Spatial and temporal distribution of Copepoda (Cyclopoida and Calanoida) of an eutrophic reservoir in the basin of upper Iguaçu River, Paraná, Brazil.

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ABSTRACT: Spatial and temporal distribution of Copepoda (Cyclopoida and Calanoida) of an eutrophic reservoir in the basin of upper Iguaçu River, Paraná, Brazil. Morphometrical and hydrological characteristics of Iraí reservoir (upper Iguaçu River basin) are favorable to the development of Cyanophyceae blooms. In this study, spatial and temporal variation of the most frequent Copepoda species were evaluated monthly during seventeen months in six stations, through analysis of correlation between environmental variables and phytoplankton abundance, in addition to the analysis of the content of food ingested by copepods. For each sample was filtered 200 liters of sub surface (0.3 meters) water in a conical plankton net (64 μm mesh size). Notodiaptomus spinuliferus was the species with the higher mean density, followed by Microcyclops anceps, Tropocyclops prasinus, Acanthocyclops robustus, and Thermocyclops decipiens. Acanthocyclops robustus and Tropocyclops prasinus did not show any correlation with water physical or chemical variables, but showed negative correlation with algae species Peridinium umbonatum and Scenedesmus sp. Only Thermocyclops decipiens did not correlate with phytoplankton species. High abundances of Microcyclops anceps, Acanthocyclops robustus and Notodiaptomus spinuliferus were associated to periods of high pluviosity and water temperature, and with some algae species, especially Bacillariophyceae and Chlorophyceae. Regarding the content of food ingested by copepods, colonial cyanophytes were identified for all species and for some others, filamentous forms were observed. The morphometry, trophic level and age of Iraí Reservoir pointed clear seasonal patterns for some copepod species, but other species did not present any pattern of seasonal and spatial distribution.
Key-words: Copepoda, Cyanophyceae, Eutrophic reservoir, Iguaçu River Basin.

RESUMO: Distribuição espacial e temporal de Copepoda (Cyclopoida e Calanoida) em um reservatório eutrófico na bacia do alto rio Iguaçu, Paraná, Brasil. Características morfométricas e hidrológicas do reservatório do Irai (bacia do alto rio Iguaçu) são favoráveis ao desenvolvimento de florações de Cyanophyceae. Nesse estudo, as variações espaciais e temporais das espécies de Copepoda mais freqüentes foram avaliadas mensalmente durante dezessete meses em seis pontos de amostragem, através de correlação entre variáveis ambientais e abundância do fitoplâncton, em adição à análise de conteúdo alimentar ingerido pelos copépodos. Para cada amostra filtrou-se 200 litros de água em rede de plâncton cônica de 64 μm de abertura de malha. Notodiaptomus spinuliferus foi a espécie com a maior densidade média, seguida por Microcyclops anceps, Tropocyclops prasinus, Acanthocyclops robustus e Thermocyclops decipiens. Acanthocyclops robustus e Tropocyclops prasinus não mostraram nenhuma correlação com variáveis físicas e químicas da água, porém apresentaram correlações negativas com espécies fitoplanctônicas Peridinium umbonatum e Scenedesmus sp. Somente Thermocyclops decipiens não mostrou relação com nenhuma espécie de fitoplâncton. Elevadas abundâncias de Microcyclops anceps, Acanthocyclops robustus e Notodiaptomus spinuliferus foram associadas aos períodos de maior pluviosidade e temperatura da água, e com algumas espécies de algas, especialmente de

Bacillariophyceae e Chlorophyceae. No conteúdo alimentar ingerido pelos copépodes, algas cianofíceas coloniais foram identificadas para todas as espécies e para algumas, algas filamentosas foram observadas. A morfometria, estado trófico e idade do reservatório do Iraí foram responsáveis por padrões sazonais claros para algumas espécies de copépodes, porém para outras espécies, não verificou-se padrões claros de distribuição temporal e espacial.

Palavras chave: Copepoda, Cyanophyceae, reservatório eutrófico, bacia do rio Iguaçu.

Introduction

The disordered occupation of areas in hydrographic basins has resulted in eutrophication of several water bodies around the world. The lack of resources to the implementation of domestic and industrial sewage treatment results in the release of the effluents in receptor water bodies (rivers and lakes), causing the effect named eutrophication (Barbosa & Garcia, 2003).

The eutrophication can be defined as the biological effects resulting from the increase in nutrient concentrations, mainly nitrogen and phosphorus, above the limits established by the current legislation. Eutrophication can cause Cyanophyceae blooms in continental waters (Harper, 1983).

In tropical eutrophied environments, several zooplankton community attributes are altered, as the composition, the richness, and the diversity. Few species dominate in high densities and are generally associated to cyanophytes blooms, influencing the aquatic biodiversity, which is important to the system dynamic equilibrium (Matsumura-Tundisi, 1999; Pinto-Coelho et al., 1999; Serafim-Júnior et al., 2005).

Phytoplankton constitutes an important compound of the diet of zooplankton organisms, influencing their reproduction and survivorship. In relation to food habits, zooplankton species can be filter feeders, like cladocerans and Copepoda Calanoida (Diaptomidae), carnivorous or omnivorous as Copepoda Cyclopoida. Even in experimental studies as well as in aquatic environments of temperate zones (considered as more eutrophic than tropical ones), some microcrustaceans have been associated to the ambient trophic level and to the phytoplankton composition, mainly Cyanophyceae species (Rietzler et al., 2002; Ferrão-Filho et al., 2000; Coelho-Botelho, 2002; Darchambeau & Thys, 2005; Pinto-Coelho et al., 2005; Matsumura-Tundisi & Tundisi, 2003).

Copepods generally represent the most part of zooplankton biomass (Sendacz et al., 2006). They constitute an important link of transference of energy and mass from primary producers to other consumers. Several species are very associated to water variables, as conductivity (Matsumura-Tundisi & Tundisi, 2003) and temperature (Rietzler et al., 2002).

Considering the frequent blooms of Cyanophyceae algae at Iraí reservoir (Paraná State, Brazil), the aim of this study was to study the effects of some environmental variables and the phytoplankton composition on spatial and temporal distribution of adult copepods, with hypothesis that these organisms show different distribution among stations and months. For this purpose, it was evaluated: (i) the abundance of these organisms in relation to physical, chemical and biological variables, (ii) the relationships between phytoplankton species and copepods, and (iii) the ingestion of phytoplankton species by copepods through the analyses of the food content.

Material and methods

Study area

Iraí Dam is located in the basin of the upper Iguaçu River, among the cities of Piraquara, Pinhais and Quatro Barras (25° 25'49" S and 49° 06'40" W). The reservoir occupies an area of 14 Km² of the alluvial plain in the intermediate stretch of Iraí River, with a stored water volume of 58 x 10⁶ m³, mean depth of 4 meters and a relatively high residence time (300 - 450 days) (Fig. 1).

The main tributaries of the reservoir are: Curralinho, Cerrado, Cangüiri and Timbú. The last presented high loads of nutrients (mainly nitrogen and phosphorus), being 90 % of the total, due to the use of the soil to agriculture and, specially, to the increase of urban occupation of the drain basin area (Andreoli & Carneiro, 2005).

Since the end of filling of Iraí Reservoir, in the beginning of 2001, many

successive Cyanophyceae genus (Anabaena, Microcystis and Cylindrospermopsis) blooms occurred and seriously affected the water quality and enhanced the costs of treatment. The reservoir was classified as eutrophic/hypereutrophic during this study (Fernandes et al., 2005).
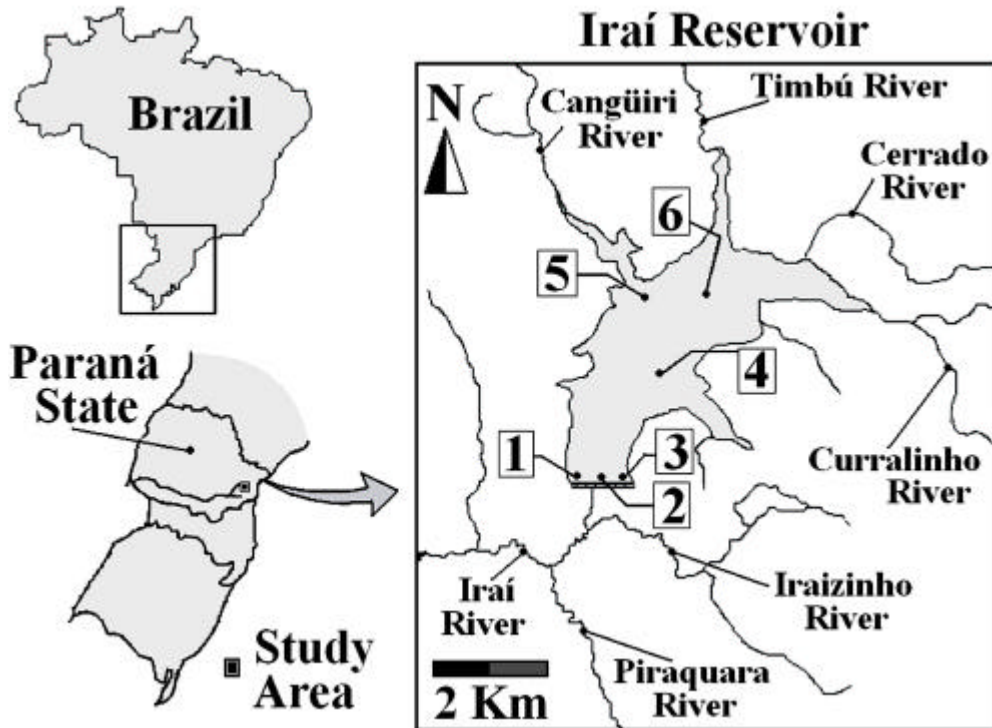

Figure 1: Localization of Iraí reservoir and sampling stations.

Sampling and data analyses

Zooplankton was collected monthly from March/2002 to July/2003, in six sampling stations (Tab. I), distributed for all the reservoir. In each station, 200 liters of sub surface water collected at 0.3 m were filtered using a motorized pump, in a conical plankton net (64 **m**m mesh size). Zooplankton sampling was done in the surface due to the low depth of the reservoir, and also to correlate with the composition and abundance of phytoplankton, obtained in the same depth, station and dates (Fernandes et al., 2005).

The filtered material was preserved in 4% formalin buffered with calcium carbonate. In the laboratory, adult copepods were identified according to Reid (1985), Matsumura-Tundisi (1986), Rocha (1998), Paggi (2001) and Silva & Matsumura-Tundisi (2005). In quantitative analyses, a minimum of 200 individuals per sample were counted (nauplius, copepodites and adults), in subsamples of 1 mL in Sedgewick-Rafter chamber, using a Stempell sampler. The abundance of individuals per cubic meter was estimated from the countings. In this study, only adult individuals of the five most abundant species are considered, when frequency of occurrence is higher than 10 %.

Data of abundance peaks were used to show the spatial distribution of

Table I: Localization and mean depth of sampling stations.

Sampling stations	Localization	Mean depth (m)
1 – 2 – 3	Dam axis	8
4 – 5 – 6	Main body of reservoir (5 and 6 near to tributaries rivers)	3

species. It can be recognized by dark patches proportional to the mean values of each point, in miniature maps of the reservoir (Fig. 2), according with the predominant winds (Fernandes et al., 2003; Gobbi et al., 2005).
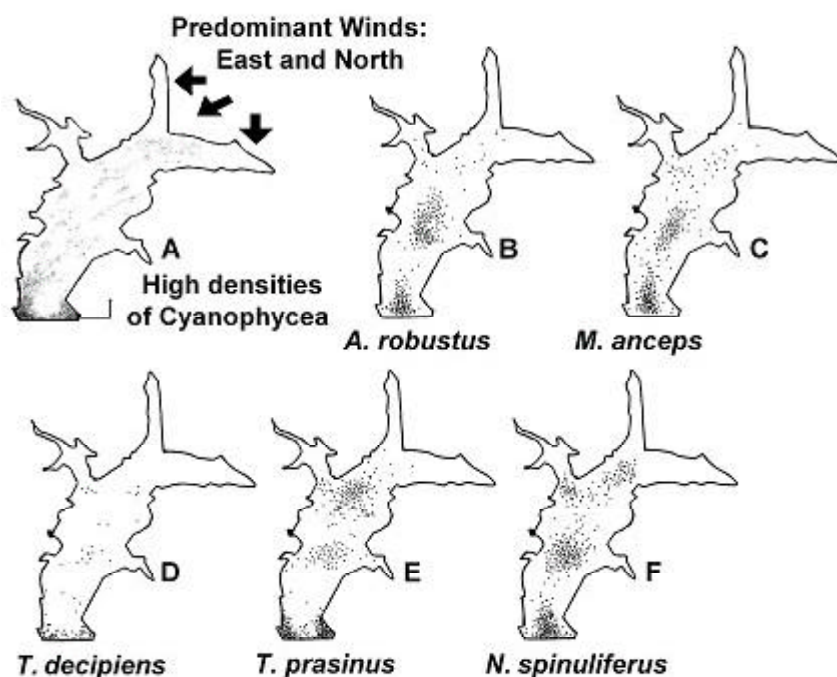

Figure 2: Spatial distribution during abundance peaks in the studied period. A. Cyanophyceae blooms in the left shore of the reservoir dam, caused by the action of the predominant winds; B. A. robustus (peaks in March and April/02); C. M. anceps (March/02); D. T. decipiens (April/02); E. T. prasinus (May/02 and May/03); F. N. spinuliferus (April/02, February/03).

Physical, chemical, and biological (phytoplankton abundance and composition) variables used in this study were obtained elsewhere (Sanepar, 2006). The following variables were used: total phosphorus, organic nitrogen, nitrite, nitrate, pH, total dissolved solids, dissolved oxygen, temperature, turbidity, conductivity, water transparency using Secchi disc and chlorophyll-a (Andreoli & Carneiro, 2005). Table II summarizes the mean, minimum and maximum values (± standard deviation) of these variables for Iraí Reservoir. Pluviometric data were obtained from the historical data base of Technological Institute Simepar to the city of Pinhais, and the mean values are referent for 10 days preceding the samplings.

Table II: Mean, minimum, and maximum values (± SD) of physical, chemical and biological variables used in this study. Legends and units: total phosphorus - TotP (mg L^{-1}), organic nitrogen - OrgN (mg L^{-1}), nitrite - Nitri (mg L^{-1}), nitrate - Nitra (mg L^{-1}), pH, total dissolved solids - TDS (mg L^{-1}), dissolved oxygen - DO (mg L^{-1}), temperature - Temp (^{o}C), turbidity - Turb (NTU), conductivity - Cond (mS cm^{-1}), water transparency using Secchi disc - Secc (m), chlorophyll-a - Chlor (μg L^{-1}) and pluviosity - Pluv (mm^3).

	TotP	OrgN	Nitri	Nitra	pH	TDS	DO	Temp	Turb	Cond	Secc	Chlor	Pluv
Mean	0.10	1.51	0.17	0.76	7.25	56.00	6.95	22.50	19.00	46.00	0.74	35.00	108.75
SD	0.05	1.20	0.17	0.36	1.37	15.35	1.87	3.70	8.50	3.50	0.15	23.00	51.61
Max	0.21	4.90	0.50	1.27	9.70	98.00	11.40	27.40	39.00	54.00	1.00	90.86	178.20
Min	0.00	0.65	0.00	0.25	5.60	35.00	3.10	15.00	7.10	41.00	0.05	5.30	4.60

After the normality test (Shapiro-Wilk) of log transformed physical, chemical and biological data (chlorophyll and phytoplankton species abundance), normal distributions were observed, requiring non parametric tests. In order to relate the mean abundance of copepods species with the other variables, Spearman correlation was used (Statistica v6.0 - Statsoft, 2002).

In order to investigate the feeding habit of the studied species, the content of the food ingested by 30 individuals of each species was analyzed. Before dissecting, total body length of individuals was measured from the ocellus until the end of the furca. The individuals were dissected using fine pins mounted in wooded holds, on Petri dishes and in slides, under a stereomicroscope (200 x). The content resulting from the dissection was observed in slides covered by coverslips in magnifications of 400 and 1000x, and thus the phytoplankton ingested species were identified by specialists.

Results

Spatial variation of plankton

First, in relation to phytoplankton, spatial distribution of algae was homogenous and almost completely dominated by Cyanophyceae (97.0 – 99.9 %). In the right and left shores from the dam axis, it was observed an accumulation of Microcystis sp. due to the action of the predominant east winds, with densities varying from 2,685 to 52,734 cells mL^{-1} and chlorophyll-a from 29.9 to 96.4 mg L^{-1} (Fig. 2A). Cylindrospermopsis raciborskii densities ranged from 26,806 to 200, 726 cells mL^{-1} and chlorophyll-a, from 19.7 to 40.6 mg L^{-1}, in the same sites.

Considering copepods, Notodiaptomus spinuliferus and Tropocyclops prasinus dominated in the samples with a total frequency of 59 %, followed by Microcyclops anceps (39 %) (Tab. III). In relation to body length, N. spinuliferus and T. prasinus showed the higher and the lowest values (1,470 mm and 450 mm, respectively).

Fig. 2 shows the spatial distribution of each species when reached abundance "peaks". Acanthocyclops robustus, M. anceps, T. prasinus and N. spinuliferus were dispersed along the reservoir during abundance "peaks", differing from Thermocyclops decipiens that was found only in the dam axis of the reservoir (Fig 2 B-D). In general, for sites 1 and 3, Cyanophyceae blooms were common. Low densities of organisms were recorded in station 1 and 3 compared to the site 2, in the middle of the dam. In 1 and 3 sites higher densities were found for T. decipiens and lower to N. spinuliferus (Fig. 2 D, F). In site 2, high densities of M. anceps (1,065 ind. m[-3]) and N. spinuliferus (906 ind. m[-3]) were found. Conversely, T. prasinus (145 ind. m[-3]) and T. decipiens (6 ind. m[-3]) presented low densities. The higher abundance of Acanthocyclops robustus (599 ind. m[-3]) was found in site 4, overcomed only by N. spinuliferus (803 ind. m[-3]). The abundance of T. prasinus varied from 145 ind. m[-3] (site 2) to 488 ind.m[-3] (site 6).

Temporal variation of plankton

Notodiaptomus spinuliferus showed two abundance "peaks", in April/02 (3,365 ind. m[-3]) and in February/03 (1,538 ind. m[-3]) (Fig. 3), when the mean water temperature was high. Tropocyclops prasinus higher densities occurred in winter, in May/02 (867 ind. m[-3]) and in May/03 (807 ind. m[-3]), with

Table III: Frequency of occurrence (Fr. %) of Copepoda (Cyclopoida and Calanoida), and body length (maximum and minimum values) (µm) of dissected organisms, during the period of March/2002 to July/2003, at Iraí Reservoir.

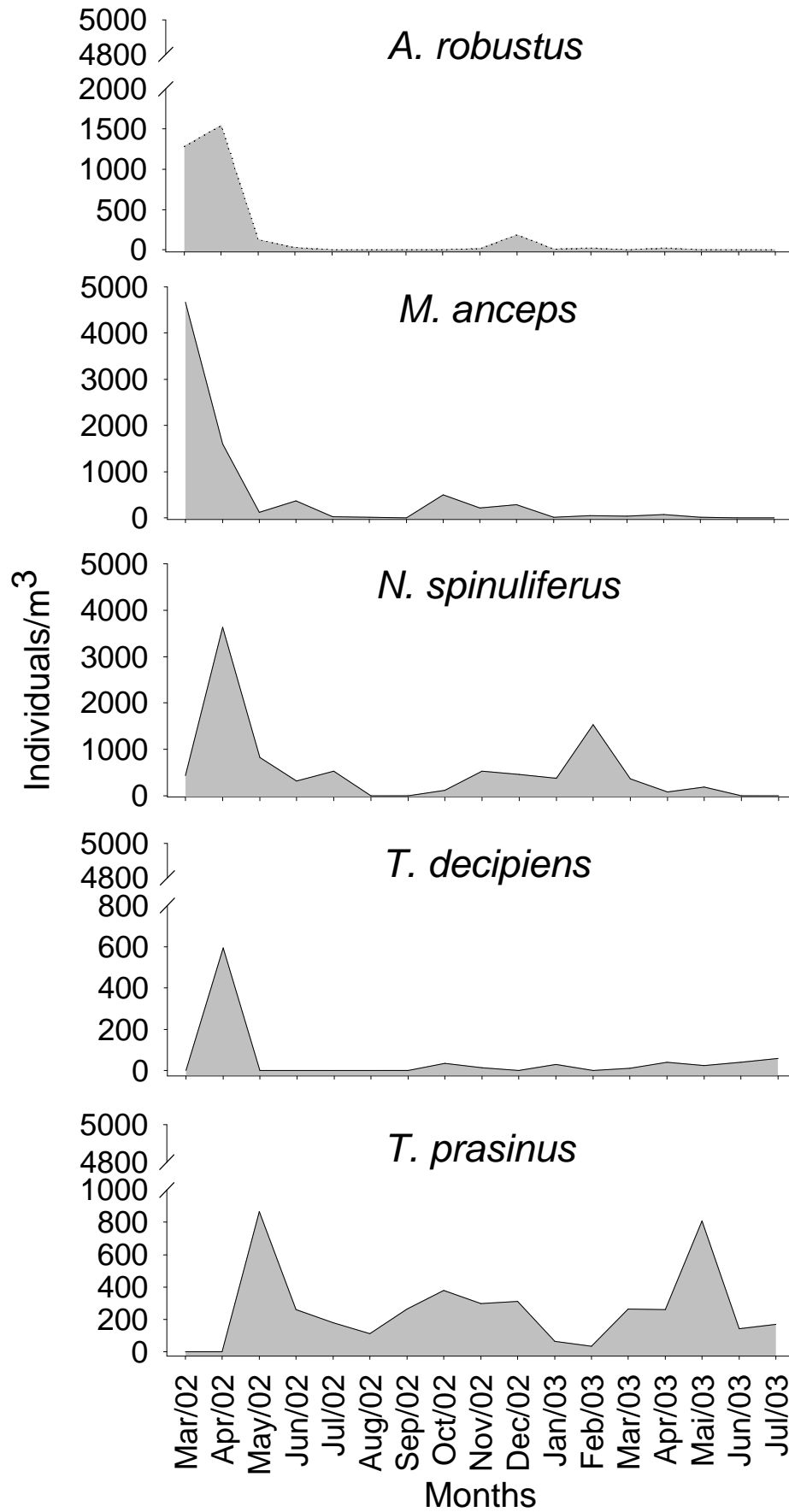| Copepoda species	Fr. %	Size (mm)	
Acanthocyclops robustus (G. O. Sars, 1863)	21	720	1,450
Microcyclops anceps (Richard, 1897)	39	610	1,000
Thermocyclops decipiens (Kiefer, 1929)	17	610	940
Tropocyclops prasinus (Fischer, 1860)	59	450	660
Notodiaptomus spinuliferus Dussart & Matsumura-Tundisi, 1986	59	900	1,470

Figure 3: Abundance temporal variation of copepod species.

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temperature values ‹ 20° C, low pluviometric values and presence of blooms of filamentous cyanophytes. The greatest abundance "peak" of Microcyclops anceps was observed in March/02 (4,671 ind. m⁻³), together with blooms of C. raciborskii. In the next month, this species declined in numbers, and N. spinuliferus and T. prasinus increased in density. Acanthocyclops robustus was also abundant in March/02 (1,284 ind. m⁻³) and April/02 (1,545 ind. m⁻³), and higher densities occurred again in

December/02 (184 ind. m⁻³), when the pluviometric values increased. In general, T. decipiens showed low abundance values during the studied period and higher mean abundance was found in April/02 (593 ind. m⁻³).

No significant correlation values were found between physical, chemical and biological variables (pluviosity, nitrite, nitrate, dissolved oxygen, turbidity, conductivity, and chlorophyll-a) and copepod species (Tab. IV).

Table IV: Spearman correlation between copepod species and environmental variables (* = significant correlation, p ‹ 0.05).

Environmental variables	M. anceps	T. decipiens	N. spinuliferus
Total P	0.329	0.59 *	-0.31
Organic N	0.25	0.04	0.58 *
pH	0.38	0.72 *	0.25
Total dissolved solids	-0.07	-0.65 *	0.16
Temperature	0.48	0.49	0.63*
Transparency (m)	-0.60 *	-0.40	-0.35
Total phytoplankton	0.70 *	0.09	0.39

Acanthocyclops robustus and T. prasinus were significantly correlated only with phytoplankton species. Microcyclops anceps was negatively correlated with water transparency and positively with phytoplankton total density. Thermocyclops decipiens presented a negative correlation with total dissolved solids and a positive correlation with total P and pH. N. spinuliferus was correlated positively with organic N and temperature.

In the dissected organisms for the food content, free cells of Microcystis, Aphanocapsa, Pseudoanabaena and Aulacoseira, and some entire and in pieces of Chlorophyceae were identified, with high frequency and abundance values (Tab. V). Small particles similar to detritus or food in an advanced digestion process were also found, but in low numbers. Aulacoseira sp., Merismopedia sp., Dicthyosphaerium sp., Microcystis sp., Ankistrodesmus sp., Pediastrum simplex and Golenkinia radiata were identified in the food content of individuals of A. robustus. The majority of M. anceps individuals dissected contained Microcystis sp. and Aphanocapsa delicatissima, and low numbers other algae, like A. solitaria, Aulacoseira sp. and Gomphosphaeria sp.. The same most

ingested algae (M. aeruginosa and A. delicatissima) were found also in T. decipiens (in addition to Scenedesmus sp., Staurastrum sp. and filamentous algae) and in T. prasinus (plus filamentous Cyanophyceae). Microcystis sp., Pseudoanabaena mucicola, Gomphosphaeria sp., Dicthyosphaerium sp., Chrococcus sp., Staurastrum sp. and Scenedesmus sp. were found in the food contents of N. spinuliferus.

Spearman correlation between T. decipiens and the phytoplankton species densities showed no significant values (Tab. VI). Tropocyclops prasinus was negatively correlated with Peridinium umbonatum and Scenedesmus sp. Acanthocyclops robustus was positively correlated with A. granulata var. angutissima, A. granulata var. angutissima f. spiralis, A. granulata var. granulata, Elakothotrix sp., Eutetramorus sp., Tetrastrum sp. Staurastrum sp., and negatively with Microcrystis sp.. Microcyclops anceps was positively correlated with A. ambigua var. spiralis, and negatively with Anabaena solitaria, Microcystis sp., P. umbonatum, Scenedesmus sp. and Urosolenia sp.. Notodiaptomus spinuliferus was positively correlated with A. granulata var. angustíssima, A. granulata var. granulata, Eutetramorphus sp. and Staurastrum sp., and negatively with Microcystis sp. and Urosolenia sp.

Table V: Food items found in the food contents of dissected individuals (frequency › 30 %), and minimum and maximum size of identified algae.

Copepoda species	Most found items (30%)	Size Mín.-Máx. (mm)
A. robustus	Aulacoseira sp., Aphanocapsa delicatissima and Microcystis sp. free cells and small colonies; small Chlorococcales; rotifer remains, nauplius, cladocerans, thecate protozoans, other not identified organisms, detritus and not recognized particles.	0.2 – 70
M. anceps	A. delicatissima, Microcystis sp free cells and small colonies; small Chlorococcales; pieces of Bacillariophyceae and filamentous Cyanophyceae; detritus and not recognized particles.	0.2 – 54
T. decipiens	A. delicatissima and Microcystis sp. free cells and small colonies; small Chlorococcales; filamentous algae, possibly Cyanophyceae and genus Aulacoseira; detritus and not recognized dark.	0.2 – 50
T. prasinus	A. delicatissima, Microcystis spp. and M. aeruginosa free cells and small colonies; Chlorococcales; filamentous algae possibly Cyanophyceae and genus Aulacoseira; detritus and not recognized dark particles.	0.2 – 44
N. spinuliferus	A. delicatissima and M. aeruginosa free cells; small Chlorococcales and remains of other algae not identified, but not filamentous; not recognized particles.	0.2 – 56

Table VI: Spearman correlation between copepod and phytoplankton species (* = significant correlation, p ‹ 0.05).

Phytoplankton species	T. prasinus	A. robustus	M. anceps	N. spinuliferus
Cyanophyceae				
Anabaena solitaria	-0.23	-0.29	-0.71 *	-0.19
Microcystis sp.	-0.04	-0.68 *	-0.57	-0.60 *
Bacillariophyceae				
Aulacoseira granulata var. angustissima (Müller) Simon.	-0.05	0.72 *	0.31	0.84 *
Aulacoseira granulata var. angustissima f. spiralis (Müller) Simon..	0.22	0.91 *	0.78 *	0.62 *
Aulacoseira granulata var. granulata (Müller) Simon.	-0.16	0.89 *	0.52	0.64*
Urosolenia sp.	0.23	-0.15	-0.46	-0.69 *
Chlorophyceae				
Elakothotrix sp.	-0.09	0.92 *	0.50	0.46
Eutetramorus sp.	0.09	0.73 *	0.48	0.66 *
Scenedesmus sp.	-0.67 *	-0.10	-0.36	-0.23
Tetrastrum sp.	-0.19	0.83 *	0.35	0.53
Zygnemaphyceae				
Staurastrum sp.	-0.27	0.83 *	0.51	0.61 *
Dynophyceae				
Peridinium umbonatum Stein	-0.67 *	-0.38	-0.70 *	-0.31

Discussion

General characteristics of the environment

Due to the low depth of Iraí Reservoir and to the intense wind action, water column is often homogenous, considering the majority of physical and chemical variables. But, stratification is frequently observed in the dam zone. Most parameters showed seasonal variations characterized by cool-dry and warm-wet periods. However, irregular seasonal patterns were recorded at Iraí Reservoir, as high temperature and precipitation in the cool-dry period (winter), typical of the regional weather considered as a temperate type Cfb from Köppen classification (Bollmann et al., 2005).

The circulation of the superficial water mass by the action of the predominant winds (east and northeast directions) in Iraí Reservoir causes the accumulation of the algae on the water surface, in direction to the dam (Gobbi et al., 2005; Fernandes et al., 2005). Among these algae, Microcystis aeruginosa was the predominant species at Iraí Reservoir and its density was correlated mainly to total phosphorus. Because of the gaseous vacuoles in its mucilaginous mass, this species tends to occupy the surface of lakes, shading the deeper layers, and thus, reducing competition effects with other algae (Fernandes et al., 2005). Another limiting factor was pluviosity, which caused the homogenization of the superficial water together the winds, reducing colonies size. Algae sinking can be observed in cases of long periods of rain and winds. Thus, the senescence of a large phytoplanktonic biomass and the lack of strong winds results in anoxic conditions in the deeper layers, caused by the decomposition of these algae, and in this way, indirectly can affect the copepods.

Copepoda and physical and chemical factors

Several variables (pluviosity, nitrite, nitrate, turbidity, dissolved oxygen, conductivity and chlorophyll-a) were correlated unsignificantly with Copepoda, suggesting an indirect influence or cumulative effects of these variables. A good example would be the effect of electric conductivity on Calanoida (Matsumura-Tundisi & Tundisi, 2003), fact that was not observed at Iraí Reservoir. The

lack of correlation between N. spinuliferus and conductivity can be attributed to the low variability (41- 54 **nß** cm⁻¹) in the reservoir during the studied period. This value can also be considered low when compared to other eutrophic reservoirs as Barra Bonita (Tietê River, SP, Brazil) (Matsumura-Tundisi & Tundisi, 2003).

Water temperature was positively correlated with N. spinuliferus. In addition to temperature, this species also showed a significant correlation with organic N, associated, probably, due to the growth of some palatable algae (ex: Staurastrum sp.). According to Rietzler et al. (2002) low temperature (17 °C) was responsible for the great mortality of copepodits and the lack of reproduction in Argyrodiaptomus furcatus and Notodiaptomus iheringi.

Temporal distribution of adult individuals of zooplankton in small and shallow reservoirs, as the case of Iraí, tends to be more relevant than in a spatial scale. Santos-Wisniewski & Rocha (2007) observed the same pattern in Barra Bonita Reservoir (Tietê River) and suggest that the great production of copepods was sustained by high primary production and by appropriate conditions of temperature, high concentrations of nutrients and chlorophyll.

Copepoda food

In eutrophic tropical lakes, the dominance of Cyclopoida over Calanoida is mainly related to the feeding habits, from omnivorous raptorial diets, while Calanoida species are herbivorous and selective to the type of food, like some species of the genus Notodiaptomus (Matsumura-Tundisi et al., 1987; Sendacz & Kubo, 1999).

In relation to body size, some authors point out a tendency of dominance of smaller species in eutrophic reservoirs (Sendacz & Kubo, 1999; Pinto-Coelho et al., 1999). In Iraí Reservoir it was observed the dominance of cyclopoids of small and medium size, despite of the dominance of N. spinuliferus and the presence of A. robustus in some months. Lansac-Tôha et al. (2005) registered high abundances of small young forms of Cyclopoida in Iraí Reservoir, and associated with chlorophyll-a. Medium and large organisms, like some of the Thermocyclops and Mesocyclops genus can also be found in high abundance (Pinto-Coelho et al., 1999).

Regarding the influence of second metabolites (cyanotoxins) on

microcrustaceans, contradictory results were pointed out (Caldwell et al., 2004). Infante & Riehl (1984) consider cyanophytes as an excellent food to zooplanktonic organisms. Conversely Ferrão-Filho et al. (2000) mention about the low nutritional and toxic properties of Cyanophyceae for Cladocera. At Iraí Reservoir, we cannot assert that there is a direct toxic effect of cyanophytes on copepods, but a relevant fact was the low density of copepods in the presence of microcystin in May/02 (2,094 μg L^{-1}) and August/03 (› 2,146 μg L^{-1}) (Serafim-Júnior et al., 2005).

A relationship between the size of the ingested particle and the size of the adult organism was also observed. But, the presence or absence of mucilaginous mass, colonies shape, digestibility and assimilation of cell content can difficult the ingestion of algae (Lampert, 1987; Ferrão-Filho et al., 2000; Turner et al., 2002).

The ingestion of Microcystis by Copepoda species can occur due to the fragmentation of the colonies by the turbulence of water caused by the action of wind. Free cells or small colonies are considered an excellent food to copepods since they were found in food contents. In a condition without turbulence and winds, Microcystis aeruginosa remains in the surface and, in cases of turbulence, the colonies can break into pieces or return to the water column (Naselli-Flores & Barone, 2003; O´Brien et al., 2004). Notodiaptomus iheringi showed higher values of grazing rates when fed on free cells and small colonies of M. aeruginosa, followed by large colonies of that alga, C. raciborskii and Anabaena sp. in an eutrophic reservoir of the Southeast region of Brazil (Panosso et al., 2003).

In this study, abundance peaks of M. anceps, T. prasinus and T. decipiens occurred in the sites located near the dam (stations 1, 2, 3). Cyanophyceae algae (filamentous and colonial, as Microcystis) and also some filamentous Bacillariophyceae, predominated in the food contents of the copepods.

The higher abundance values of Acanthocyclops robustus and Notodiaptomus spinuliferus were recorded in sites located in the main body of the reservoir (stations 6, 4 and 5). In these sites, it was also observed the higher abundance of large Cladocera (Daphnia), a filter feeder, as well as the most

elevated phosphorus levels (Carneiro et al., 2003; Serafim-Júnior et al., 2005). The spatial distribution of these planktonic organisms can be related to the appropriated abiotic and biotic conditions (ex: water temperature, nutrients, resource of food, ausence of predators), especially the Cyanophyceae blooms (Roseinweig, 1991; Bernot et al., 2004).

Notodiaptomus spinuliferus was one of the most frequent and abundant species, suggesting that it is able to reproduce in Iraí Reservoir, in contrast with other Calanoida species, as some of the Argyrodiaptomus genus. Notodiaptomus spinuliferus showed a positive significant correlation with some species of Bacillariophyceae and negative with Microcystis sp. and Urosolenia sp., although Microcystis has been found in the food content analyzed, together to Aphanocapsa delicatissima. These Cyanophyceae are probably not a main compound of the diet of N. spinuliferus.

When individuals of N. spinuliferus used for dissection were sampled (March/02), a brief and intense bloom of Cylindrospermopsis raciborskii occurred (Fernandes et al., 2005), but, this species was not found in the food content of N. spinuliferus. We can relate this to an alimentary preference of this Calanoida species that decreased in density in April/02, probably due to intense blooms of filamentous cyanophytes. In November/02, January and February/03, when higher pluviometric indexes, large blooms of M. aeruginosa and other colonial cyanophyceans were recorded, the Calanoida density increased again. Monteiro (1996) observed a reduction in the filtering capacity and populations densities of Calanoida in eutrophic reservoirs, mainly in the presence of filamentous cyanophytes. Several Calanoida species are able to discriminate algae not only by size and shape, but also using chemical features, i.e., since they possess chemioreceptors (chemiosensors) located in their antennae that detect food of low and high quality (Ventelã et al., 2002).

Due to the small size (0.2 μm) of free cells of Microcystis and cells of other Cyanophyceae species, N. spinuliferus feed of particles varying from 0.2 to 50 μm. This size range was similar to that observed to N. iheringi while Argyrodiaptomus furcatus (an organism with larger body size) prefer

feeding on larger algae as Aulacoseira spp., Staurastrum spp., Cosmarium and Monoraphidium spp. (Rietzler et al., 2002; Panosso et al., 2003). These copepods feed on different phytoplankton classes, like Cyanophyceae, Bacillariophyceae, Dinophyceae, Euglenophyceae and Chlorophyceae. However, the data of the present study indicate the ingestion of few or none filamentous cyanophyceans that are hard to manipulate or to ingest.

Despite the lack of correlation between A. robustus and the water physical or chemical variables, this species showed a significant positive correlation with phytoplankton (Bacillariophyceae and Chlorophyceae) and, a negative correlation with Microcystis sp. The dominance of these groups of algae in the reservoir can be considered as one of the factors responsible for the low occurrence of A. robustus. This species showed higher densities in the warm-wet period when a decrease of Microcystis was observed. This species is typical of summer periods, with fast embryonic and post-embryonic development, tolerant to adverse ambient conditions, like low levels of dissolved oxygen, and is frequently found in eutrophic lakes (Vijverberg & Ritcher, 1982; Maier, 1990, Bruno et al., 2002). In Iraí Reservoir, filamentous algae (Cyanophyceae and Bacillariophyceae) and other shaped forms (Chlorophyceae), as well as nauplius and rotifers, were found in the food contents of A. robustus (Serafim-Júnior et al., 2005).

The negative correlation of Microcyclops anceps with water transparency and the positive with total phytoplankton suggests that M. anceps has a great plasticity in adapting to different conditions and also have an ample food spectrum. In studies carried out in tropical region, M. anceps was found in several environments, like reservoirs, floodplains, marginal lakes and others (Lopes et al., 1997; Lansac-Tôha et al., 2002).

Although Tropocyclops prasinus did not correlate with water physical or chemical variables neither with cyanophyceans, a negative correlation with dynophyceans and chlorophyceans was recorded. In the food contents, the cyanophyceans A. delicatissima, Microcystis spp. and M. aeruginosa and the bacillariophycean Aulacoseira sp. were observed. This can reflect an alimentary preference or an adaptation of this copepod in ingesting different types of algae. T. prasinus was found in several water bodies in São Paulo state (Melão & Rocha, 2004; Silva & Matsumura-Tundisi, 2005). Sendacz & Kubo (1999) noticed that a significant abundance of T. prasinus was associated to T. decipiens and Metacyclops mendocinus in Billings's complex.

The relationship between T. decipiens and total P levels was also found in other Brazilian reservoirs, suggesting that this species is adapted to eutrophic environments. This species showed a negative correlation with total dissolved solids and also a positive with pH. Conversely, no correlation with phytoplankton was detected. Thermocyclops is a genus able to break algal colonies and detritus aggregates into pieces, and in Brazil, is represented by 2 species: T. decipiens and T. minutus (Pinto-Coelho, 2002). T. decipiens has been considered a species associated to meso-eutrophic environments in several studies (Tundisi & Matsumura-Tundisi, 1992; Lopes et al., 1997; Sendacz & Kubo, 1999; Pinto-Coelho, 2002; Sendacz et al., 2006; Silva & Matsumura-Tundisi, 2005).

General considerations

In this study, a regular seasonal pattern of some species like M. anceps and T. decipiens was not recognized, and they showed occasional abundance "peaks" in March/02 and April/02, respectively. However, they presented a successional pattern in relation to the seasons: A. robustus presenting "peaks" in summer, T. prasinus between autumn and winter and N. spinuliferus in summer/autumn. Fernandes et al. (2005) did not find a regular pattern to phytoplankton species composition, which changed continuously during the studied period. Regarding the spatial distribution, the highest abundance occurred in the dam axis, although a clear pattern is not observed possibly due to a long water residence time. Velho et al. (2005) commented that the long water residence time can minimize the effect of longitudinal distribution of zooplankton in Iraí Reservoir.

Considering that sampling initiated in the second year after filling of Iraí Reservoir, the instability, absence or hard interpretation of successional patterns of aquatic communities can be explained by the time necessary to the adaptation and

colonization of the new ambient. Generally, high fluctuations of physical and chemical variables have direct and indirect influence on phytoplankton and tend to interfere indirectly on the composition and abundance of copepods that feed on them.

More detailed studies about the alterations in copepod associations (Cyclopoida and Calanoida) serve as tools to monitor water quality (Gannon & Stemberger, 1978). The presence of some species can reflect trophic conditions of the ambient. In São Paulo State, *Argyrodiaptomus furcatus* was reported in oligotrophic conditions, being replaced by *Notodiaptomus iheringi* in more eutrophic environments (Sendacz & Kubo, 1999; Matsumura-Tundisi, 1999; Matsumura-Tundisi & Tundisi, 2003).

The presence of massive Cyanophyceae blooms suggests the adaptation of copepods in feeding mainly on these algae, in addition to protozoans, bacterias, and other organisms, which parts were observed in the food content analyzed.

The major number of Cyclopoida species can be associated to their plasticity in relation to food, and to physical and chemical conditions. Only *N. spinuliferus* was dominant during the studied period and this can be related to its ability to ingest Cyanophyceae, since variables considered responsible to Calanoida alterations, like conductivity, presented low values and did not correlate significantly with *N. spinuliferus*.

Descriptive and experimental studies about copepods and their relationship with phytoplankton dominated by Cyanophyceae are really necessary. The real importance of other phytoplankton classes or unknown food relationships on the diet of Copepoda species, as well as the influence of physical and chemical variables on shallow and eutrophic reservoirs could be studied. Furthermore, studies on planktonic Copepoda species of upper Iguaçu River are also necessary due to the scarcity of data.

Acknowledgements

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