Trophic status of a Brazilian urban reservoir and prognosis about the recovery of water quality.

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ABSTRACT: Trophic status of a Brazilian urban reservoir and prognosis about the recovery of water quality. Garças Lake is a small tropical urban reservoir, with 68 days hydraulic residence time (annual theoretical mean) located in São Paulo city (Brazil). In order to develop management strategies for the recovery of its water quality, a diagnosis of the trophic state was performed. Phosphorus and nitrogen mass balances and the development of a model to evaluate the nutritive condition of the lake were included. Incoming annual phosphorus and nitrogen loads by the seven tributaries were, respectively, 6,519 kgP and 37,157 kgN. From the total phosphorus load, 45% proceeded from the creek of Zoological Garden Foundation of São Paulo (the most important point-source), while 32% were from the Agricultural and Food Supply Department (the second most important point-source). From the nitrogen total incoming load, 62.8% corresponded to biological fixation; 1.4% to non-point sources; 1% to wet precipitation and 34.7% to point-sources. Mass balances revealed high nitrogen (85% of total input) and phosphorus (61% of total input) retention in the reservoir. The annual observed mean of total phosphorus in the water surface was 132 mg.l^{-1}, indicating a hypereutrophic condition. A hypothetical scenario of 90% reduction in the load from the seven tributaries could change the trophic status of the reservoir to an oligotrophic condition (17 mgTPl^{-1}). Reservoir management strategies for the improvement of water quality are discussed.

Key-words: phosphorus load, mass balance, eutrophication model, reservoir management.

RESUMO: Status trófico de um reservatório urbano brasileiro e prognóstico sobre a recuperação da qualidade da água. O Lago das Garças é um pequeno reservatório urbano tropical com tempo de residência hidráulico de 68 dias (média teórica anual) localizado na cidade de São Paulo (Brasil). Com finalidade de desenvolver estratégias para a recuperação da qualidade de suas águas, um diagnóstico do estado trófico foi realizado. Balanços de massa de fósforo e nitrogênio e o desenvolvimento de um modelo para avaliar a condição nutritiva do lago foram incluídos. As cargas anuais de fósforo e nitrogênio introduzidas pelos sete tributários foram, respectivamente, de 6.519 kg P e 37.157 kg N. Da carga total de fósforo, 45% provém de pequeno curso de água da Fundação Parque Zoológico de São Paulo (a fonte pontual mais importante), enquanto 32% veio da Secretaria de Agricultura e Abastecimento (a segunda fonte pontual mais importante). Do total da carga de nitrogênio introduzida, 62.8% correspondeu à fixação biológica; 1.4% às fontes pontuais; 1% à precipitação úmida e 34.7% às fontes não pontuais. Os balanços de massas revelaram elevadas retenções de nitrogênio (85% do total introduzido) e fósforo (61% do total introduzido) no reservatório. A média anual observada de fósforo total na água de superfície foi 132 mg.l^{-1}, indicando uma condição hipereutrófica. Um cenário hipotético de redução de 90% da carga dos sete tributários poderia mudar o status trófico do reservatório para uma condição oligotrófica (17-mg PT.l^{-1}). Estratégias de manejo do reservatório para a melhoria da qualidade da água são discutidas.

Palavras-chave: carga de fósforo, balanço de massa, modelo de eutrofização, manejo de reservatório.

Introduction

The exponential growth of human population worldwide has increased the water demand in great amount, not only for its basic necessities (water supply) but also for other purposes, such as industrial, recreational and agricultural activities. The concentration of human population in urban centers has produced, on a large scale, wastes that it are dumped without treatment in aquatic ecosystems, specially in tropical regions (Havens et al.,1996). The “cultural” eutrophication of lentic environments via the introduction of untreated wastewaters, develops faster in sites of high demographic density and eutrophication has proved to be one of the most widespread and serious anthropogenic disturbances to aquatic ecosystems (Lampert & Sommer, 1997).

Any plan for the restoration and protection of water quality requires a previous diagnosis of the aquatic environment and, the development and application of ecosystem behaviour models. A basic requirement for eutrophication models is the determination of nutrient mass balances (Jorgensen, 1986) and tools for the trophic state evaluation of the lakes include the use of phosphorus loading models (Vollenweider, 1975; 1976). The early model of Vollenweider (1975) assumes a constant setting velocity, while the second estimates the phosphorus trapping from the lake’s hydraulic retention time (Vollenweider, 1976).

Toledo et al. (1983) presented modifications in the original trophic state indexes of Carlson (1977), for the tropical lakes and reservoirs, introducing sedimentation coefficients and, a weighting system in the indexes, because of the measured variables behaviour. Using data from 26 reservoirs of South America and Brazil, Salas & Martino (1991) developed predictive models for in-lake total phosphorus concentrations, based on the incoming phosphorus load, hydraulic retention time and mean depth.

Although the eutrophication process is favored by year-round high temperatures in tropical regions and is a very widespread problem, very few studies have been undertaken on phosphorus and nitrogen mass balances in Brazilian waterbodies.

Studies on nitrogen and phosphorus balance were conducted in Brazil for urban (Barbosa et al., 1998), mean (Rios, 1999) and high (› 200days) hydraulic retention time reservoirs (Henry et al., 1999). Tundisi & Matsumura-Tundisi conducted a study in Barra Bonita Reservoir (São Paulo State) about the increasing eutrophication and showed that rainfall, wind, flushing rate and residence time are the main forcing functions on nutrient cycles, biomass, and primary production of phytoplankton.

Aiming at the proposal of management strategies for the recovery of waters quality, a study was performed in an urban reservoir that has a unique scenario in the Latin America, since it is located in a Biological Reserve with Atlantic Forest remnants (Protection Area), which is surrounded by the 4th largest metropolitan area worldwide, the municipality of São Paulo (Vitor & Costa Neto, 2003). The system contributes to local biodiversity and is a migratory route of bird species. Thus, present study aims at contribute with water recovery management strategies towards protection of biodiversity in an Atlantic Forest fragment under intense urbanization pressure. The diagnosis includes a mass balance of nutrients and the use and development of mathematical model for the evaluation of the lake trophy and the presentation of hypothetical scenarios of probable incoming phosphorus load reductions.

Study area

Garças Lake is located (23° 38’S and 46° 37’ W) in the Biological Reserve of Ipiranga Headsprings State Park in São Paulo, Brazil (Fig.1). Considering Latin America, the reserve is one the largest green areas containing remnants of the Atlantic Forest in a highly inhabited (14 million people) urban city; it has a mean altitude and a total surface area, of 798m and 526 ha, respectively (Fernandes et al., 2002). Santos & Funari (2002) have classified the local regional climate, as humid, mesothermic, without water deficiency and with an excess of water in the summer. The mean annual precipitation is 1,368mm; the mean air temperature of the coldest month (July) is 15.0 °C, and temperature range during the hottest months (January-February) is 21.4-21.6°C.

Garças Lake was shaped by the damming of several creeks in 1917 for water public supply (Bicudo, D. et al., 2002). It is a small reservoir (surface area: 88,156 m^2; mean and

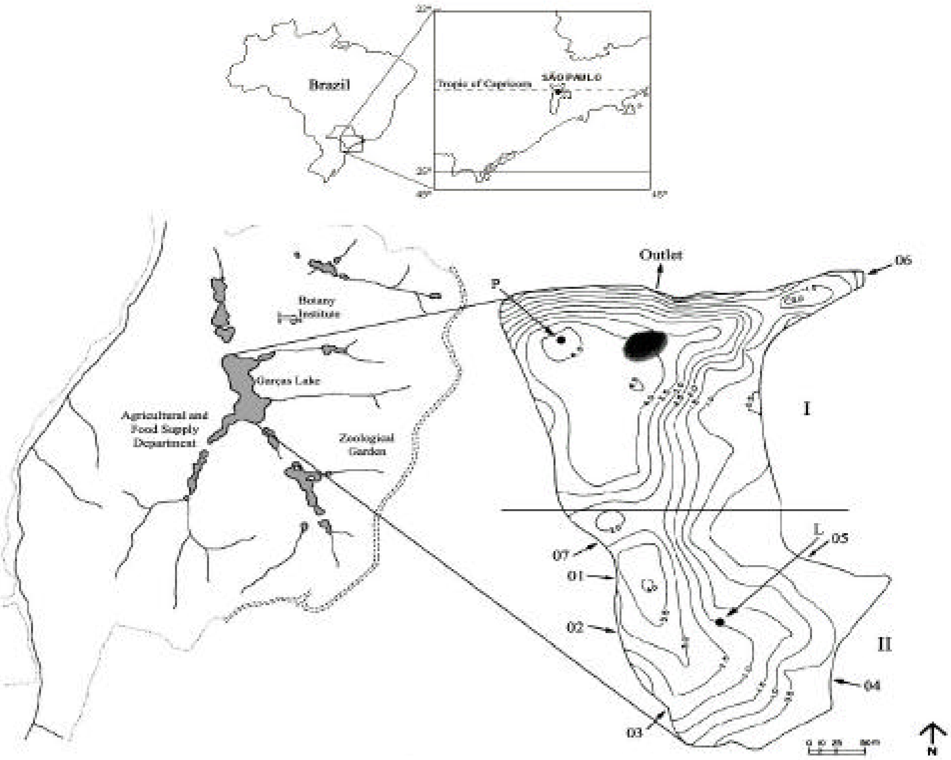

Figure 1: Study area (Garças Lake, São Paulo, Brazil) with batimetric map; Compartments I and II of the lake; L and P stations for water sampling; 01 to 07 inputs for incoming loads.

maximum depths 2.14 and 4.70m, respectively; maximum length: 512m; shoreline and volume indexes:1.46 and 1.36, respectively). The reservoir has a residence time of 68 days (annual theoretical mean), and receives water from seven small tributaries (catchment area: 2.62 km²); three of these inflows (inputs 03, 04 and 05, see Fig.1) are derived from the Zoological Garden and, have had great impacts on the lake since 1958. According to the trophic state formulation of Toledo et al. (1983), this reservoir is classified as a eutrophic and hypereutrophic system (Nogueira & Ramirez, 1998; Mercante & Tucci- Moura, 1999; Bicudo, D. et al., 2002). Garças Lake is thermally stratified and typically develops a hypolimnetic oxygen deficit from October to February ; it is isothermal from March-April to August-September (Henry, 1999; Bicudo, D. et al., 2002).

From August (the end of the winter) on, thermal gradients in the lake are more evident and surface thermoclines are observed between 14 and 22 hours (Ramirez, 1996). Thermal stability occurs from spring (in September) on and this physical characteristic is the trigger for the onset of Microcystis aeruginosa blooms (Nogueira, 1997). These cyanobacterial blooms persist from September to January-March because the suitable environmental conditions such as high stratification stability; high pH values; low N/P ratios; reduced mixing zone and low NH_4^+ and NO_3^- concentrations. From 1997 on, when macrophytes started proliferation in the reservoir, Cylindrospermopsis raciborskii blooms over particularly associated to the spring period. Co-occurrence of other cyanobacteria species as Synechococcus nidulans and Microcystis aeruginosa was found (Tucci & Sant'Anna, 2003). An annual recurrent pattern of temporal and spatial fluctuation of the water abiotic factors is observed in the Garças Lake, determined by the mixing and thermal stability and, by the algae blooms occurrence (Bicudo, D. et al., 1999). The direct and indirect impacts of Garças Lake eutrophication include proliferation of mosquitoes (Mansonia sp), macrophytes (Eichhornia crassipes), deaths of sloths trapped by the floating macrophytes stands; fish kill events, and the occurrence of toxic cyanobacteria species (Sant'Anna & Azevedo, 2000; Bittencourt-Oliveira, 2003).

Material and methods

Sampling was monthly conducted in two compartments (I and II) of the reservoir (from January, 1997 to June, 1998). Water samples were collected in the surface and at the bottom in the P and L stations of compartments I and II, respectively (Fig.1). In P station three other depths were included (1,2 and 3m depths).

Total N and P were measured using the Valderrama (1981) method. After, oxidation and digestion, nitrate and phosphate were determined according to MacKereth et al. (1978) and Strickland & Parsons (1960), respectively.

Total N and P daily loads from the seven point-sources and from the outlet were evaluated by the product of the water fluxes and nutrient concentrations. Monthly loads corresponded to the product of daily loads by time (days) between the sampling periods.

Rain water was collected in a funnel (30cm diameter) attached to a plastic bottle. A coarse tissue was placed above the funnel to prevent inputs of insects and plant detritus. After each rainfall episode, nitrate and phosphate were determined in the water sample (› 100ml). Monthly N and P loads from wet precipitation were evaluated by the product of water volume introduced by the rain on the reservoir surface (computed according to Tubelis & Nascimento, 1987) and the nutrient concentrations.

N and P loads from non-point sources to the lake were estimated using the coefficients of Jorgensen (1986) which are based upon geological classification and the soil uses of the watershed.

Sedimentation fluxes of nitrogen and phosphorus were determined in the dry (July, 1997) and rainy (February, 1998) seasons. Sediment traps with a height/diameter ratio of 3: 1 (10cm diameter), were incubated at two depths (30 and 70% of z_{max}). Gross sedimentation fluxes (Ts) were computed according to Edmondson & Winberg (1971):

$$Ts = (C \times V \times A)/a_c \qquad \text{(eq.1)}$$

where C = N or P concentration in the trap; V = trap volume, A = lake area.; a_c = opening area of the trap.

Nitrogen and phosphorus mass balances correspond to the difference between the input and the output loads of each element. For compartment II, the retention was evaluated based on the addition of the nutrient contained in the lake water and, the amount of the detained element. For compartment I, the retention is the value corresponding to the difference between the input and output loads.

Nitrogen fixation was estimated based on the difference between the total input load and a value corresponding to the outlet, plus the retention in sediment and the amount in the reservoir water and of the non-point source.

The model developed by Salas & Martino (1991) for 26 tropical reservoirs, was used to identify the trophic status of the lake:

$$P_l = 0.29 \times L_{(p)}^{0.891} \times \frac{t_w^{0.676}}{z^{0.934}} \qquad \text{(eq. 2)}$$

where P_l = mean annual phosphorus concentration ($mg.l^{-1}$); L(p) = annual areal load of phosphorus ($mg.m^{-2}$. year $^{-1}$); t_w = hydraulic residence time (years) and z = lake mean depth (m).

A similar model was developed, by adding the values of Garças Lake. Data were log transformed to process multiple regression analysis.

The model was used to make predictions. The following scenarios were tested: reductions of 80% and 90% the phosphorus annual total load introduced by all the tributaries of the lake, and a complete reduction of the phosphorus annual total load introduced by the point-sources of greatest importance (inputs 03 and 07).

Results

Nitrogen annual total input by the seven point-sources in Garças Lake was around 37 tonne (Tab. I; N/P loading ratio = 5.7:1). From the nitrogen total load, 47 % and 16% were introduced by inputs 03 and 05, both point-sources from the Zoological Garden (Fig.2). From the 6.5 tonne of phosphorus annual total load introduced in Garças Lake, 45% came from the Zoological Garden (input 03), while 32% of the annual total load came from the Agricultural and the Food Supply Department, the second point source (input 07) in importance (Fig.3). From the nitrogen total load coming into the lake, 61% and 88% are introduced in the compartments I and II and, for phosphorus, 97% and 99% respectively (Tab. I).

The contributions of N and P non-point sources to Garças Lake were 0.53 tonne N and 0.02 tonne P, respectively, during the studied period. This corresponds to 4% (Fig.2) and less than 1% (Fig.3) of the total fluvial load of these elements.

From the nitrogen total input in the reservoir (37,156.76 kg), 62.8% is derived from nitrogen fixation; 1.4% from non-point sources; 1% from wet precipitation; and 34.7% from point-sources. For total phosphorus, 99.5% is derived from point-sources, 0.3% from non-point sources; and 0.1% from rainfall.

Table I: Mass balance of total nitrogen and phosphorus in each compartment and for Garças Lake from January, 1997 to June, 1998.

Lake/Compartments		Total Nitrogen (kg)	Total Phosphorus (kg)
Lake	Input	37,156.76	6,519.04
	Output	5,523.27	2,560.81
	Retention	31,633.49	3,958.23
I	Input	22,644.11	6,339.77
	Output	5,523.27	2,560.81
	Retention	17,120.85	3,778.95
II	Input	32,685.40	6,460.48
	Output	18,172.76	6,281.48
	Retention	14,512.64	179.00

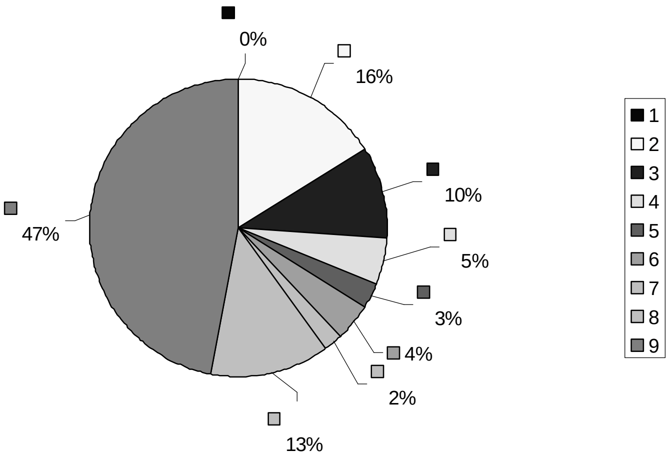

Figure 2: Relative contribution (%) of nitrogen load into Garças Lake by the seven tributaries (1-7), the non-point sources (9) and the wet precipitation (8) over the study period (from January 1997 to June 1998).

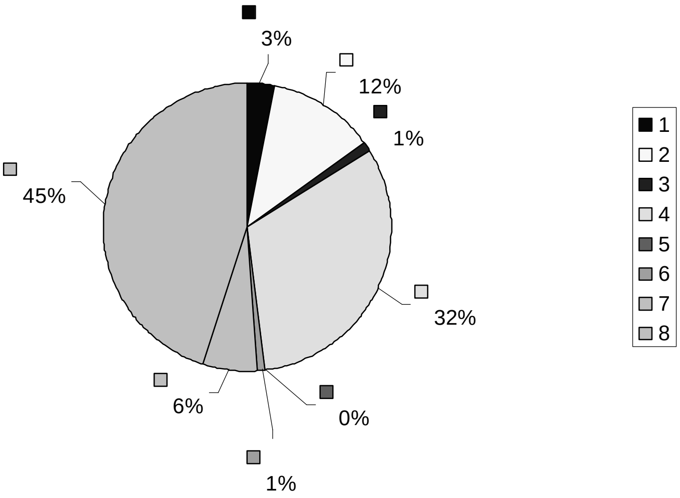

Figure 3: Relative contribution (%) of phosphorus load into Garças Lake by the seven tributaries (1-7), the non-point sources (9) and the wet precipitation (8) over the study period (from January 1997 to June 1998).

A positive correlation between monthly rainfall and nitrogen (r = 0.86* ; P< 0.01) and phosphorus loads (r = 0.74* ; P < 0.01) was found (Fig.4). Higher loads of nitrogen and phosphorus in rain waters were observed during the months of highest precipitation (January, 1997 and February-March, 1998). However, the relative contribution of the loads by wet precipitation to the Garças Lake was not significant, around 3% for nitrogen (Fig.2) and less than 1% for phosphorus (Fig.3).

The mass balances showed high retention of nitrogen (85% of the total input) and phosphorus (61% of the total input) in the reservoir (Tab. I). On spatial level, lower phosphorus retention ($\cong$ 3%) in relation to the input was recorded in compartment II. In relation to nitrogen, around 44% of the amount introduced in this compartment was detained. In compartment I, the nitrogen and phosphorus retention was higher (76 and 60%, respectively) in relation to the introduced load.

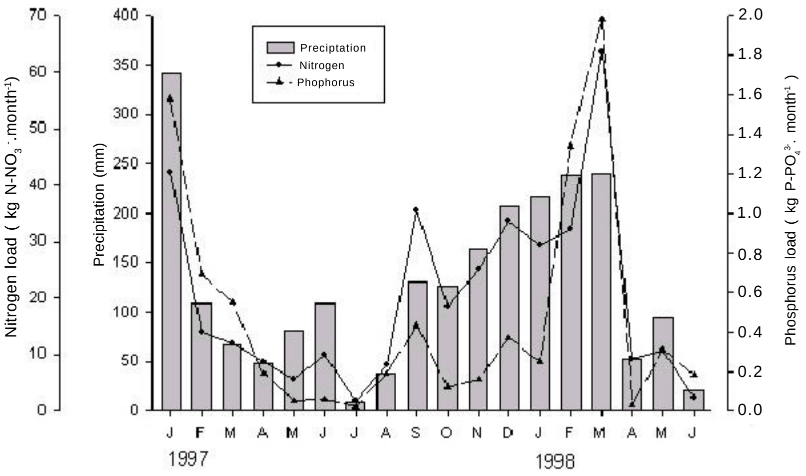

Figure 4: Monthly rainfall and, nitrogen and phosphorus loads in rain waters in Garças Lake.

Nitrogen higher sedimentation rates were found during the isothermal period (July, 1997) when compared with the values of thermal stratification period (February, 1998) (Tab. II). The highest rates were found at the bottom traps (around 28% higher than at the surface during the two periods). Although the sedimentation rates were slightly higher at the bottom, the temporal and spatial differences were insignificant for phosphorus. Considering that mean values, corresponding to 540.7 $mg.m^{-2}. day^{-1}$ for nitrogen and to 0.84 for phosphorus sedimentations (at 30% of z_{max} in the station P), were representative for the whole reservoir and during the entire study period (18 months), the amount in sedimentation would be 26 ton. for nitrogen (70% of the total load) and 40.5 kg for phosphorus (62% of the total load).

The areal annual phosphorus load of compartments I and II corresponds, respectively, to 78 and 94% of the load for the lake (Tab. III).

Table II: Sedimentation rates of phosphorus and nitrogen ($mg.m^{-2}.day^{-1}$) at 30 and 70% of Z_{max} in Garças Lake.

Month	**Nitrogen**		**Phosphorus**	
	30% Z_{max}	70% Z_{max}	30% Z_{max}	70% Z_{max}
July/1997	578.37	737.65	0.83	0.87
February/1998	503.02	646.82	0.85	0.88

Table III: Prognosis of total phosphorus ($mg.l^{-1}$) in the water of Garças Lake.

Lake/Compartment/Strategy	**Phosphorus load** ($mg.m^{2}. year^{1}$)	**Phosphorus concentration** ($mg.l^{-1}$) Equation 3
Lake	4,891.54	130
Compartment I	3,821.60	114
Compartment II	4,618.69	136
With a **reduction** of 80% total input	978.31	33
With a **reduction** of 90% total input	489.15	17
Without input of point-source 03	2,794.16	86
Without input of point source 07	3,181.97	97
Without input of point sources 03 and 07	1,804.58	36

Point-source 03 = Zoological Garden; Point-source 07 = Agricultural and Food Supply Department

Fig.5 shows the seasonal variation of total phosphorus observed concentrations in Garças Lake.

From an annual mean of the seasonal variation on the total phosphorus concentrations in the Garças Lake and data from Salas & Martino (1991) for 26 tropical reservoirs, a modified equation (eq.3) for eutrophication modelling was developed:

$$P_l = 0.378 \times L_{(p)}^{0.910} \times \frac{t_w^{0.634}}{z^{0.993}} \qquad \text{(eq. 3)}$$

Using the model (eq.3), the phosphorus values found for the reservoir as well compartments I and II alone, allowed identification of the trophic status of Garças Lake as eutrophic. To change the trophic state of the reservoir from a eutrophic (> $35mg.TPl^{-1}$) to a mesotrophic condition (10-35mg. $TP.l^{-1}$), an 80% reduction of the areal annual load would be necessary (Tab. III). An oligotrophic condition would only be attained with annual loads lower than 500 $mg.m^{-2}.year^{-1}$ which corresponds to 90% reduction of the phosphorus amount introduced to the reservoir. The complete removal of total input of phosphorus by point-sources 03 or 07 (the two main loads) would not be enough to modify the trophic reservoir classification (Tab. III). Only the complete removal of phosphorus inputs by both 03 and 07 point-sources would change the system to a mesotrophic condition (Tab. III).

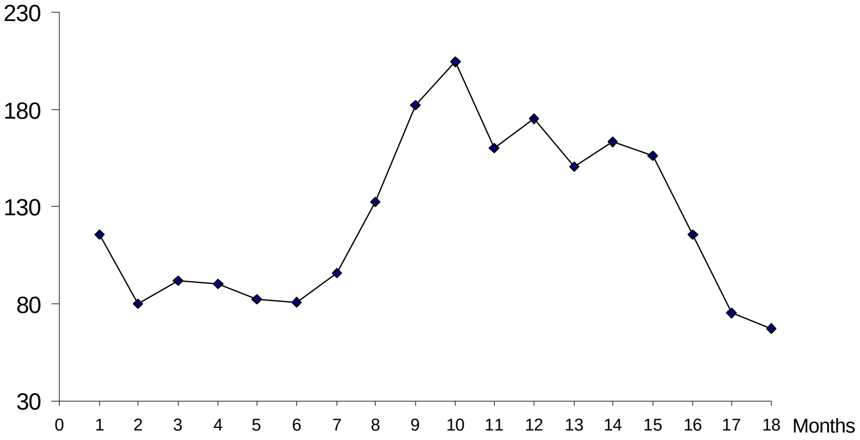

Figure 5: Seasonal variation of observed values of total phosphorus ($mg.l^{-1}$) in Garças Lake from January,1997 (Month 1) to June, 1998 (Month 18).

Discussion

The use of the eutrophication model allowed to us confirm the trophic identification of the reservoir. It is a eutrophic-hypereutrophic environment, corroborating previous trophic classification based on TP and chlorophyll-a concentrations, as well on Secchi transparency (Nogueira & Ramirez, 1998; Mercante & Tucci-Moura, 1999 and, Bicudo, D. et al., 2002). This condition is mainly due to the external load of the tributaries. Four of the seven tributaries of Garças Lake correspond to untreated sewage: three (inputs 03,04 and 05) receive excrements from animals confined in the Zoological Garden of São Paulo (since 1958, year of zoo opening) and one (input 07) receives human feces coming from the Agricultural and Food Supply Department. Input 03 contributes with the highest total N (47%) and P (45%) loads. Since it consists of untreated sewage, a high phosphorus and nitrogen contribution was expected. However, according to Salas & Martino (1991) excretion estimated values for animals have higher amount of N than P. In input 03 from the Zoological Garden, food residues (as rations and green crops) are mixed with animal excrements and enrich the outflow with nitrogen compounds. Moreover, the great number of birds (including the migrators) is another factor of nitrogen enrichment that it is introduced to the reservoir. Input 07 (the second point-source in importance for the reservoir) receives water discharges from the Agricultural and Food Supply Department, contributing with 5 and 32%, respectively, of the total load of nitrogen and phosphorus into reservoir.

Considering the introduced amount by the tributaries, the majority of the load is retained in the system. Comparing to Brazilian reservoirs, nitrogen retention in Garças Lake exceeds the values of Barra Bonita Reservoir (47% of the input according to Oishi, 1996), and Pampulha Reservoir (67.5%, estimated from data of Barbosa et al., 1998), both eutrophic reservoirs (the second, a urban reservoir). According to Straskraba (1999), deep reservoirs seem to have low, sometimes negative value. Negative retention of nitrogen (corresponding to export) was found in Jurumirim Reservoir (a reservoir with a z_{max} of 40m) probably attributed to nitrogen fixation by cyanobacteria (Henry et al., 1999). For Pampulha reservoir, high N retention (67%) was attributed to the presence of macrophyte stands at the mouth zone of the tributaries (Barbosa et al., 1998). Similar condition (mono-specific stands of Eichhornia crassipes near the input 03 upper zone, compartment II) is found in Garças Lake. However, N retention was higher at the lower zone (Compartment I) of this reservoir. Higher retention in compartment I can be attributed to internal load by nitrogen liberation from sediment, since the deeper portion of the reservoir presents periods of anoxia over the year (Henry, 1999; Bicudo, D. et al., 2002). Another possibility of nitrogen enrichment in Garças Lake is the biological fixation by cyanobacteria which are dominant over the spring-summer time (from September to February-March). During the study period, Cylindrospermopsis raciborskii dominated over the spring time when 9% of filaments carried heterocytes (Tucci & Sant'Anna, 2003), indicating that part of the population was fixing nitrogen. Although in lower abundance, Synechococcus nidulans co-occurred with the bloom, and according to Schallenberg & Burns (2001) some species of this genus can fix nitrogen directly and indirectly by producing polysaccharides that stimulate nitrogen fixation by diazorophic planktonic. Recent findings have demonstrated that many unicellular and filamentous cyanobacteria fix N_2. Some of them that lacked heterocytes evolved structurally, biochemically and ecologically diverse strategies aimed at exploiting oxygenated, N limited waters (Paerl, 2000). Low inorganic nitrogen concentrations have been reported for Garças Lake during periods of cyanobacterial blooms (Nogueira, 1997; Bicudo,D. et al., 1999). The presence of heterocytes in Cylindrospermopsis has been noted during low-DIN phases in other Brazilian reservoirs (Huszar et al., 2000). Furthermore, Carmo (2002) reported the highest values of non-point nitrogen load (58-77 kg. month^{-1}) in Garças Lake during September-October months (spring), giving support to the nitrogen enrichment hypothesis by biological fixation. According to Howarth et al. (1998), cyanobacteria are responsible for most planktonic nitrogen fixation in freshwaters and the rates are only high when these organisms are present in large numbers. Based on comparison of seven eutrophic lakes, these authors showed that nitrogen fixation accounted for 6-82% of the nitrogen load, differing markedly between lakes.

In relation to phosphorus, the relative retention, in Garças Lake is lower than the values of Salto Grande Reservoir (Rios, 1999: 76%), Jurumirim Reservoir (Henry et al., 1999: 77%) and the estimated value for Pampulha Reservoir, (Barbosa et al., 1998: 97%) but higher than in Barra Bonita Reservoir (Braga et al., 1998: 44%). Based on temperate lakes, Straskraba (1999) showed that phosphorus retention is related to the residence time. Also according to that same author, reservoir with 50 days t_w presented 80% P retention, which is higher than our evaluation for Garças Lake (61%). Considering the compartments alone, P retention was markedly higher at the lower zone (compartment I) due, most probably, to the release of phosphorus from the anoxic sediments (internal loading) mainly during the spring-summer period.

Sedimentation is another factor affecting elements retention in a reservoir. Concerning phosphorus, Garças Lake values were higher than in Salto Grande Reservoir (range: 0.07-0.48 mgP.m^{-2}.day^{-1}, in the upper and lower zones respectively), a Brazilian eutrophic reservoir (Rios, 1999). Higher nitrogen sedimentation in relation to phosphorus (Garças Lake: › 600 times) is also an indication of great allochthonous contribution. However, on a vertical scale, the highest sedimentation rates at the bottom signalize an "autochthonous production" of nitrogen by cyanobacteria which are dominant in the lake (Nogueira, 1997). High sedimentation rates were observed during the dry period (July 1997), when the reservoir presented a high t_w (88 days). In February 1998, factors such as thermal stratification development (Henry, 1999), a lower t_w (43 days) and the water discharge by the outlet, from the euphotic zone, can contribute to the removal of autochthonous matter and, thus, nitrogen export.

The phosphorus mass balance showed that the non-point and precipitation loads are not significant in comparison to allochthonous loads for the in-lake content. Salas & Martino (1991) found a mean concentration of 119mg P.l^{-1} in 16 eutrophic ecosystems of tropical region. In the Garças Lake, the phosphorus content in water ranged from 58 to 247mg.l^{-1} (annual mean: 116mg.l^{-1}) for the station P and, from 46 to 467mg.l^{-1} (annual mean: 150mg.l^{-1}) in station L (Carmo, 2000). In non-polluted lakes and reservoirs, the total P concentration varied from 10 to 50mg.l^{-1} in the surface (Wetzel, 1993). The magnitude of P values in Garças Lake clearly indicates a highly disturbed environment that receives a nutrient overload of anthropogenic origin.

Several methods for controlling the eutrophication of lakes and reservoirs have been proposed (Sellers & Markland, 1987; Lampert & Sommer, 1997). They include the removal of the nutrient inputs by the tributaries; increasing export of nutrient from the lake/reservoir, enhancing the immobilization of nutrients in the sediment; the removal of the chemical elements, specially phosphorus, from the water; the decrease of the residence time of lakes/reservoirs and, the mixing and aerating of the water column. For the Garças Lake, three last strategies seem not to be practicable and successful as a first management measure. The phosphorus removal from the water cannot be suggested because, after a treatment as flocculation for instance, phosphorus stocked in the sediments, will be released from the anoxic sediments, what sets in motion the self-acceleration of eutrophication. The manipulation of the residence time is also not feasible, since there is no management system that can change the outlet discharge. The mixing and forced aerating processes of the reservoir, aiming the acceleration of the organic matter degradation as well to maintain the hypolimnion oxygenated, is expensive and at with success not confirmed for all the aquatic ecosystems worldwide. Moreover, these three strategies don't involve the control of eutrophication causes. The mass balance phosphorus demonstrated that the external inputs by tributaries are the most important factor for the in-lake content. The load reduction simulation from the two most important point-sources showed that oligotrophic condition can be attained, which represents a 90% reduction or an annual load of 500 mgP.m^{-2}. This finding for the present tropical reservoir is accordance to the general figure provided in Smil (2000), by which comparisons of polluted lakes and estuaries have shown that excessive eutrophication can be generally prevented if annual loadings are lower than 1g P.m^{-2} of water surface. Therefore, the first restoration measure absolutely necessary is water treatment or the wastewater diversion of the inputs from the Zoological Garden and the Agricultural and Food Supply Department for the improvement of water quality. Moreover, even after nutrient has been reduced, there is often a lag in the reservoir's response, which sometimes takes several years mainly due to the internal loading (e.g. Lampert & Sommer, 1997). Consequently, other restoration techniques may be necessary. These measures may include increasing P export by diversion of hypolimnion water or retaining P in the reservoir bottom by improving the redox conditions in the sediments and hypolimnion.

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