Limnological Characteristics of an Old Tropical Reservoir (Ribeirão das Lajes Reservoir, RJ, Brazil).

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ABSTRACT: Limnological Characteristics of an Old Tropical Reservoir (Ribeirão das Lajes Reservoir, RJ, Brazil). Ribeirão das Lajes Reservoir was filled in 1908 for electric power generation and domestic supply to districts of Rio de Janeiro City. In order to determine spatial and temporal patterns of limnological variables of Ribeirão das Lajes Reservoir, samples were taken monthly, from July 2001 to December 2002, at eight sampling stations. The waters were characterized by a neutral pH (7.19) and low average content of nutrients, 19.61 mg.L^{-1} of total P and 397.66 mg.L^{-1} of total N. Temporal fluctuation pattern was associated with column stability in most part of the year, and to the water mixing in July. The main horizontal spatial heterogeneity corresponded to differences between the riverine region, with influence of Tócos Tunnel discharge with higher nutrient concentration, and the limnetic area of the reservoir, with comparatively higher water temperature, transparency, conductivity and pH. According to average values of total phosphorous, total nitrogen and Secchi disk transparency Ribeirão das Lajes Reservoir was considered mesotrophic. The nitrogen and phosphorous content near the dam were influenced by water column conditions. In winter, the mixing of the water column influenced all the analyzed physical and chemical variables.
Key-Words: tropical reservoir, physical and chemical features, column mixing, water quality.

RESUMO: Características limnologicas de um reservatório tropical antigo (Represa Ribeirão das Lajes, RJ, Brasi). O reservatório de Ribeirão das Lajes foi formado em 1908 para a geração de energia elétrica e abastecimento doméstico para o município do Rio de Janeiro e adjacências. Para determinar os padrões espaciais e temporais das variáveis limnológicas do Reservatório de Lajes, foram efetuadas amostragens mensais em oito pontos, de julho de 2001 a dezembro de 2002. As águas foram caracterizadas por terem pH neutro (7.19) e baixa concentração de nutrientes, 19.61 mg.L^{-1} de P total e 397.66 mg.L^{-1} de N total. As variações temporais foram associadas com a estabilidade da coluna d'água na maior parte do ano, e com a homogeneização da água em julho. A heterogeneidade espacial horizontal correspondeu principalmente às diferenças entre a região fluvial, sob influência da descarga do túnel de Tocos com alto teor de nutrientes, e a área limnética do reservatório, com maiores valores de temperatura da água, transparência, condutividade e pH, comparativamente. De acordo com os valores médios de fósforo total, nitrogênio total e transparência pelo disco de Secchi, o reservatório de Ribeirão das Lajes foi considerado mesotrófico. As concentrações de N e P próximas à barragem foram influenciadas pelas condições da coluna d'água. A mistura da coluna d'água verificada no inverno, influenciou diretamente todas as variáveis físicas e químicas analisadas.
Palavras-chave: reservatório tropical, características físicas e químicas, homogeneização da coluna d'água, qualidade da água.

Introduction

At present, hydroelectric power supplies around 25% of global electrical energy, in Brazil this percentage attains 97% (Kelman et al., 2002).Most of the Brazilian reservoirs were constructed in the last four decades and have also been assuming special importance besides the hydroelectric power generation, in the water supply for agriculture and urban activities, flood control, fish farming and recreational uses.

The several uses and exploitations in catchment's basin related to waste disposal, raw sewage input, land filling, agriculture and erosion have accelerated nutrient accumulation in most of the reservoirs in the southeast part of the country in the last three decades (Giani, 1994; Branco et al., 2002; Espíndola et al., 2004; Henry et al., 2004). Excessive growths of algae, cyanobacteria and aquatic macrophytes in these ecosystems are reducing and impairing the uses for domestic supply, agriculture, recreation, navigation and power generation.

The State of Rio de Janeiro, located in the southeast part of Brazil has comparatively few reservoirs for water and/or electricity supply. Two reservoirs (Funil and Juturnaíba Reservoirs) are eutrophic, and were built in the beginning of 1969 and in 1980, respectively, with frequent occurrence of cyanobacteria blooms (Marinho, 2000; Branco et al., 2002). But, another reservoir (Ribeirão das Lajes Reservoir) despite that was shaped in beginning of 1900 was considered an oligotrophic to mesotrophic ecosystem (FEEMA, 1987).

The present study aimed at evaluating occurrence of temporal fluctuation patterns and horizontal spatial heterogeneity of limnological variables in Ribeirão das Lajes Reservoir, and up to what extent an old reservoir may be subjected to eutrophication.

Among the few studies done in the reservoir, thermal stratification and a pattern of hypolimnetic oxygen depletion for several months per year have been reported and it is considered monomitic with mixing occurring in winter (FEEMA, 1987). Due to its dendritic configuration and the input of nutrients through a main tributary (FEEMA, 1987), a horizontal heterogeneity and a longitudinal gradient in limnological variables are expected. Considering the agriculture activities in the drainage basin, the long retention time of the reservoir and the long time since it was filled, this study intends to corroborate the hypothesis that Ribeirão das Lajes Reservoir is in an increasing process of eutrophication.

Study area

Ribeirão das Lajes Reservoir was the first impoundment constructed in the Rio de Janeiro State and it is one of the first filled in the southeast part of Brazil. It was built in 1908 damming up waters of the Piraí and Ribeirão das Lajes rivers for hydroelectric power generation. Since 1940, the reservoir waters have been used for domestic supply of districts of the Rio de Janeiro City through an aqueduct. Nowadays, Ribeirão das Lajes Reservoir belongs to a system of reservoirs of Light SA, with a power generation of 612 MW and a water supply of 96% to the Rio de Janeiro municipalities (CEIVAP, 2001).

The Ribeirão das Lajes Reservoir (22º43'S and 22º46'S of latitude and 44º30'W and 44º60'W) lies among the hills of the Serra das Araras, at 415m a.s.l. in a relatively undisturbed area mostly surrounded by rain forest, with a few cattle farms and a fishing club. Since 2002, a tilapia (Oreochroimis nilotica) cage culture project has been developed in one bay of the lake.

The lake has a surface area of 30.73 km^2 at the level of 415 m, an average depth of 15 m and an accumulated volume of $450x10^6$ m^3. The littoral zone is poorly developed, since the slopes of the surrounding hills are abrupt, probably caused by variation of water level. Due to its long retention time (297 days), it has been considered highly subjected to eutrophication. Most of the incoming waters of the reservoir come from Piraí River, through Tócos Tunnel. This is a 7 km under-rock pipeline that takes water from Tócos Reservoir (0.59km^2) in Piraí creek, which lies in a farm region and receives nutrients from a small village.

Material and methods

Samples were taken monthly from July 2001 to December 2002 at eight different stations (Fig. 1). Water temperature, pH, electric conductivity, dissolved oxygen concentration and redox potential were measured using a multi-sensor probe YSI 6920. Water samples were taken at sub-surface level with a 2-liter Van Dorn bottle for analysis of $P\text{-}PO_4^{3-}$, total-P, $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, nitrogen Kjeldahl (macro-Kjeldahl method) and total nitrogen analysis (APHA, 1985). Additional samples for nutrient analysis were taken at station 8 at 10 and 20m depths. A principal component analysis (PCA) was performed on all log (x+1) transformed physical and chemical data (except pH) in order to summarize relations among environmental variables. Rainfall and reservoir water level data were obtained from meteorological and hydrological stations of Light SA, respectively.

The climate of Ribeirão das Lajes Reservoir region is sub-humid, classified as Aw in Köppen's system and the average air temperature during the period of study was 22.4°C, minimum average 17.5°C in July of 2002, and maximum average 24.4°C in March of 2002.

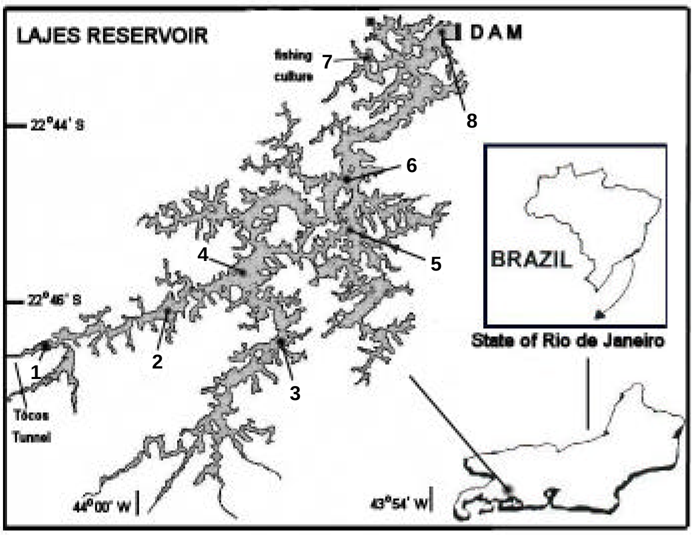

Figure 1: Ribeirão das Lajes Reservoir, indicating the eight sampling stations.

Results

The rainy season begins in November and ends in March. The rainiest months were December, February and March in the studied years (Fig.2). Annual rainfall was 1,478 mm in 2001 and 1,647 mm in 2002. These two years presented high precipitation, compared to the year of 2000 with only 640 mm of annual rainfall.

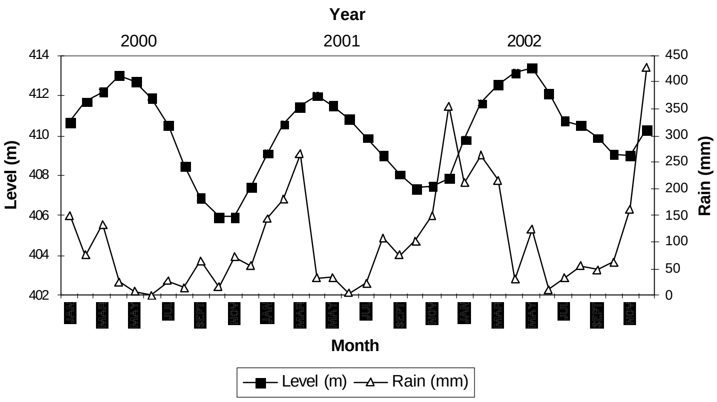

Figure 2: Water level (in meters) and pluviosity (in milimeters) in Ribeirão das Lajes Reservoir from January of 2000 to December of 2002.

Surface water temperature had an average value of 26.08ºC, annual range of 16.4 to 30.8 ºC, and followed climatic variation with lower values in winter (July, August and September). The inflow of the Piraí creek through Tócos Tunnel contributed to a low water temperature at station 1 during all the study period (Fig.3).

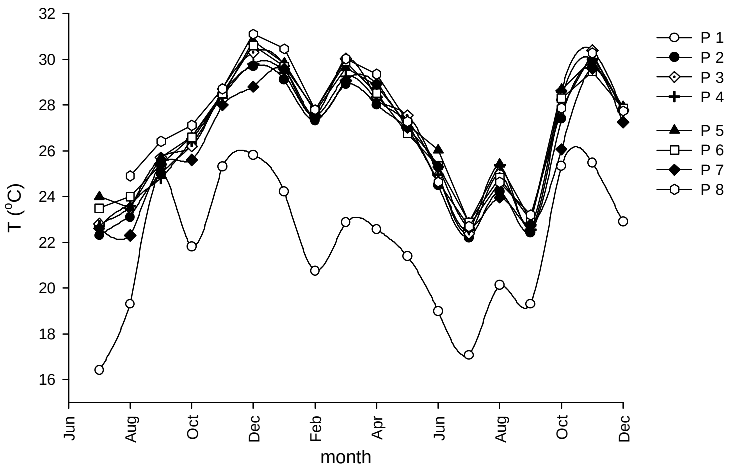

Figure 3: Water temperature (ºC) at the eight sampling stations during the period of study.

Station 1 in the riverine zone and shallower (5 meters of depth) than the other stations was considerably more turbid and presented lower Secchi disk transparency (Fig.4a). Water transparency attained higher values at stations 6 and 8 and the annual range was from 0.4 to 5.5 meters. Despite the influence of the creek inflow, values of conductivity were lower at station 1 (Fig. 4b) and showed average values between 28.4 and 30.2 mS.cm^{-1} at the other sampling stations.

Piraí creek inflow also influenced values of pH, which were lower at station 1 and increased at stations 2, 3 and 4 (Fig. 4c). The pH of all the samples had an average value of 7.19 and a standard deviation of 0.53, varying between 8.50 to 5.67.

Dissolved oxygen had an average value of 8.20 mg.L^{-1} at the surface of the sampling stations and decreased from station 1 towards stations 5 and 7 (Fig. 4d). High average oxygen content was found at station 8, near the dam.

High values of redox potential were found at stations 1, 2 and 3 and lower at stations 6 and 7 (Fig. 4e). During the study period the redox average value was 182.13 mV The minimum value recorded was(-25.10 mV) and maximum +447.00 mV.

Total phosphorous content decreased from stations 1 to 6, and an increase was recorded at station 7(Fig.5). Average value of total phosphorus was 27.1 mg.L^{-1} at station 1, and 14.7mg.L^{-1} at station 8, near the dam. Maximum content of total phosphorus was 50.0 mg.L^{-1} detected at station 1 in March and at station 7 in December. Orthophosphate content was undetectable most times, except at sampling station 1.

Nitrate concentration also decreased from station 1 to 3 and then presented a slight increase at station 4. Mean annual value of nitrate was 56.78 mg.L^{-1} and maximum content was 600.0 mg.L^{-1}, recorded at station 4 in November. Organic nitrogen, corresponding to N Kjeldahl values showed a decrease from station 1 to 8 but presented a significant increase at station 7. The highest value of TKN (2,200 mg.L^{-1}) was found at this site in September 2002. The annual average value of TKN in station 7 was the highest between all the points of this study, being around 5% higher than station 1 (Fig. 5).

A difference of 8ºC between the surface and 20m was recorded during the summer (Fig.6). This difference was decreasing as seasonal cooling began in the surface. An increase of dissolved oxygen at 10m depth began in May, as well as values of redox. By July, an overturn occurred. This event affected dissolved oxygen and redox potential at 10 and 20m depth. Despite the same water temperature at the mixing

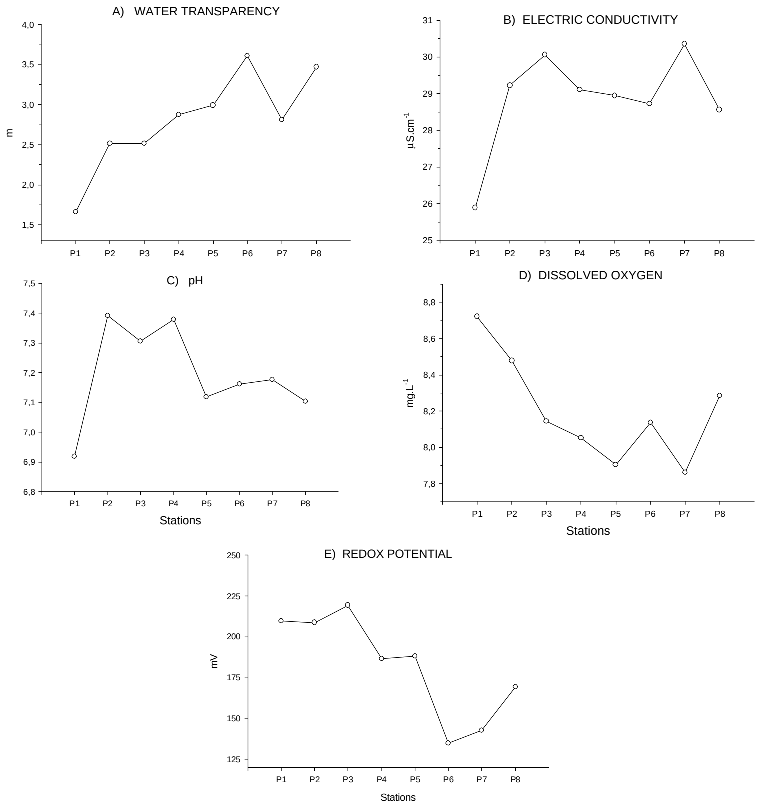

Figure 4: Average values of Secchi depth (meters), electric conductivity (mS.cm-1), pH, dissolved oxygen (mg.L-1) and redox potential (mV) at the sampling points during the study period.

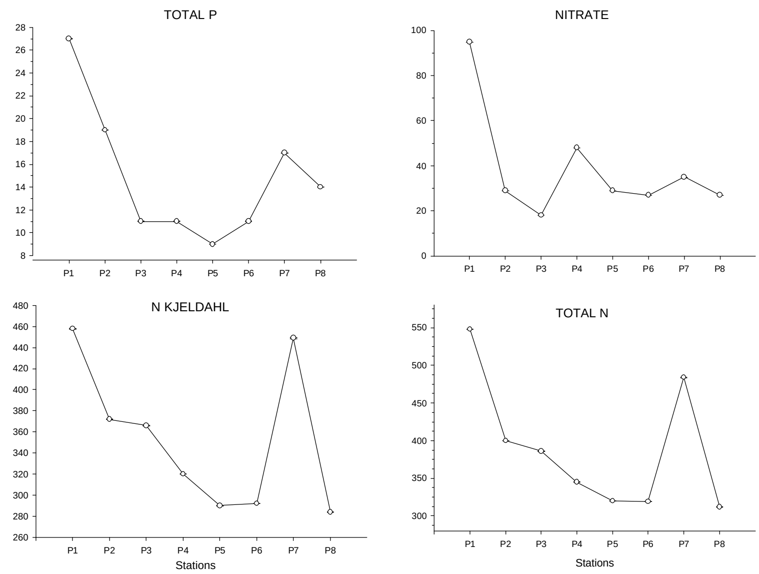

Figure 5: Average values of total phosphorus (mg.L-1), NO_3^- (mg.L-1), Kjeldahl nitrogen (mg.L-1) and total nitrogen (mg.L-1) at the sampling points during the study period.

period dissolved oxygen differed at the three depths (0, 10 and 20m depths) due to hypolimnium oxygen deficit. The redox potential (ORP) variation was no similar to the dissolved oxygen changes (Fig. 6) redox had higher values at the surface and at 10m and lower at 20m except during the mixing in July, and in the two following months (August and September)

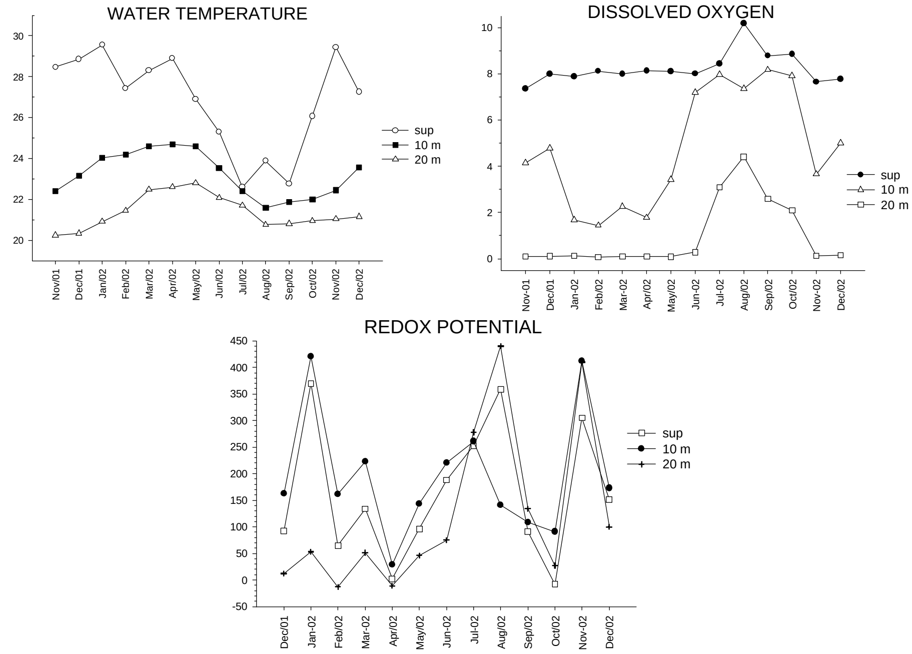

Figure 6: Monthly values of water temperature (ºC), dissolved oxygen (mg.L^{-1}) and redox potential (mV) at the surface, 10m and 20m of sampling point 8 during the study period.

The water mixing also affected total phosphate concentration near the dam. High values were usually found at 20 m depth, except in August of 2002 (Fig.7). While NO_3^- values changed monthly, with high values at 10 or at 20 m, NH_4^+ concentration and TKN were always-higher at 20 m. TKN values followed NH_4^+ values at 20m, where most nitrogen was in inorganic form. The mixing period also affected organic nitrogen values at 20m and low TKN concentrations were found in July and August.

The first three factorial axes of the PCA accounted for 58.9% of total surface data variability (Fig. 8). This analysis summarized the influence of nitrogen forms, specially TKN, total nitrogen, and water temperature on the observed data variability. Component one of the PCA corresponded to the temporal fluctuation pattern of limnological variables in the reservoir. Left part of the first factorial axis (factor 1) is associated with column stability in most part of the year, from September to June of the next year and corresponding to the increase of variables with negative coordinates (P=0.005) with this axis, such as TKN, total N, water temperature, ammonia and water transparency. Right part of the first factorial axis corresponded to the water mixing, in July, which also affected water conditions in August, causing increase of nitrate content in the surface as well as dissolved oxygen and redox potential. According to the PCA result total P content and water conductivity were not so changed by this temporal pattern.

The second component of the PCA corresponded to the main horizontal spatial heterogeneity of limnological variables in Ribeirão das Lajes Reservoir. Upper part of the second factorial axis (factor 2) corresponds to the riverine region, with influence of Tócos Tunnel discharge with higher nutrient concentration, and dissolved oxygen. Lower part of the factorial axis is associated with conditions of the limnetic area of the reservoir, with comparatively higher water temperature, transparency, conductivity and pH.

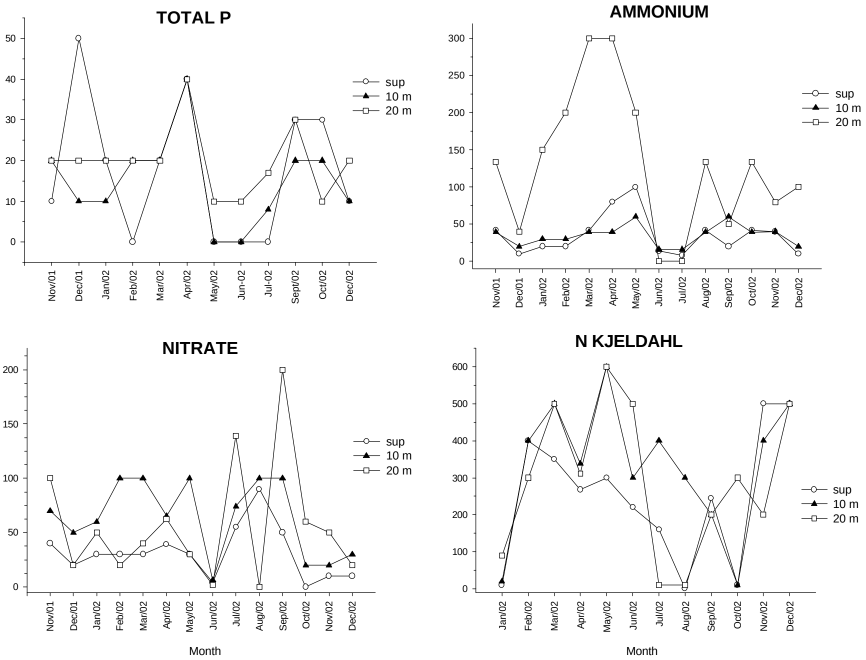

Figure 7: Monthly values of total phosphorus ($mg.L^{-1}$), NO_3^- ($mg.L^{-1}$), NH_4^+ ($mg.L^{-1}$) and total Kjeldahl nitrogen ($mg.L^{-1}$) at the surface, 10m and 20m of sampling point 8.

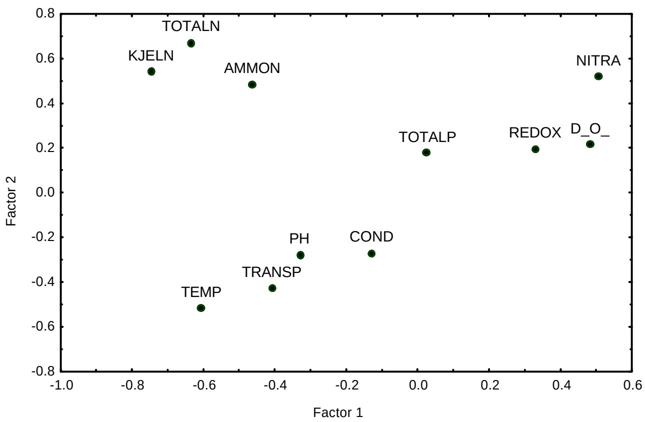

Figure 8: Principal component analysis with environmental variables. AMMON = NH_4^+, COND = electric conductivity, D_O_ = dissolved oxygen, NITRA = NO_3^-, NKJEL = total Kjeldahl nitrogen, NTOTAL = total nitrogen, PH = pH, REDOX = redox potential, TEMP = water temperature, TOTALP = total phosphorus and TRANSP = water transparency.

Discussion

Climate is closely related to latitude and influences the thermal pattern of reservoirs. Despite the reduced air temperature variation in tropical areas, data on lake thermal regime on both sides of the equator such as in Mexico (Alcocer et al., 2000), Africa (Talling, 1969), Australia (Boulton & Brock, 1999) and Brazil (Henry, 1999) have shown a tendency of mixing during the winter. According to Branco (2004), Ribeirão das Lajes Reservoir stays stratified all the year of 2002, except in July, when an isothermy was found, as well reported by FEEMA (1991) for August of 1987 and 1988.

According to data from Light S.A. hydrological station, the annual fluctuation of the water level (+/- 8m) of the reservoir is affected by the rain. The volume of the reservoir is maintained artificially attaining the highest level in April, after the rainy period and the lowest in November. Due to water supply strategies the level of the reservoir has been increased annually (Fig. 2), and the minimum level of 406m in November 2001, was kept at 409m in 2002. This procedure was adopted after the necessity to improve the volume of water for domestic supply from Ribeirão das Lajes Reservoir due to a decrease of water availability from other reservoirs of the system of Light SA in the year of 2001.

Except at station 1, surface water temperature range was around 3ºC, being similar to other lentic tropical systems (Arumugam & Furtado, 1980; Pinto-Coelho et al., 1997; Branco & Senna, 1996). The influence of the creek inflow at station 1, was shown by the lower values of water temperature, transparency, conductivity and pH at this site. The region of this station corresponds to the riverine zone of the reservoir. Most results of limnological variables showed the horizontal spatial heterogeneity in Ribeirão das Lajes Reservoir from this riverine region to the dam.

Dissolved oxygen had an average value of 8.20 $mg.L^{-1}$ at the surface of the sampling stations and decreased from station 1 towards stations 5 and 7. High average oxygen content was found at station 8, near the dam, possibly caused by operational discharge procedures. Values of redox potential followed the tendency of comparatively high values at stations 1, 2 and 3 and lower at stations 6 and 7. The annual average value of 182.13 mV suggests a constant oxidation condition of the water. The minimum value (-25.10 mV) was found at station 6 in the beginning of the dry season (April 2001), where lower values of this variable were usually found, possibly associated with the presence of reduced chemical species. The redox potential is a measure of tendency to acquire or loose electrons of a particular chemical species. Arbitrarily, the standard hydrogen electrode was assigned a potential of zero. Thus, species like MnO_4^-, Cu^{2+} and cromium have more oxidizing power than hydrogen, and species like alkaline metals, $PbSO_4$ and Mn^{2+} have more reducing power than hydrogen.

Total phosphorous content decreased from stations 1 to 6. An increase was recorded at station 7, which possibly influenced a relatively higher content of total phosphate at station 8. The results showed that the water from Tócos Tunnel is the main phosphate source to the reservoir, since most of the other tributaries present low volume and come from protected areas. Orthophosphate content was undetectable most times, except at sampling station 1, where probably the low transparency and the presence of particulate matter reduced phytoplankton community production (Branco, 2004).

According to Overbeck (2000), nitrogen and phosphorus are consumed by phytoplankton at an average mass ratio of 7.2:1, and the critical balance in which phosphorus begins to be limiting is about 10:1. Forsberg et al. (1978) in algae assays considered that phosphorus is a limiting factor in a Total N / Total P above 12. In this study, average TN/TP was 20.4 and the lowest value was found at sampling station 1 (20.3), indicating that orthophosphate is a limiting factor to phytoplankton, but other processes can be involved in nitrogen and phosphorus cycling as interactions among organisms of the aquatic ecosystem. Pinto-Coelho et al. (1997), in a study of zooplankton and bacteria contribution to phosphorous cycling, concluded that planktonic bacteria are able to consume directly phosphorous excreted by zooplankton.

Phosphorus has been reported as a critical nutrient in determining eutrophication status of reservoirs (Marinho & Huszar, 2002), and Ribeirão das Lajes Reservoir with a high retention time tends to accumulate a load of phosphorus by the sedimentation of particulated matter. The stratified lakes, which develop an anoxic hypolimnion, were believed to suffer from internal P loading due to the redox-dependent release of iron-bound phosphorus (SØndergaard et al., 2001). These features of the reservoir highlight the importance of phosphorus input control in the lake.

Nitrate content also decreased from station 1 to 3 and N Kjeldahl and total N decreased from station 1 to station 6. The lowest values of NH_4^+, NO_3^- and NO_2^- were found at the surface of station 8, near the dam. The highest value of TKN was found at station 7 and the annual average in this station was the highest among all the points of this study and it was due to the fish cage culture.

Total Kjeldahl nitrogen has been used as one of the measures of trophic state in lakes (Boulton & Brock, 1999), and it was an effective variable in ranking lakes, having the highest rank correlation against chlorophyll-a of all methods tested in 44 test lakes by Lambou et al. (1983). The results of TKN showed that the nitrogen compounds remains in Ribeirão das Lajes Reservoir mainly in the organic form.

Sources of TKN include the decay of organic material such as plant material and animal wastes, and drainages from forest areas can export 150-500 mg of nitrogen per square meter per year (Jørgensen, 2000). It can be suggested that besides the input by the Tócos Tunnel, drainage from the soil of the surrounding forest in which organic nitrogen is normally associated with humus is another origin for the organic nitrogen in Ribeirão das Lajes Reservoir.

Besides being a source of phosphate, the fish culture may also become an important supply of organic nitrogen to the reservoir, since the highest value of TKN (2,200 $mg.L^{-1}$) was found at this site. Intensively fed fish generate fecal waste and uneaten food debris that impact the water with the increase of dissolved nitrogen and phosphorus contents and of the biological oxygen demand of decaying organic matter. The environmental impact associated with farming fish in cages in reservoirs has been reported (Beveridge & Muir, 1999).

While differences in physical and chemical variables among stations delineated horizontal heterogeneities in Ribeirão das Lajes Reservoir, the sampling at station 8 (surface, 10 and 20m depth) helped in evaluating the occurrence of temporal fluctuation patterns in the reservoir. This fluctuation was related to the effect of water mixing and rainy period in summer on environmental variables.

Organic nitrogen concentrations increased at surface during the stratification period and decreased after the water mixing whereas inorganic nitrogen and phosphorus compounds increased in summer. This finding is common in tropical areas, where heavy summer rains carry soils and urban drainage into reservoirs and thus inorganic nutrients. Branco & Senna (1996) found an increase in nutrients in the beginning of the rainy season in Paranoá Reservoir and Marinho & Huszar (2002) registered a mean NO_3^- value of 19 $mg.L^{-1}$ in the dry season and 409 $mg.L^{-1}$ in the wet season in Juturnaíba Reservoir.

Difference in water temperature between the surface and 20m was high (8ºC) during the summer and decreased as seasonal cooling began in the surface. An increase of dissolved oxygen at 10m depth began in May, as well as values of redox, both probably associated with the fall of air temperature causing incomplete mixings. By July an overturn occurred. This event affected values of dissolved oxygen and redox potential at 10 and 20m depth. According to Branco (2004), there was an isothermy in July in most sites of the reservoir including near the dam. From September, increasing solar radiation warmed the surface layer and the thermal stratification was re-established.

Despite the same temperature at the mixing period, dissolved oxygen differed at the three depths (0, 10 and 20m depths) due to the hypolimnium oxygen deficit. Hypolimnetic oxygen depletion is a function of lake productivity, oxidation of dissolved organic compounds and water temperature (Hannan et al., 1979). Even low productivity in the euphotic zone can govern the content of oxygen in the hypolimnion (Boland & Padovan, 2002). The continued deposition of organic material in Ribeirão das Lajes Reservoir, produced in the epilimnion for decades and the subsequent decomposition were probably sufficient to create a great hypolimnion oxygen deficit. Hutchinson (1975) related the capacity for oxygen consumption to the volume of the hypolimnion. Accordingly, the epilimnetic oxygen production is not sufficient to promote high dissolved oxygen in the deeper part of the hypolimnion during overturn. Once the stratification was established, the hypolimnion soon became depleted of dissolved oxygen.

The oxi-reduction potential (ORP) variation was no similar to the dissolved oxygen changes. Dissolved oxygen was always higher at the surface, while redox had higher values at 10m, except from July to September (Fig. 6). Relative redox potential and associated water chemistry of the different ions and compounds would determine the time of anoxic environment and various differing chemical conditions. According to Boulton & Brock (1999), NO_3^- is reduced at a redox potential less than approximately +225mV and Fe^{+3} at +120mV. The seasonal variation of redox can interfere with water quality for domestic supply at 10m since the availability of iron and solubility of other metals can be enhanced according to changes in the redox potential.

The water mixing also affected total phosphate concentration near the dam. High values were usually found at 20m depth, except in August of 2002 (Fig.7). Anoxic and low redox potential conditions release iron-bound phosphorus from sediments, in April of 2002, when a drop in redox corresponded to high phosphorus content at 20m. On the other hand, well-oxidized conditions throughout the water column and higher redox potential may bind phosphate with iron oxides, and hydroxides in the sediments and, also prevent phosphorus release and may explain the decrease in total phosphorus in August. Drainages from surrounding forest possibly influenced high total phosphorus concentrations found at the surface in December of 2001 and October of 2002.

While NO_3^- values changed monthly, with high values at 10 or at 20 m, NH_4^+ concentration and TKN were always-higher at 20 m. Accumulation of nutrients in metalimnion may explain high NO_3^- values at 10m, and was also found in other reservoirs (Infante & Infante, 1994). The content of nitrogen forms at 20m was affected by the availability of dissolved oxygen, since drops in NH_4^+ values during the mixing corresponded to an increase in NO_3^- concentration, what was also reported by Hannan (1979) for a water mixing in a temperate reservoir.

The PCA summarized the temporal fluctuation pattern of limnological variables and the horizontal gradient of them in Ribeirão das Lajes Reservoir. The temporal variation was considered more important than the horizontal difference to explain variables changes, and was associated with the effect of water mixing during winter on nitrogen forms, specially TKN, and total nitrogen. The first component of the PCA can also be interpreted as a gradient of organic to inorganic forms of nitrogen. As the bulk of the nutrients remains in Ribeirão das Lajes Reservoir mainly in the organic nitrogen form, most of the content of inorganic nitrogen is derived from oxidation of organic forms. So, the oxidized species of nitrogen are related to high oxygen content. There was a slight increase in NO_3^- values in winter, during mixing with low water temperature, and when reduced forms of nitrogen in the hypolimnion were oxidized.

The second component of the PCA corresponded to the main horizontal gradient that exists in the reservoir, from the riverine region, with higher nutrient concentration, dissolved oxygen, and redox potential to the limnetic area of the reservoir, with comparatively higher water temperature, transparency, conductivity and pH. It suggests that station 1 is really the main nutrient input to Ribeirão das Lajes Reservoir, as verified also by FEEMA (1987).

Comparing the mean results of the last limnological surveys done in Ribeirão das Lajes Reservoir by FEEMA in 1986 (FEEMA, 1987) and by Light in 1991 (IESA, 1991) with this study, water transparency values decreased from 4.10m (3.0-7.0m)(IESA, 1991) to 2.81 (0.40-5.5). The decrease on Secchi disk reading was due to an increase of phytoplankton biomass in the reservoir, since chlorophyll-a values in 1991 were around 0.64 $mg.L^{-1}$ and in 2000 were 1.8 $mg.L^{-1}$ (Marinho, pers. comm.). No significant difference on the electric conductivity values was found, since the annual averages were of 25mS.cm^{-1} in 1987-1988, 26mS.cm^{-1} in 1991 and 29mS.cm^{-1} in 2002.

The electric conductivity values of Ribeirão das Lajes Reservoir were lower than in other Brazilian reservoirs (Arcifa et al., 1986; Branco & Senna, 1996; Espíndola et al., 2000; Branco et al., 2002; Marinho & Huszar, 2002), indicating low human influence on the reservoir basin drainage. Furthermore, comparing with the data of IESA (1991), the average concentration of total phosphate at station 1 dropped from 33 to 27 $mg.L^{-1}$. The decrease in urban expansion in the basin of Piraí creek from 1985 to 2000 may explain this finding. However, comparing the results of IESA (1991) with the obtained in this study, the average concentration of total nitrogen at station 1 increased from 381 $mg.L^{-1}$ to 550 $mg.L^{-1}$, probably related to an increase of cattle farm activities upstream Tócos Reservoir.

Evaluating average values of total phosphate found in this study with OECD criteria values (Vollenweider, 1982) and, average characteristics of lakes according to trophic state (Smith et al., 1999), Ribeirão das Lajes Reservoir is considered as mesotrophic system. However, some values above the eutrophic condition (>35mg.L^{-1}), were found at the surface of sampling stations 1 in December of 2001 (40 mg/L) and March 2002 (50 mg/L), station 8 in December of 2001 (50mg/L) and April of 2002 (40 mg/L), and at station 7 in September of 2002 (40 mg/L).

The hypothesis that Ribeirão das Lajes Reservoir is in an increasing process of eutrophication was not confirmed by this study. The protected surrounding forest and low human activity in the drainage basin undoubtedly contributed to the low the nutrient input. However, new human activities in the reservoir, such as fishing culture can accelerate the increase of nutrients input into the reservoir, which has been delayed for decades.

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