1})	2,712.0 ± 1,023.2 (1,057.0-4,380.0)	985.3 ± 278.5 (832.0-1,670.0)	2,656.9 ± 506.1 (2,027.0-3,577.0)
Total Phosphorus (µg.L^{-1})	26.0 ± 15.2 (2.0-62.0)	18.5 ± 6.8 (8.0-30.0)	27.3 ± 9.2 (16.0-41.0)

material showed values between 1.7 and 8.3 mg.L^{-1}, and organic material suspended had higher values during dry period (maximum 6.2 mg.L^{-1}), while inorganic material suspended had higher values during rainy period (maximum 3.6 mg.L^{-1}). Chlorophyll-*a* remained with a narrow range of values during rainy period (from 1.5 to 4.2 µg.L^{-1}). Higher values of chlorophyll-*a* were obtained during dry period (maximum 14.2 µg.L^{-1}), and among monthly data (maximum 17.4 µg.L^{-1}, October/05). This arm of reservoir was well oxygenated (up to 70%; 4.7 mg.L^{-1}), pH remained neutral (from 6.8 to 7.6) and water conductivity was above 90 µS.cm^{-1}. Among the inorganic nutrients, ammonium attained the highest values (minimum 948.0 µg.L^{-1}), followed by total nitrogen (minimum 832.0 µg.L^{-1}) and nitrate (minimum 110.0 µg.L^{-1}).

In relation to shorter periods, higher values were obtained during rainy-2005 for water temperature, inorganic suspended material, ammonium and total nitrogen (TN) (Z-Test, $p < 0.05$). In contrast, higher values were obtained during dry-2005 for water electric conductivity, organic suspended material, nitrate, nitrite, total phosphorus (TP), and chlorophyll-*a* concentrations (Z-Test, $p < 0.05$). There was no significant difference for euphotic zone, Secchi transparency, total suspended material, pH and dissolved oxygen (Z-Test, $p > 0.05$).

Great part of the limnological variables was interdependent and the first two axes of the PCA explained 59.81% of the total variability (Figure 4). The first principal component (PC1) accounted for 41.86% of total variance and it positively correlated to: total suspended material, water electric conductivity, nitrate and chlorophyll-*a*. The variables negatively correlated to PC1 are: euphotic zone, pH, ammonium and total nitrogen. This principal component may be considered as the influence of the precipitation on the reservoir limnology. The variables positively correlated to PC1 tended to obtain higher values in the dry season, while the variables negatively correlated to PC1 tended to obtain higher values in the rainy season, as defined by shorter periods sampling. The second principal component (PC2) accounted for 17.95% of total variance and may be related to variables more constant along the study, chiefly Secchi transparency (as euphotic zone) and dissolved oxygen. The variable positively related to PC2 is water temperature. The variables negatively related to PC2 are: dissolved oxygen and total phosphate.

In PCA, the hottest and rainy period (from January to April/05) shaped a uniform cloud near to variables with higher values in the rainy season. The driest period (from May to August/05) was grouped around lower part of Axis 2 and near to variables more constant along the study. The four final months (from September to December/05) formed a larger cloud encompassing the final stage of dry season and part of rainy period. This group was near to variables with higher values in the dry season (Figure 4).

Homogeneous profiles were obtained up to six meters for pH, dissolved oxygen and water electric conductivity. There were no differences among the depths (ANOVA, $p > 0.05$).

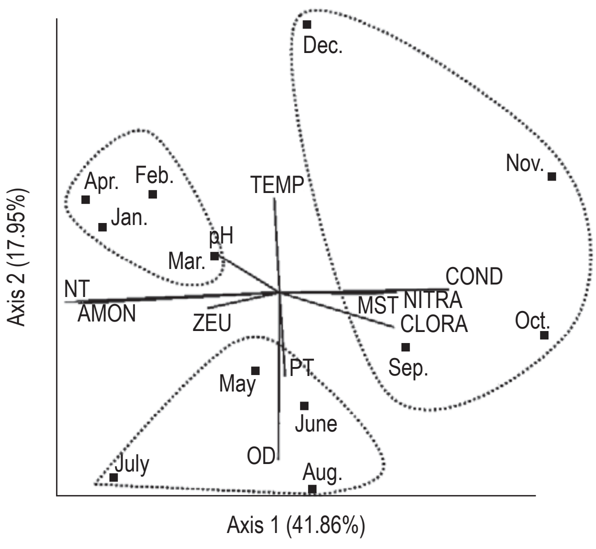

Figure 4. Ordering's diagram (PCA) of the monthly samples depending on the abiotic variables in Riacho Fundo branch, Paranoá Reservoir, DF, central Brazil. Only the variables with $r > 0.5$ on one of the ordination's axes were represented in the graph. NT (total nitrogen), AMON (ammonium), ZEU (euphotic zone), pH (pH), OD (dissolved oxygen), TEMP (water temperature), PT (total phosphorus), CLORA (chlorophyll-*a*), NITRA (nitrate), MST (total suspended material), COND (conductivity).

4. Discussion

Although many studies have been developed on reservoir trophic state, the majority displays about eutrophication process related to changes of limnological features and biological responses, including tropical systems (Branco et al., 2002; Tundisi and Matsumura-Tundisi, 2003). Reservoirs subjected to restoration measures are less frequent, especially in the urbanized area as Lake Paranoá, and the outcome is often uncertain, as reported by Horn (2003).

This uncertainty often reflects the fact that restoration of lakes, and specifically the appropriate reduction of nutrient availability, generally takes a long time (Scheffer et al., 1993; Dokulil and Teubner, 2003). This delay in responding to nutrient loading reduction is due to aquatic systems must be structured under new bases, as suggested by Donabaum et al. (2004) in an evaluation of the restoration process of River Danube. Under this condition, short-term fluctuations may be a complement set of trophic evaluation in the context of a long-term series (Ruggiu et al., 1998; Goldyn et al., 2003).

The flushing of Lake Paranoá has probably acted as the main intervention in breaking the system's stable state, thus starting a new state with difference in water quality in terms of phosphorus concentration and algae biomass, and consequent improvement in water transparency (Angelini et al., 2008; Mendonça-Galvão and Padovesi-Fonseca, sub). This result shows that operation of the reservoir had been controlled and hindered by a community structured under a stable eutrophic state. This state was only interrupted by a major disturbance integrating two scales: reduction in residence time and hydraulic drainage of a high water volume. Hosper (1998) lists a host of additional measures that could be fundamental forces in the change from a stable eutrophic status into another less eutrophic status. Among them, he highlights the washout or hydraulic drainage or flushing.

After flushing, a reduction in chlorophyll-*a* concentration and an increase in water transparency in Lake Paranoá were reported (Fonseca, 2001; Angelini et al., 2008; Mendonça-Galvão and Padovesi-Fonseca, sub.). These have also been observed by water quality restoration studies in temperate systems (Carvalho and Kirika, 2003).

In 1997 (five years after the implementation of measures to reduce nutrient loading) trophic status-related variables such as water transparency and electric conductivity, among others, showed values similar to those of previous years (Fellizato et al., 2000), with even greater deterioration in some cases, with anoxia events, massive fish death and blooms of *Microcystis aeruginosa* (*e.g.*, Padovesi-Fonseca and Philomeno, 2004).

These results indicate a delay in the response of some limnological and biological properties to nutrient loading reduction. In this case a delay of over six years that could possibly have been longer if the reservoir had not been flushed. Similar results were reported in oligotrophication studies in temperate systems (*e.g.*, van Duin et al., 1998).

During 2005, seven years after the flushing, the recovery process in Lake Paranoá remained unclear. Some limnological features indicate higher trophic state (as view by Fellizato et al., 2000), and confirmed by this study in relation to water electric conductivity and inorganic nutrient concentrations. In this way, in this study conductivity, total nitrogen and ammonium reach higher values, if compared to preceding period of intense eutrophication (Branco and Senna, 1996).

As these results are from the most eutrophicated part of the Lake Paranoá (Riacho Fundo arm), the response to nutrient loading reduction and further flushing tended to have a different and local pattern of changes. In other parts of the reservoir water transparency reached 6.0 m with the same conditions from limnological features (Angelini et al., 2008; Mendonça-Galvão and Padovesi-Fonseca, sub).

The temporal variability of Lake Paranoá is in part due to hidraulic regime (residence time and outflow) and in part to seasonal climate. During 2005, the climatological conditions were typical, with a warm-rainy and a cool-dry period, as reported by Ferrante et al. (2001), although the dry period was extended until October. The regional climate is windy, producing total circulation in the reservoir, especially in the dry season, and the reservoir occasionally stratifies in the rainy season (Ferrante et al., 2001). As an urban reservoir, the trophic state is better described by human influence and with the hydraulic regime and the regional climate altogether can identifying the ecology and the system's function mechanisms.

The seasonal course of limnological variables tended to exhibit a temporal pattern associated to precipitation regime. Rainy months were related to higher values of inorganic nutrients as allochthonous source, while intermediate periods (from dry to rainy season) resulted to higher values of phytoplankton biomass (estimated by chlorophyll-*a*), water electric conductivity and total suspended material as autochthonous source.

Although higher content of ammonium were obtained during rainy period (Feb-Mar/05), this nutrient attained with high values along the year (above 1,500 $\mu g.L^{-1}$), except October and November. In this way, the high content of this nutrient suggests an additional autochthonous source ammonium from the bottom layer of the lake. It is necessary to do further studies for explaining better this topic.

The influence of rainfall resulting in allochthonous fluxes into the reservoir from the basin and dilution effect was observed during the rainy period. This situation has widely been reported, including cases for Brazilian reservoirs (Tundisi and Matsumura-Tundisi, 2003). This way, higher inflow of suspended material and inorganic nutrients resulted to lower phytoplankton biomass and lower conductivity.

During shorter periods, the differences between dry and rainy seasons were more evident to inorganic features (as nutrients and inorganic suspended material for the dry season), and organic features (as chlorophyll-*a*, organic suspended material for the rainy season). Other variables, as higher temperature during rainy season, and higher conductivity during dry season confirmed this tendency.

During the dry season, the reservoir tends to have a lower water level and reduced dam outflow, resulting in a higher residence time. The dry period in 2005 was longer than a typical seasonal cycle, extending to October. As a consequence, higher levels of authochthonous variables were registered during this period, as phytoplankton biomass and organic suspended material related to higher content of nitrate and water electric conductivity.

In this reservoir the mixing conditions were prevalent and governed by the wind action, the precipitation and the dam outflow. This situation have been usually observed for shallower and well-mixed systems as many Brazilian reservoirs (Padovesi-Fonseca, 1997; Pinto-Coelho, 1998; Calijuri et al., 2002; Branco et al., 2002).

This study shows a marked temporal variability of limnological features, which were seasonal-dependent and related to wind and precipitation effects as well as dam operation. A major flushing event of Lake Paranoá (sudden release of water on November/98) was an abrupt intervention on water quality and to the increase of plankton diversity (Padovesi-Fonseca, Philomeno and Andreoni-Batista, *in prep.*). This intervention may have being a permanent impact to reach a new level of equilibrium, since has an effective control mechanism feedback (between nutrients and phytoplankton biomass) to avoid the return to eutrophication. Bicudo et al. (2007) also evaluated the limnological responses to macrophyte removal and they classified as an abrupt permanent impact in Garças Reservoir (southeastern Brazil).

The recovery process in Lake Paranoá is in progress and as urban reservoir a further efficient lake management is need to the maintenance on lower trophic degree and adequate water quality.

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