Spatial and temporal variation of limnological features, *Microcystis aeruginosa* and zooplankton in an eutrophic reservoir (Funil Reservoir, Rio De Janeiro).

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ABSTRACT: Spatial and temporal variation of limnogical freatures, *Microcystis Aeruginosa* and zooplankton in an eutrophic reservoir (Funil, Reservoir, Rio de Janeiro). Among the consequences of the uncontrolled nutrient loading into Funil reservoir are an increasing eutrophication process, and the constant presence of the cyanobacteria *Microcystis aeruginosa* all over the lake. Aiming the evaluation of spatial and temporal changes of limnological variables, zooplankton community and *M. aeruginosa* abundance in Funil Reservoir, samples for plankton and environmental variables analysis were taken at the surface, the limit of the euphotic zone and near the bottom of six different stations. Most times, the water column was stratified with a well-defined thermocline at 2-4 m depth. Despite having low temporal changes constant zooplankton taxa showed differences in spatial distribution possibly related to longitudinal gradients in the reservoir. Clear differences in species composition were observed among the studied stations of the main basin. Contrasting vertical density of organisms was also detected at most stations with a tendency of increase in the limit of euphotic zone. The increasing trophic conditions enhanced the environmental longitudinal gradient in December since the occurrence of *Microcystis aeruginosa* bloom at the upper part of the main basin changed the frequency of occurrence of the zooplankton species, favoring some taxa considered indicative of eutrophy.

Key-words: eutrophic reservoir, spatial-temporal distribution, zooplankton, *Microcystis aeruginosa*.

RESUMO: Variação espacial e temporal de fatores limnológicos, *Microcystis aeruginosa* e zooplâncton em um reservatório eutrófico (Represa do Funil, Rio de Janeiro). No reservatório do Funil, o processo de eutrofização e a constante presença da cianobactéria *Microcystis aeruginosa* ao longo do lago estão entre as conseqüências do aporte contínuo de nutrientes ao sistema aquático. Com o objetivo de serem obtidas informações sobre variações espaciais e temporais de variáveis limnológicas, da comunidade zooplanctônica e da abundância de *M. aeruginosa* foram realizadas coletas na superfície, no limite da zona eufótica e no fundo de seis pontos distintos do reservatório ao longo de nove meses. Na maior parte das amostragens, a coluna d'água apresentou-se termicamente estratificada e com uma termoclina bem definida entre 2 e 4 metros de profundidade. Os táxons zooplanctônicos considerados constantes, apesar de terem apresentado pouca variação temporal, demonstraram diferenças na distribuição espacial, provavelmente relacionadas com gradientes ambientais longitudinais. Observaram-se também diferenças quanto à distribuição vertical dos organismos, havendo uma abundância maior de certos grupos no limite da zona eufótica. O aumento das condições de trofia no mês de dezembro acentuou diferenças ambientais longitudinais devido à floração de *M. aeruginosa* na parte superior do corpo principal do reservatório, com conseqüente mudança na freqüência de ocorrência de espécies do zooplâncton, havendo favorecimento de táxons considerados indicadores de eutrofia.

Palavras-chave: reservatório eutrófico, distribuição espaço-temporal, zooplâncton, *Microcystis aeruginosa*.

Introduction

Artificial reservoirs are distinguished from natural lakes by their horizontal and vertical circulation systems produced by both natural characteristics and management procedures. These man-made lakes have level fluctuations and retention times established according to public requirements (energy production, water supply, flow regulation) or subjected to rainfall. Most Brazilian reservoirs have a typical dendritic basin with long shorelines, islands and bays (Klapper, 1998). As a consequence, the heterogeneity of longitudinal gradients produces subsystems with distinct abiotic and biotic features that are difficult to control since different water quality management approaches are needed.

Nutrient and sediment input from the drainage basin accelerated by human activities, the sink of those materials at some compartments of the ecosystem, and the high biomass of primary producers due to eutrophication process have been the most common troubles for the management of Brazilian reservoirs. Eutrophication affects the specific composition of zooplankton community through changes in physical and chemical features, alteration of phytoplankton composition (Sendacz, 1984) and biomass, and in the predation pressure by high-level consumers. On the other side, changes in species assemblage and density of the zooplankton have been considered as sensitive responses to disturbances in aquatic ecosystems (Lampert, 1988; Attayde & Bozelli, 1998; Branco et al., 2000).

Funil Reservoir receives inflow of a highly industrialized region and it acts as a natural sink to pollutants and sediments, improving the water quality downstream. Monitoring programs carried out by the Fundação Estadual de Engenharia do Meio Ambiente (FEEMA) have followed the decrease of the water quality of Funil Reservoir. Monthly data of physical and chemical variables and phytoplankton community in 1978 showed a reservoir with low primary productivity, low phosphorus content and dominance of Chlorophyta taxa (Amorin & França, 1981; FEEMA, 1987) whereas the same procedure performed between 1987 and 1991 showed higher phosphorus concentration and cyanobacteria dominance (FEEMA, 1989; Gômara et al., 1995). Among the consequences of this increasing eutrophication process is the constant presence of the cyanobacteria *Microcystis aeruginosa* along the reservoir. It has been demonstrated that this species, presenting blooms in the lake during some periods of the year, is able to produce toxins (Bobeda, 1993).

The purpose of this article is to give information on spatial and temporal variation of limnological variables, zooplankton community and *M. aeruginosa* in Funil Reservoir.

Study Area

Funil Reservoir (22°30'S, 44°45'W, alt.440m) lies in southeast Brazil, between the States of São Paulo and Rio de Janeiro (Fig.1). It was built up in 1969 to generate hydroeletric power and to control the Paraíba do Sul river flow, which is the most important water source for many municipalities of the Rio de Janeiro State including the city of Rio de Janeiro. The reservoir has a 16,800 km^2 catchment area, surface of $40km^2$, mean depth of 22m and total volume of $890x10^6$ m^3. Water retention time is between ten and fifty days, according to the season of the year and management procedures. The lake has a central wider and longer part, corresponding to the Paraíba do Sul River valley, and two arms associated with Santana and Lajes tributaries, respectively.

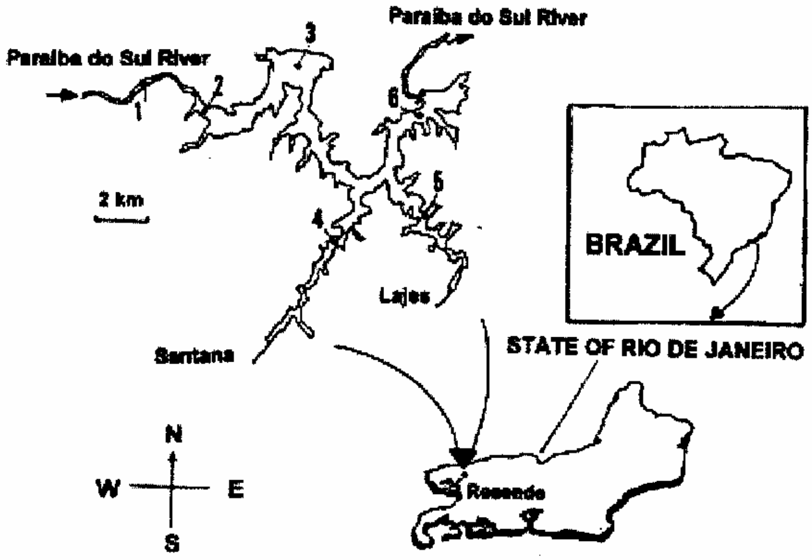

Figure 1: Funil reservoir, indicating the main tributary and sampling stations.

Methods

Samples for environmental variables were taken at six different stations (Fig.1) from April to December of 1995. Station 1 was located upstream the reservoir, at Paraíba do Sul River, station 2 in a shallow inlet region of the reservoir and the others in the main basin. Water temperature and dissolved oxygen were measured from the surface to the bottom at all sampling stations using a Yellow Spring Instrument apparatus. Water transparency was evaluated using a Secchi disk and the limit of the euphotic zone was established using a radiometer. Other environmental variables such as pH, conductivity, ammonium, nitrite, nitrate, chemical oxygen demand, orthophosphate, total phosphate (nutrients according to APHA, 1985) and chlorophyll-*a* (Lorenzen, 1967) were analyzed at the surface, limit of the euphotic zone and bottom of each sampling station. Water samples and plankton were taken with a 5-liter Van Dorn bottle. Plankton samples were collected at the surface and at the limit of the euphotic zone in April, June, October and December. Plankton samples near the bottom at the deepest stations were also taken in October and December.

For examining the zooplankton and *M. aeruginosa* colonies, 20 liters of water were filtered using a 68-µm mesh plankton net, fixed with 5% formaldehyde and analyzed quantitatively in Sedgwick-Rafter chamber of 1 ml. The zooplankton community was evaluated by total abundance and frequency of taxa occurrence according to Gomes (1989), considering constant the species with frequency › 50%, common with frequency between 10% and 49%, rare below 10%.

Results and Discussion

According to the water temperature profile, sampling stations 1 and 2, at the riverine zone of the reservoir were not stratified presenting a gradual decrease from surface to bottom. The other sampling stations were thermally stratified and most of the time, the profiles had three layers and a well-defined thermocline at the depth of 2-4 m. The first layer probably corresponded to a higher solar irradiation at the water column surface and the deepest one was probably associated to the river flow near the bottom, with lower water temperature and higher density. During the warmer months of November and December, the difference between surface and bottom water temperature reached about ten-Celsius degrees. A main tributary flow through the hypolimnion producing distinct chemical and biological properties that has been already observed elsewhere in other reservoirs (Infante & Infante, 1994) was probably present in Funil Reservoir. As the inflow density usually differs from the water surface density of the reservoir, inflows enter and move through reservoirs as density currents (Ford, 1990). The difference of densities can be caused by temperature, conductivity and suspended solids as observed for Paraíba do Sul River and Funil Reservoir.

The dissolved oxygen profiles of stations 3, 4, 5 and 6 were either stratified or presenting a gradual decrease from surface to bottom. It is worthy of note that a significant oxygen concentration reduction in the hypolimnetic zone was not observed as expected for an eutrophic reservoir. This fact can be associated with the influence of river waters underflow through the hypolimnion in the central part of the reservoir. Interflows have also been shown to increase dissolved oxygen of reservoirs (Ford, 1990).

Average and standard deviation values of limnological variables at sampling stations are presented in table I. Funil Reservoir presented low water transparency but higher values in the central part. The lower values at riverine sampling stations were due to upstream sediments increasing water turbidity. As expected, pH values were lower at the bottom than at the surface of the sampling stations. Among the

Table I: Mean values and standard deviation of limnological variables at the studied stations. (temp. = water temperature; w.t. = water transparency; d.o. = dissolved oxygen; c.o.d. = chemical oxygen demand; Kj.N = Kjeldahl nitrogen; orth. = orthopohosphate; total P = total phosphorus; chlor. = chlorophyll-*a*)

variable **station**	**temp.** **(°C)**	**w.t.** **(m)**	**pH**	**d.o.** **(mg/l)**	**cond.** **(µS/cm)**	**c.o.d.** **(mg/l)**	**NH4+** **(mgN/l)**	**NO2-** **(mgN/L)**	**NO3-** **(mg/l)**	**Kj. N** **(mgN/l)**	**orthop.** **(mgP/l)**	**total P** **(mgP/l)**	**TN/TP**	**chlor.** **(µg/l)**
1 surface	23.34	0.44	7.03	8.10	66.41	20.50	0.04	0.04	0.59	0.94	0.05	0.20	6.25	7.05
std dev	2.23	0.45	0.26	0.90	17.11	3.32	0.03	0.02	0.18	0.45	0.01	0.00		5.19
2 surface	23.26	0.55	7.60	8.18	57.03	25.25	0.05	0.02	0.44	1.40	0.05	0.16	13.3	10.91
std dev	2.39	0.33	1.40	1.15	8.12	17.23	0.04	0.00	0.18	1.07	0.02	0.03		12.88
2 euphotic limit	22.08		7.30	8.12	68.10	22.00	0.06	0.02	0.76	1.04	0.04	0.17	12.0	8.18
std dev	2.36		1.01	0.88	6.55	5.70	0.05	0.01	0.59	0.67	0.01	0.07		2.86
3 surface	25.51	0.60	7.08	9.05	62.78	36.25	0.02	0.02	0.47	7.63	0.03	0.06	155.5	33.17
std dev	3.70	0.29	0.29	3.21	3.58	16.52	0.01	0.02	0.32	8.09	0.02	0.03		56.41
3 euphotic limit	23.95		7.00	7.90	61.57	13.33	0.02	0.01	0.62	0.55	0.03	0.04	31.3	6.53
std dev	2.66		0.17	1.97	5.21	2.89	0.01	0.01	0.20	0.22	0.01	0.02		4.49
3 bottom	23.09		6.93	5.93	60.10	20.00	0.01	0.02	0.62	1.00	0.04	0.06	29.3	8.04
std dev	1.15		0.25	1.25	2.82	13.23	0.01	0.01	0.16	0.87	.0.02	0.04		3.50
4 surface	26.70	1.43	7.47	9.07	61.17	14.33	0.01	0.01	0.49	1.03	0.01	0.04	39.0	7.71
std dev	3.56	1.02	1.24	0.81	3.75	5.13	0.01	0.01	0.41	0.84	0.01	0.02		2.48
4 euphotic limit	24.60		7.50	8.07	66.10	15.33	0.01	0.00	0.37	0.55	0.02	0.04	32.6	9.50
std dev	3.32		1.13	1.61	4.60	5.03	0.01	0.00	0.31	0.13	0.02	0.03		1.99
4 bottom	22.00		7.00	3.70	65.13	11.33	0.03	0.01	0.62	0.47	0.03	0.06	18.6	10.34
std dev	2.69		0.35	2.72	6.83	2.31	0.03	0.02	0.23	0.31	0.01	0.01		0.72
5 surface	27.13	1.52	7.70	9.00	63.70	17.00	0.02	0.00	0.44	0.53	0.04	0.05	30.0	5.13
std dev	4.12	0.63	1.13	0.98	3.24	6.93	0.01	0.00	0.42	0.06	0.04	0.05		5.01
5 euphotic limit	24.67		8.00	8.13	66.93	15.39	0.02	0.01	0.39	0.84	0.02	0.04	43.0	8.89
std dev	3.31		1.56	2.57	0.58	4.43	0.01	0.01	0.33	0.47	0.01	0.03		3.31
5 bottom	22.17		6.90	2.53	66.00	15.39	0.03	0.02	0.61	0.73	0.02	0.05	28.0	9.0
std dev	2.37		0.14	2.14	5.16	4.43	0.02	0.01	0.18	0.60	0.01	0.03		2.37
6 surface	25.86	1.36	7.08	7.98	62.75	13.31	0.02	0.01	0.48	0.85	0.02	0.04	39.7	7.03
std dev	3.58	0.44	0.13	1.32	2.78	1.9	0.01	0.01	0.30	0.78	0.01	0.02		3.51
6 euphotic limit	24.47		7.7	7.27	62.83	17.67	0.01	0.01	0.52	0.93	0.02	0.03	43.6	8.25
std dev	3.01		1.07	1.02	2.93	4.04	0.01	0.01	0.36	0.92	0.02	0.01		3.12
6 bottom	23.47		7.13	4.57	67.27	17.67	0.04	0.03	1.15	0.68	0.03	0.06	27.0	8.03
std dev	3.56		0.42	0.38	7.45	10.79	0.05	0.03	1.13	0.48	0.02	0.04		3.49

norganic nutrients, ammonium was highest at stations 1 and 2 and at the bottom of tation 6, where nitrite also had an increase. Nitrate concentrations usually reached igher values at the limit of the euphotic zone of stations 2 and 3 and at the bottom of tations 4, 5 and 6. The average values of nitrate were the highest at this last station nd were probably associated with the physical barrier of the thermocline possibly rapping nutrients at the hypolimnion near the dam. It is worth to note that all the alues of nitrate at the surface of all studied stations were almost two times higher han the mean nitrate concentration (0.28 mg.l^{-1}) in 1989 (FEEMA, 1989).

Differently from nitrogen forms, orthophosphate and total phosphate showed ighest values at the surface of stations 1 and 2, confirming the Paraiba do Sul river s the main source of this nutrient. Upstream the reservoir, this river receives vastewater including untreated sewage from several municipalities and phosphorus oading into the lake is evident. The decrease of phosphorus concentration along the eservoir suggested retention due both to biological absorption, adsorption and sedimentation. The mean TN:TP ratio increased from 6.25 at station 1 to 155.5 at station 3, showing a change from nitrogen to phosphorus limitation from upreservoir o the main channel. Comparing with data from previous studies, excepting stations and 2, total phosphorus concentrations at surface of the sampling stations were similar to those found by FEEMA in 1989 (FEEMA, 1989).

Kjeldahl nitrogen as well as chemical oxygen demand were high at the surface of station 3 where chlorophyll-*a* showed the highest mean values. Chlorophyll-*a* showed an increase in December up to 117.16 µg.l^{-1} corresponding to a *Microcystis aeruginosa* bloom at this station. The increased eutrophication condition in this region of Funil Reservoir has been already recognized by former studies, one of which have found up to 42.0 µg.l^{-1} of chlorophyll-*a* at this area in December of 1989 (FEEMA, 1989). According to Klapper (1998), Funil Reservoir showed six compartments: 1- an inlet region, shallow in consequence of siltation, visible flow velocity, turbid river water; 2 – upper part of the main basin, highly eutrophicated; 3 – central part of the main basin, eutrophic; 4 – deepest part of the main basin, near the dam, mesotrophic; 5 and 6 – two side arms slightly different from the main basin, shallower, eutrophic-mesotrophic. *Microcystis aeruginosa* blooms occur in parts 3 and 4.

The station 3, located at compartment 3 of Klapper classification, is an important region to the management of Funil Reservoir, where the nutrient input shows some of its detrimental consequences. Most organic matter coming into a reservoir with inflows does not immediately settle out in the sedimentation zone, but due to its small size and weight, will travel to the end of the main sedimentation zone (Cole & Hannan, 1990) where considerable oxygen demand is required. The region with less suspended matter and increased nutrient concentration corresponded also to higher phytoplankton biomass in other reservoirs submitted to anthropogenic influences, which have also a high phytoplankton production (Kimmel & Groeger, 1984; Armengol et al., 1999).

Microcystis colonies larger than 68 µm occurred throughout the reservoir all months. From April to October this species was found with densities below 1,000 colonies per liter. The highest density was found in December, reaching up to 250,000 colonies per liter at the limit of the euphotic zone at station 3 (Fig.2). The ratio of TN/TP (361) also presented an increase at the surface of this station during the bloom, showing a high phosphorus limitation condition.

Bobeda (1993), studying toxin production by a cyanobacterial bloom in December of 1991 at Funil Reservoir, where *M. aeruginosa* was the dominant species, isolated hepatotoxines, characterized as microcystines. According to this author, the reservoir showed environmental conditions favorable to the development of *Microcystis* blooms that can be summarized as water column stability, water temperature between 15 and 30° C, and high level of nutrients. It is well known that features of the end of the dry season such as increased levels of organic pollution, increase of water temperature and solar irradiation promote the occurrence of *Microcystis* blooms in several Brazilian eutrophic reservoirs. Since the end of 1980's, technical reports (Amorim, 1988; FEEMA, 1989) concluded that cyanobacteria blooms are expected at the beginning of summer in some parts in Funil Reservoir.

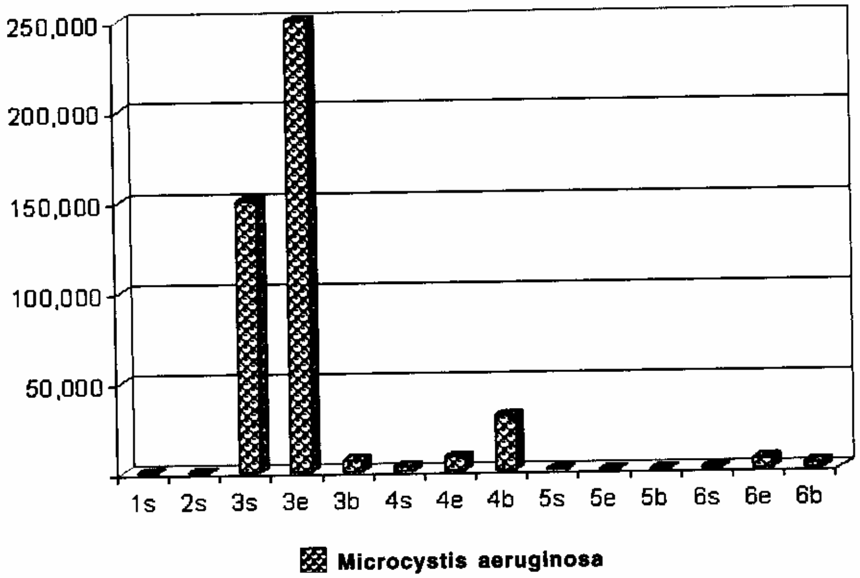

Figure 2: *Microcystis aeruginosa* density (colonies per liter) measured in December (s = surface, e = limit of euphotic zone, b = bottom).

It is interesting to note that chlorophyll-*a* values were higher at the limit of euphotic zone and bottom than at the surface of stations 4,5 and 6, showing the presence and possible deposition of colonies at the deepest part of the reservoir. According to Kimmel et al. (1990), in stratified reservoirs, deep chlorophyll peaks can be formed by the accumulation of viable cells settled from the mixed layer, by active growth of cells adapted to low light but with high nutrient of deeper layers, and/or by subsurface transport of phytoplankton entrained from more productive surface waters upreservoir.

The zooplankton community was represented by 19 rotifers species, 4 copepods, and at least 7 cladocerans since Chydoridae and Macrothricidae species were grouped (Tab. II). Testate amoeba, insect larvae and Turbellaria were also present but with low frequency and relative abundance. Mean zooplankton richness and densities per sample were, respectively, 10 and 208 individuals per liter. Total zooplankton abundance ranged between 3 and 1,009 ind.l^{-1}.

According to the frequency of occurrence, 5 species of rotifer (*Conochilus unicornis*, *Keratella americana*, *Keratella cochlearis*, *Keratella tropica* and *Polyarthra vulgaris*), 3 cladocerans (*Bosmina longirostris*, *Ceriodaphnia cornuta* and *Diaphanosoma birgei*) and 2 copepods (*Thermocyclops decipiens* and *Notodiaptomus iheringi*) were considered constant in the zooplankton community. Among them, *Conochilus*, *Keratella*, *Bosmina*, *Diaphanosoma* and *Ceriodaphnia cornuta* are the most frequent genera and species found in reservoirs of southern Brazil (Arcifa, 1984; Sendacz, 1984; Landa & Mourguis-Schurter, 2000).

Despite the low temporal variation, constant taxa showed differences in spatial distribution possibly related to longitudinal gradients of the reservoir. According to the synthesis of Vismann et al. (1994), the research on spatial patterns in zooplankton distribution has recognized large scale patterns induced by vectorial or seasonal and morphometric factors, medium scale patterns induced by currents or by the combined effects of shore avoidance and vertical migration, and small scale patterns associated with Langmuir circulation cells and swarm caused by behavioral interactions. Trends of horizontal distribution of zooplankton in reservoirs have also

Table II: Zooplankton taxa occurrence per month and mean density during the study.

Month Taxa	April	June	October	December	Average Density (ind.m^{-3})
ROTIFERA					
Ascomorpha ecaudis			■		5,250
Asplanchna girodi			■		9,912
Brachionus angularis				■	740
Brachionus calyciflorus			■	■	45,767
Brachionus caudatus	■				1,200
Conochilus unicornis	■	■	■	■	23,695
Euchlanis dilatata		■	■	■	29,613
Filinia longiseta		■	■		3,100
Hexarthra intermedia	■			■	832
Keratella americana	■	■	■	■	6,527
Keratella cochlearis	■	■	■	■	3,923
Keratella tropica	■	■	■	■	7,111
Lecane ludwigii		■			500
Lepadella patella		■			750
Polyarthra vulgaris	■	■	■	■	9,990
Ptygyra libera				■	1,250
Rotaria rotatoria	■	■		■	3,430
Testudinella patina	■				1,500
Trichocerca capucina	■	■	■	■	3,690
CLADOCERA					
Bosmina longirostris	■	■	■	■	2,292
Ceriodaphnia cornuta	■	■	■	■	6,668
Daphnia gessneri	■	■	■		2000
Diaphanosoma birgei	■	■	■	■	14,472
Moina minuta				■	1,250
Chidoridae					210
Macrothricidae				■	300
COPEPODA					
Nauplii	■	■	■	■	60,290
Diaptomidae (*Notodiaptomus iheringi, Scolodiaptomus corderoi*)	■	■	■	■	17,395
Cyclopidae (*Metacyclops mendocinus, Thermocyclops decipiens*)	■	■	■	■	53,001
OTHERS					
Sarcodina (testate amoeba)					1,164
Turbellaria					5,623
Diptera larvae					742

Constant (F>50%) ■
Common (10%<F<50%)
Rare (F<10%)

been associated with water retention time, influence of tributaries and spatial heterogeneity of water quality variables (Freire & Pinto-Coelho, 1986; Matsumura-Tundisi et al., 1990; Armengol et al., 1999; Rocha et al., 1999; Tundisi et al., 1999).

Most of the constant taxa were present at sampling stations located at the central region and arms of the reservoir (stations 3,4,5 and 6). The longitudinal gradient frequently observed along the reservoir is responsible for changes in population density, species composition and reproductive performance of zooplankton (Marzolf, 1990). This gradient was present in Funil upreservoir region, where sampling stations 1 and 2 were characterized by low zooplankton density. Lotic characteristics and low values of dissolved oxygen may impair the presence of most truly planktonic taxa at those riverine regions. Testate amoeba and insect larvae such as chironomids were more frequent at sampling station 1 where the river inflow was probably responsible for the presence of these groups characteristic of the bottom fauna of running waters. Testate amoeba dominance has also been found near river drainage in reservoirs (Henry & Nogueira, 1999).

There was a numeric dominance of copepods, mainly nauplii, followed by rotifers, at most sampling stations in April and June (Fig.3). Copepods make up a major part of the biomass and productivity of freshwater ecosystem (Dussart & Defaye,

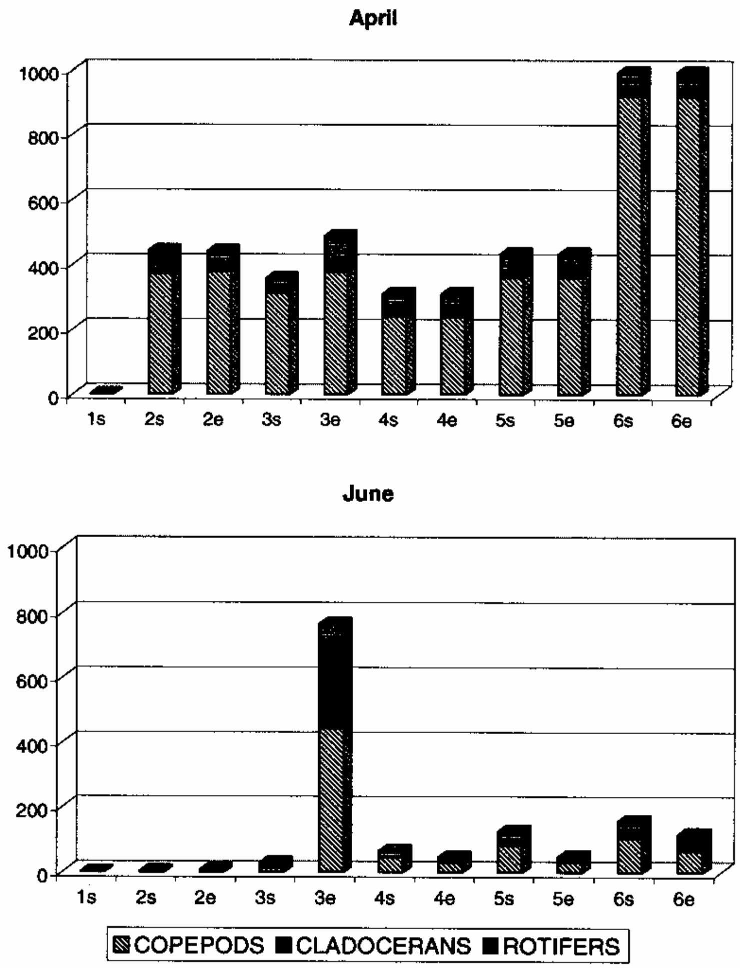

Figure 3: Total zooplankton density (individuals per liter) in April and June (s = surface, e = limit of euphotic zone)

1995; Williamson & Reid, 2001). According to these authors, the most compelling hypotheses to explain oscillations in copepod populations are temperature, food limitation, predation and seasonal variations in physical and chemical characteristics of the environment.

The dominance of copepods followed by rotifers was not observed only at station 1 in April and June, at station 2 in June, and at the limit of euphotic zone at station 3 in this last month when cladocerans showed higher densities than rotifers. Despite of being disfavored by sediment input by rivers, what could explain their low frequency at stations 1 and 2, copepods exhibited less heterogeneity in distribution than cladocerans (Branco & Senna, 1996; Visman et al., 1994). All copepod species found in this study have already been associated with eutrophic conditions, such as *Metacyclops mendocinus*, *Notodiaptomus iheringi* and *Agryrodiaptomus furcatus* in reservoirs of Tietê River (Sendacz & Kubo, 1999). Among the copepods, the cyclopoids were more abundant than calanoids. According to Dussart & Defaye (1995), the calanoid/cyclopoid-cladoceran ratio is used as a water quality index in limnological studies. High values indicate oligotrophic conditions and low values such as in this study indicate eutrophy.

Cyclopoida have been considered a more successful group than Calanoida in eutrophic systems. Larger zooplankters, such as calanoid copepods, are selective feeders, being disfavored by cyanobacteria blooms, which could explain their lower density during *Microcystis* bloom in Funil reservoir. Conversely, due to its raptorial feeding habits, cyclopoid can capture large particles such as colonial and filamentous algae that usually become dominant in eutrophic systems (Rocha et al., 1999). The positive relationship between *Thermocyclops decipiens* commonly found in Funil Reservoir and cyanobacteria was substantially verified in Lake Valencia by Infante (1978) and in Paranoá reservoir by Pinto-Coelho (1983) and Branco & Senna (1996). According to Reid (1989) some species of *Thermocyclops* are capable of maintain high populations relative to those of other herbivorous copepods using blooms of cyanobacteria, which most other cyclopoid and calanoid copepods are unable to exploit effectively.

Rotifers were dominant at most stations in October, and at station 3 in December (Fig.4) with a heavy *M. aeruginosa* bloom. It has been often shown rotifers dominance in Brazilian reservoirs (Arcifa, 1984; Arcifa et al., 1992; Rocha et al., 1995; Branco & Senna, 1996; Lopes et al., 1997) which can be explained by the biological features of rotifers such as coexistence of closely related species in the same area utilizing the same resource pool due to selective feeding and different temporal and spatial distribution (Matsumura-Tundisi et al. 1990). In addition, some rotifers are favored

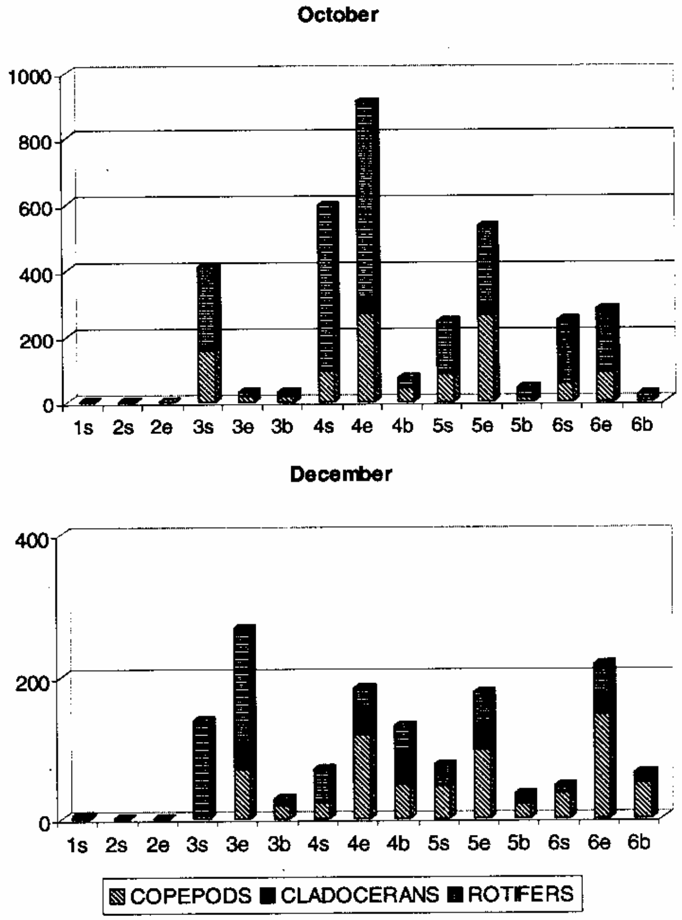

Figure 4: Total zooplankton density (individuals per liter) in October and December (s = surface, e = limit of euphotic zone, b = bottom).

by increasing eutrophication, which could explain their population increase observed in October, when there was an increase of nitrate, total phosphate concentration and C.O.D.

High densities of *Euchlanis dilatata*, *Ascomorpha ecaudis* and *Brachionus calyciflorus* were observed during the *M. aeruginosa* bloom. These species and also *Keratella americana*, *Asplanchna brightwelli* and *Polyarthra dolichoptera* were already identified as taxa commonly found in eutrophic waters (Branco & Senna, 1996; Rocha et al., 1999). However, some biological interactions may also explain population increases. *A. brightwelli* was probably associated with the presence of *B. calyciflorus* which was frequently found in samples as the most spined-form, described as an antipredatory feature against *Asplanchna* spp. .

The three species of cladocerans considered constant in the samples were also found in several Brazilian mesotrophic and eutrophic man made lakes. *B. longirostris* populations usually reflect the trophic conditions of reservoirs (Branco & Cavalcanti, 1999; Sendacz & Kubo, 1999), and *Ceriodaphnia cornuta* and *Diaphanosoma birgei* have been found in the limnetic area and also near the influence of tributaries in lakes (Freire & Pinto-Coelho, 1986; Arcifa et al., 1992). *Diaphanosoma* was suggested to be adapted to silt-laden water (Threlkeld, 1986) what probably explains its presence in Funil Reservoir at riverine stations in April and June.

It is interesting to note that the three most common cladoceran species were present with high abundances at the limit of the euphotic zone at station 3 in December, with the highest concentration of *M. aeruginosa*. According to De Bernardi & Giussani (1990) many rotifers and small cladocerans such as *Bosmina* and *Ceriodaphnia* mantain high population densities when blooms of cyanobacteria occur. Fulton & Paerl (1987) recognized two different types of behaviour of zooplankton species associated with *M. aeruginosa* blooms: one represented by *Diaphanosoma brachyurum*, which did not show negative influence in its feeding behaviour by the presence of colonies and does not use cyanobacterias; the second, represented by *Bosmina longirostris* and *Brachionus calyciflorus* are able to consume a large amount of them.

While the common cladocerans did not seem to be affected by increased eutrophic conditions in December, *Daphnia gessneri* was not present in the samples of this month. According to Arcifa et al. (1992) *D. gessneri* was a superior competitor over rotifers and other cladocerans such as *Diaphanosoma birgei* and possibly *Ceriodaphnia cornuta* in Lake Monte Alegre, an eutrophic Brazilian reservoir. These authors also concluded that food and predation were the main factors affecting the fluctuations of the efficient grazer *D. gessneri* in the reservoir. On the other side, Zago (1976) and Sendacz (1984) found a replacement *of Daphnia gessneri* by *Diaphanosoma* sp. in Americana and Billings reservoirs, due to a better endurance of the latter to eutrophic environments.

Decline in biomass and production of cladocerans, including *Daphnia* spp., associated with summer blooms of *Microcystis* has been extensively reported in both temperate and subtropical ecosystems. However, the inhibitory effects of these cyanobacteria are not noticeable on small-bodied cladocerans (Jarvis, 1986). Furthermore, Hanazato (1991) emphasized the importance of bacteria in the decomposition of *Microcystis* as food for small cladocerans. This author also suggested that high water temperatures certainly prompted the growth of bacteria, which were active in the decomposition of *Microcystis* and as result the production of cladocerans, which feed mainly on bacteria possibly will increase. This may also happen in Funil Reservoir allowing the energy flow through the detritus food-chain and the continuous production of small cladocerans such as *Bosmina longirostris*, *Ceriodaphnia cornuta* and *Diaphanosoma birgei*.

In addition to spatial differences in zooplankton occurrence, vertical changes in species abundance at a same sampling station were frequently found. Usually, the highest densities occurred at the limit of the euphotic zone. This difference was enhanced by cladocerans that frequently reached higher densities at the limit of euphotic zone. Cladoceran populations have been observed to migrate on a daily cycle in freshwaters, and the greatest depth of migration is often set by the bottom of the lake, by the depth of light penetration, or by the sufficient oxygen (Dodson & Frey, 2001). Notwithstanding the importance of light in cladocerans vertical migration, the escape from predators is considered the most important element influencing this movement (Lampert, 1993) and this may have influenced the cladocerans population movements in Funil Reservoir.

The highest density of cladocerans was observed at the limit of euphotic zone of station 3 in June (Fig. 3) corresponding to 3 meters deep. This was due to high *D. birgei* populations, which reached 245 ind.l^{-1}. The same species was represented by 2 ind.l^{-1} at the surface of the same station. Besides the vertical migration, this fact probably showed an aggregation of individuals.

Vertical movements of organisms in lakes may transverse the entire water column, if stratification is not well established (Hargrave, 1991). Despite the presence of stratification, the zooplankton density registered in October and December at the bottom was about a quarter or less of the observed at the surface. The presence of zooplankton, mainly rotifers and copepods at the bottom of the deepest sampling stations, such as 4, 5 and 6, respectively at 40, 30 and 55 meters, was probably possible due to the existence of an hypolimnion with dissolved oxygen. The lowest level of dissolved oxygen (1.3 mg.l^{-1}) occurred at the bottom of sampling station 5 in December, where *Hexarthra, Keratella* spp., *Rotaria* sp., *Bosmina longirostris, Diaphanosoma birgei*, nauplii and copepodites were surprisingly found.

Different vertical distribution was also observed for other groups. Turbellaria were only found at the limit of the euphotic zone at stations 3, 4, 5 and 6 in December, with densities between 5 and 12 ind. l^{-1}. Planktonic Turbellaria are common in both natural and man-made lakes in Brazil and their population densities are generally low when compared to other zooplankton groups (Rocha et al., 1990). Since flatworms consume preferentially copepods and cladocerans, their presence in the samples at the limit of the euphotic zone in December could be associated with a high abundance of zooplankton at this region. On the other hand planktonic Turbellaria are intensively preyed by invertebrates and vertebrates, what could explain their common low numbers at the water column.

Concluding, comparing sampling stations, clear differences in zooplankton species composition were observed between riverine stations and those in the main basin. Contrasting vertical density of organisms was detected at most stations with a tendency of increase in the limit of euphotic zone. The most eutrophic conditions enhanced a environmental longitudinal gradient at the reservoir in December since the existence of a *Microcystis aeruginosa* bloom at the upper part of the main basin, corresponding to the transitional zone of the reservoir, favored some taxa already considered indicators of eutrophy and changed the frequency of occurrence of common species. Despite the association of zooplankton assemblages with environmental conditions, probably other biological factors not considered in this study such as competition, food availability and predation pressure may have also affected the spatial and temporal distribution of the zooplankton species in Funil reservoir.

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