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ZOOPLANKTON DYNAMICS IN AN EUTROPHIC URBAN RESERVOIR: FOUR SCENARIOS OVER A HYDROLOGICAL CYCLE

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ABSTRACT

The Ibirité reservoir, built in the 1960's in order to attend the Petrobras water demand, receives untreated wastewater, which results in a process of eutrophication, with periodic cyanobacterial blooms. The present study describes the zooplankton community of the Ibirité reservoir in terms of richness, composition and abundance throughout a complete hydrological cycle (Oct/2007 to Oct/2008), and considering some environmental variables. Four scenarios, with different environmental conditions that reflected in the zooplankton community structure were identified and described with the aid of analysis ordination (DCA and CCA) and variance: Scenario 0 -characterized by the onset of the rainy season (summer) (Oct/2007 and 2008), a period of high temperatures, high relative water column stability and apex of cyanobacterial blooms. In this scenario, the zooplankton was dominated by rotifer *Brachionus calyciflorus*.-Scenario 1 (Dec/2007, Feb and Apr/2008) -the rainy season apex and collapse of the cyanobacterial bloom by dilution. A reduction in the abundance of rotifers and nauplii (microzooplankton) was recorded in this period as a consequence of dilution and flushing these organisms through the spillway. -Scenario 2 (Jun/2008) -refers to the dry season, during which the reservoir had a low stability of the water column and no cyanobacterial bloom. In this period we registered the highest values of species richness and abundance, mainly rotifers and cladocerans. This can be explained by an hydrodynamic instability favoring *r*-strategists (*e.g.* rotifers) and reduction of predation pressure by vertebrates as consequence of fish mortality has occurred during this period. -Scenario 3 (Aug/2008), which represented the transition between the dry (winter) and rainy (summer) seasons, found the reservoir partially stratified, with the onset of algal bloom. In this period, the presence of the invasive rotifer *Kellicottia bostoniensis* was recorded for the first time in Ibirité reservoir.
Keywords: Urban Reservoir; eutrophication; zooplankton; cyanobacteria bloom; hydrological cycle.

RESUMO

DINÂMICA ZOOPLANCTÔNICA EM UM RESERVATÓRIO URBANO EUTROFIZADO: QUATRO CENÁRIOS AO LONGO DE UM CICLO HIDROLÓGICO. O reservatório de Ibirité (MG), construído na década de 60 para atender as demandas de água da Petrobrás, recebe hoje esgotos sem tratamento, o que acarretou em um processo de eutrofização artificial, com ocorrências periódicas de florações de cianobactérias. Este estudo descreve a comunidade zooplanctônica do reservatório de Ibirité, em termos de riqueza, composição e abundância, ao longo de um ciclo hidrológico (out/07 a out/08) e considerando algumas variáveis ambientais. Foram identificados e descritos, com o auxílio de análises de ordenação (CCA e DCA) e variância, quatro cenários com condições ambientais distintas, e que refletiram na estruturação da comunidade zooplanctônica, cenário 0 - caracterizado pelo início da estação chuvosa (verão) (out/2007 e 2008), período de temperaturas elevadas, alta estabilidade relativa da coluna de água e ápice das florações de cianobactérias.

Neste cenário, a comunidade zooplanctônica foi dominada pelo rotífero *Brachionus calyciflorus*; -cenário 1 (dez/07, fev. e abril de 2008) -ápice da estação chuvosa e colapso da floração de cianobactérias por diluição. Neste período foi registrada uma redução na abundância de rotíferos e náuplios (microzooplâncton) devido ao carreamento destes organismos pelo vertedouro e pela diluição; -cenário 2 (jun/08), refere-se à estação seca, período no qual o reservatório apresentou uma baixa estabilidade da coluna de água e ausência de floração de cianobactérias. Neste período foram registrados os maiores valores de riqueza em espécies e abundância, principalmente para rotíferos e cladóceros, fato que pode ser explicado pela instabilidade da coluna de água favorecendo os r-estrategistas (ex: rotíferos) e redução da pressão de predação por vertebrados, pois ocorreu uma mortandade de peixes durante este período; -cenário 3 (agos/08), que representou a transição entre a estação seca (inverno) e chuvosa (verão), período no qual o reservatório encontrava-se parcialmente estratificado e registrava o início da floração algal. Neste perído foi realizado o primeiro registro da espécie de rotífero invasor *Kellicottia bostoniensis* no reservatório de Ibirité.
Palavras-chave: Reservatório urbano; eutrofização; zooplâncton; floração de cianobactéria; ciclo hidrológico.

INTRODUCTION

Reservoirs are a complex and interactive network between the biotic and abiotic environments. In these systems, the relationships between biological communities and their physical-chemical environment are in permanent process of responding to climatological forces (wind, rain and cold fronts) and effects produced by the operational management of the dam (Tundisi 1999). The increase of human activities impacting the surrounding water bodies promotes an excessive supply of nutrients leading to eutrophication. As consequences of this process, we have a deterioration of water quality and increased primary productivity, promoting algal blooms and macrophytes proliferation (Thornton *et al.* 1990, Bollmann & Andreolli 2005).

The need for limnological studies in tropical reservoirs is due primarily to a larger number of these environments, in comparison to natural lakes present in this latitudinal band, the socio-economic importance, and the growing level of impact in such environments, primarily by the dumping of sewage and removal of vegetation in their watersheds. Furthermore, understanding the mechanisms of functioning of tropical reservoirs is important to establish the foundations for rational use of these water resources (Nilssen 1984, Marouelli *et al.* 1988, Pinto-Coelho 1998).

Built in the 1960's to meet the water demand from the Gabriel Passos Refinery (REGAP) / PETROBRAS SA, the Ibirité reservoir is presently in an accelerated process of eutrophication, mainly because one of its larger tributaries, the Ibirité river, and this river's largest contributor, the Pintados creek, drain an extensive and densely populated industrial area, receiving mostly domestic untreated sewage, which affects the quality of its waters. As a result of this eutrophication process, intense cyanobacterial bloom events happen mainly during the first months of the warm/rainy season, when the temperature is high and the precipitation level is not high enough to dilute and wash out the bloom. Despite the importance of the Ibirité reservoir for the industrial sector and for the surrounding population's leisure, few studies have been carried out in this environment, and of these only one addressed the zooplankton (Pinto-Coelho 1998b).

In this paper we analyzed the zooplankton community (Rotifera, Cladocera and Copepoda) variations in terms of composition, richness and abundance, and the influence of some environmental factors on the structure of this community throughout a hydrological cycle (Oct/07 to Oct/08). In this context, we formulated the following hypothesis: Scenarios characterized by cyanobacterial blooms and high rainfall will negatively influence species richness and density of the micro and mesozooplankton.

MATERIAL AND METHODS

STUDY AREA

Ibirité Reservoir (19°07'00''20°02'30'' S; 44°07'30''44°05'00'' W) is located in the Paraopeba river basin, a large tributary of the São Francisco river (Minas Gerais state). Its basin is formed by the Pintados, Retiro and Onça sub-basins (Fundação João Pinheiro 2001). In its surrounding areas there are *Eucalyptus* plantations, small farms, industrial and urban areas with neighborhoods and slums (Callisto *et al.* 2005) (Figure 1).

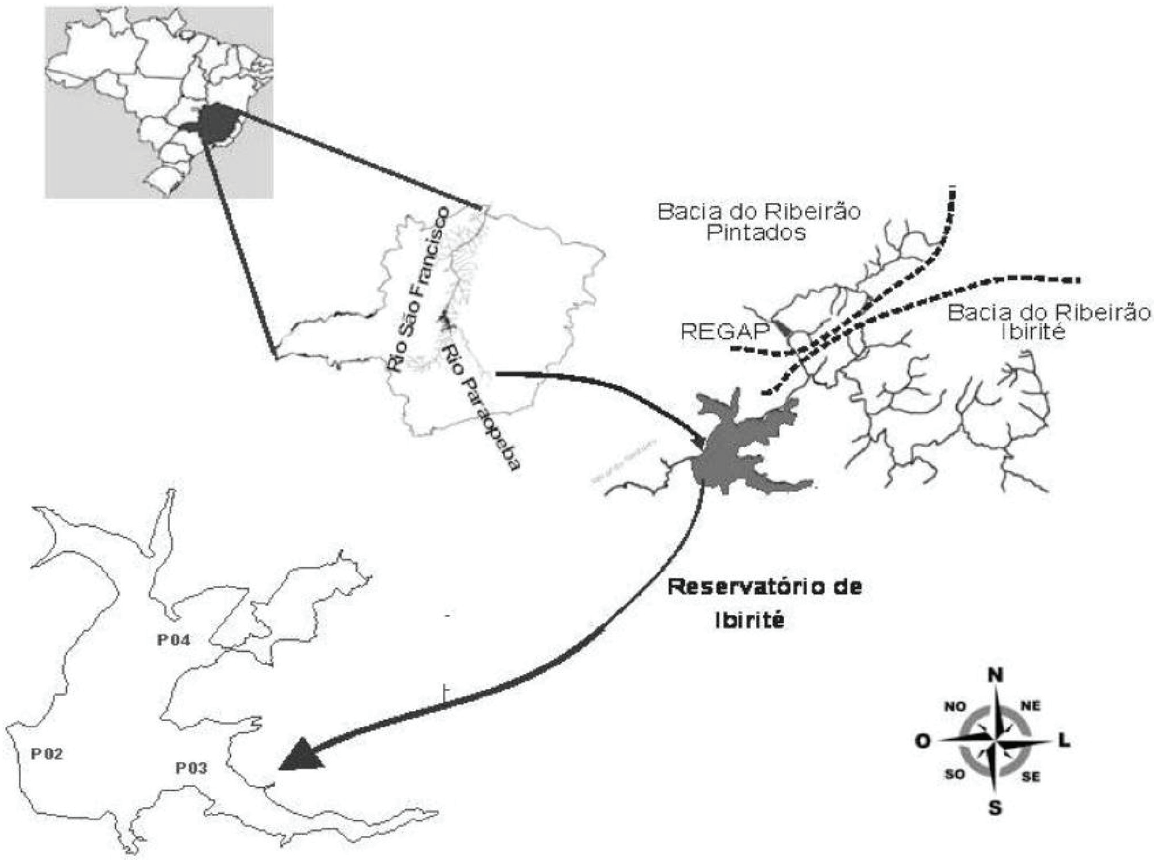

Figure 1. Localization of the Ibirité reservoir, Ibirité river and Pintados creek. Highlighted in the larger image are the sampling sites within the reservoir.
Figura 1. *Localização do Reservatório de Ibirité, e do rio Ibirité e ribeirão Pintados. Em destaque a localização dos pontos de amostragem no reservatório.*

The regional climate type is tropical sub-humid, with wet summer and dry winter. The reservoir, which is classified as hot monomitic, and circulates during the winter months (June-August) (Garcia *et al.* 2009), has an area of 2.05km^2, a total volume of 11.6 x10^6 m^3, and average and maximum depth of 5.6 and 17.67m, respectively (Pinto-Coelho 2010).

SAMPLING CHARACTERIZATION AND PERIODICITY

Three sampling points were defined: P02 (20^{o}01'24.8''S; 44^{o}07'06.1''W) near the dam, P03 (20^{o}03'02.7''S; 44^{o}06'32.2''W) near the Employees of Petrobras' Country Club (CEPE) and P04 (20^{o}01'34.6''S; 44^{o}06'24.5''W) near the mouth (lotic zone) of the Ibirité river, the reservoir's main tributary. Sampling was performed at two-month intervals from October 2007 to October 2008.

ABIOTIC VARIABLES AND CLOROPHYL-A

Precipitation data were obtained through the National Water Agency (ANA) information system, generated at the weather station (code 2044012), located in the Ibirité municipality (Minas Gerais state), at coordinates 20º02'34''S e 44º02'35,9''W. The variation of the reservoir level (FNR) was determined by the altitude data, the temperature data and dissolved oxygen were obtained with the aid of a multi-analyzer probe (HORIBA U-22) and water transparency through the depth of visual disappearance of the Secchi disc. Water samples were collected at depths determined by Secchi disk reading

(100%, 10%, 1% of light incident on the surface and aphotic zone) to determine concentrations of chlorophyll-*a* according to Lorenzen (1967).

SAMPLING AND LABORATORY ANALYSIS OF ZOOPLANKTON

Zooplankton samples were collected at depths determined by Secchi disk reading by filtering 100 liters of water in a plankton net (68µm). For the quantitative analysis, subsamples were taken and counted in a Sedgwick-Rafter chamber under a light microscope. The results were expressed in organisms per liter (org L^{-1}). Microzooplankton (< 200µm) and mesozooplankton (> 200µm) fractions were analyzed separately.

DATA ANALYSIS

For the variables collected throughout the water column (zooplankton density, chlorophyll-*a* and temperature), the mean of water column depths samples were used. Data on changes in the level of the reservoir (FNR) were treated through the monthly average of the differences between altitudes. The relative stability of the water column (RWCS) was calculated according to Padisák *et al.* (2003), and the water densities calculated from temperature values, with the use of the Water Density Calculator software, available at http://antoine.frostburg.edu/chem/senese/javascript/water-density.html.

In order to reduce data size and explore the dynamics of zooplankton during the study period, we utilized ordination exploratory analysis (DCA and CCA), by using the software PC-Ord 4.0 (McCune & Meffort 1999) with data log transformed (log x+1). Data distribution was evaluated by the Shapiro-Wilk normality test. Differences between scenarios for the abiotic and biotic variables were assessed using one-way analysis of variance ANOVA (Zar 1999) for variables with normal distribution, and Kruskal-Wallis test for the variables with non-parametric distribution, followed by Tukey (the sequential ANOVA) and Dunn tests (the sequential Kruskall Wallis) (Zar 1999). The correlations (Pearson, for normally distributed variables and Spearman for variables with non-parametric distribution) between the abiotic and biotic variables were verified using the Statistica 7.0 software (Statsoft Inc. 2005). For determining the characteristic species of the different scenarios of the reservoir along the hydrological cycle, the Indicator Species Analysis was used (Dufrêne & Legendre 1997) with the help of the software PC-Ord 4.0.

RESULTS

ABIOTIC VARIABLES

The rainfall volume recorded during the study period ranged from 429.3 mm (January 2008) to 0 mm (May and July/2008). In December 2007 (0.08 m), February (0.006 m), June (0.07 m) and July (0.09 m) 2008, the reservoir remained on or near its maximum elevation (797.5 m). During the other months it displayed irregular variations (Figure 2).

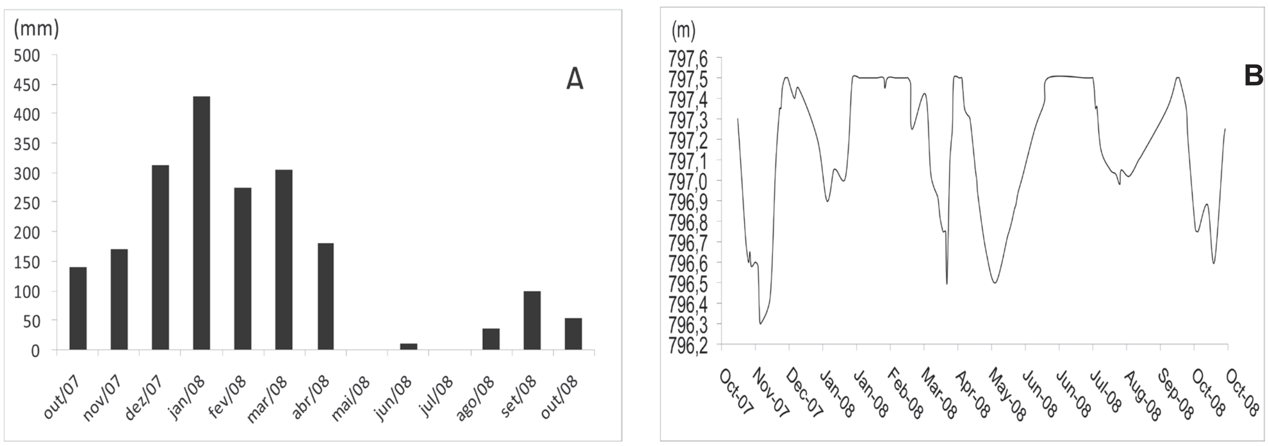

Figure 2. Variation of rainfall (mm) in the Ibirité reservoir basin (A); Variation of the Ibirité reservoir level from October 2007 to October 2008. Records from altitude data (m) (B).

Figura 2. *Variação da pluviosidade (mm) na região da bacia do reservatório de Ibirité (A); Variação do nível do reservatório de Ibirité durante o período de outubro de 2007 a outubro de 2008. Dados das cotas altimétricas (m) (B).*

The reservoir has remained thermally stratified during most of the sampling period, with average temperatures ranging from 22 to 28°C. The instability of the water column was greater in June 2008 in the three sampling sites, during which the reservoir was in the mixing process. The average concentration values for chlorophyll-*a* varied from 456.2µg.L^{-1} (P04) to 39.8µg.L^{-1} (P02), and for surface dissolved oxygen from 5.0 to 20.0mg.L^{-1} (Figure 3).

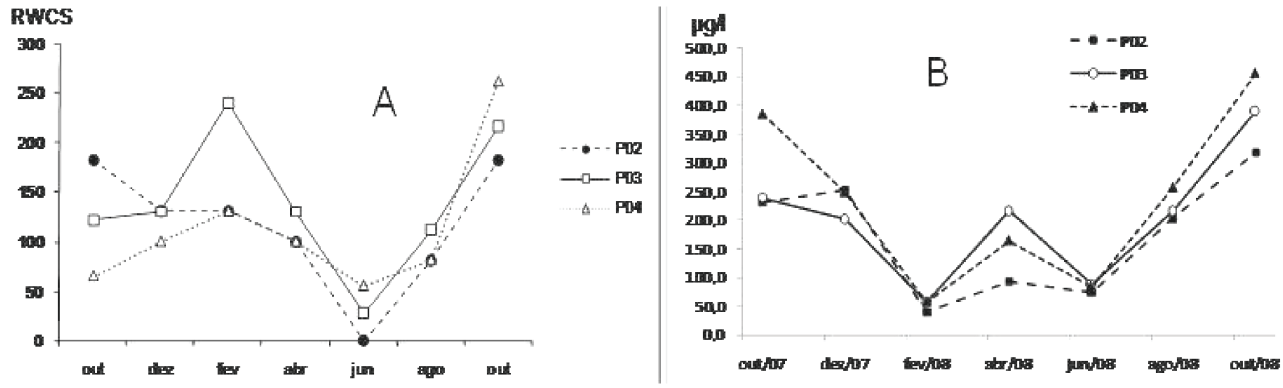

Figure 3. Variation of relative water column stability (RWCS) (A); and variation of the average values of chlorophyll-a (µg.L^{-1}) (B), in the sampling stations (P02, P03 and P04) during the period October 2007 to October 2008.
Figura 3. *Variação dos valores de estabilidade da coluna d'água (RWCS) (A); e variação dos valores médios da concentração de clorofila-a (µg.L^{-1}) (B), nas estações amostrais (P02, P03 e P04) durante o período de outubro de 2007 a outubro de 2008.*

The hypolimnion remained close to anoxia during the months of stratification, with variations from 2.3 to 0.8mg.L-1during mixing of the water column. During this period, the highest values of water transparency (0.9 and 1 meter) were also recorded (Figure 4).

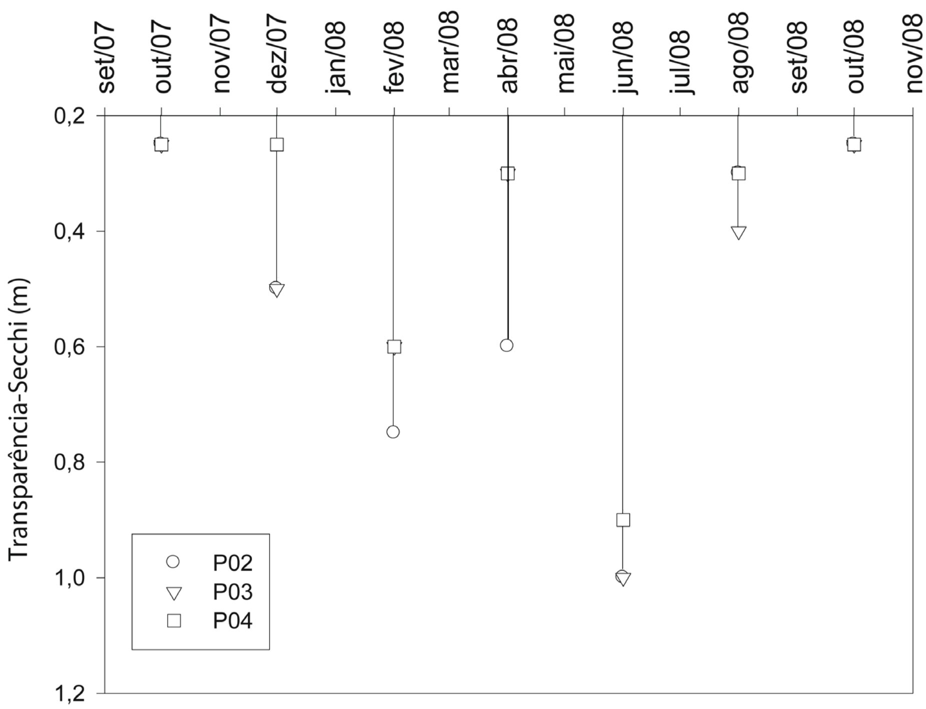

Figure 4. Water transparency (Secchi disk reading) in the three sampling stations (P02, P03 e P04) during the study period.
Figura 4. *Transparência da água (leitura do disco de Secchi) nas três estações amostrais (P02, P03 e P04) ao longo do período estudado.*

ZOOPLANKTON COMMUNITY STRUCTURE

Species richness and composition

A total of 75 species was identified in the Ibirité reservoir. Rotifers were the most representative group on richness (55 taxa), followed by Cladocera (11 taxa), and copepods (9 taxa). Among rotifers, the family Brachionidae presented the highest number of taxa (20 species), followed by Lecanidae (9). Among Cladocera, Daphniidae was the most representative family with five species. The family Cyclopoidae (Copepoda) presented seven species.

Total zooplankton densities ranged from 5982.4org.L^{-1} (P03 Aug/08) to 499.2org.L^{-1} (P02 April/08), with the highest values being recorded during mixing of the water column. The highest values of species richness were also recorded during the mixing of the water column (Jun and Aug) and lowest in the months of highest rainfall (Dec, Feb and Apr) (Figure 5).

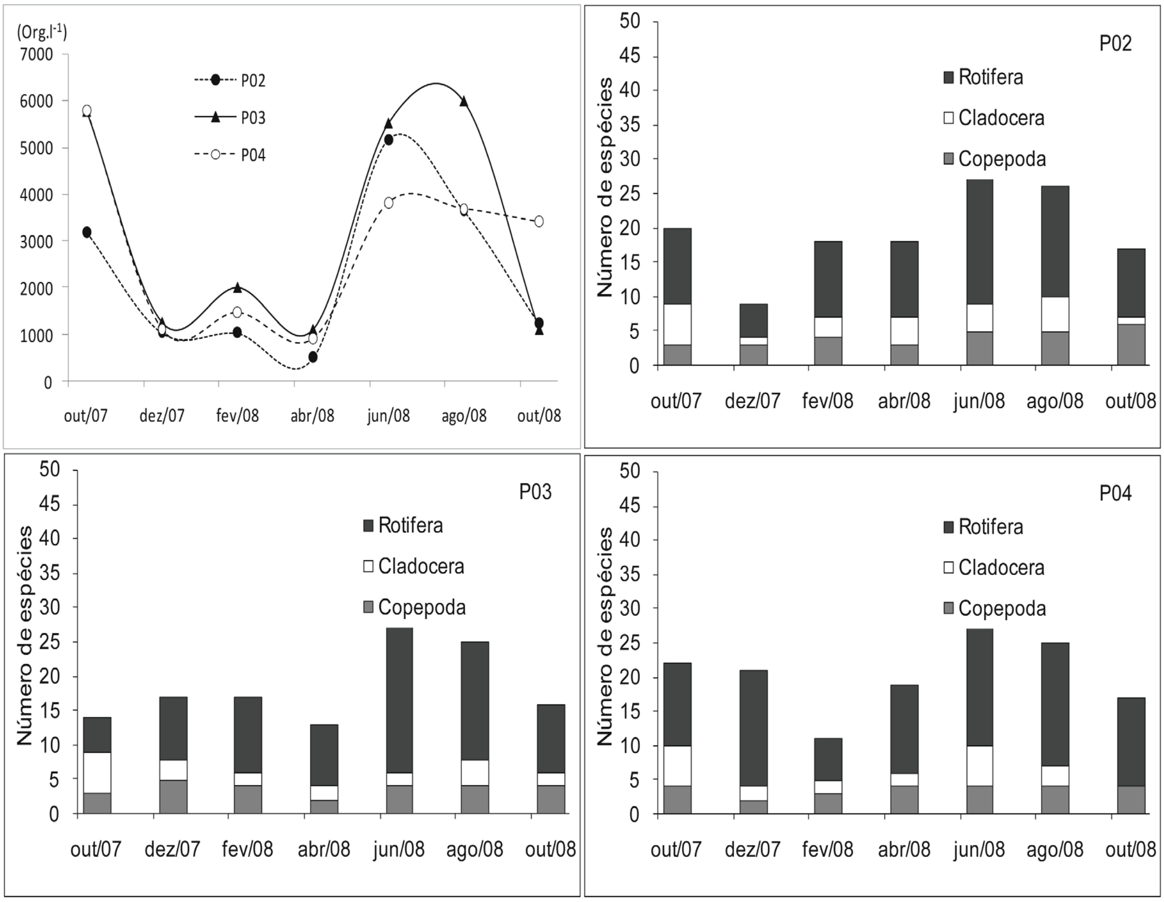

Figure 5. Variation of total zooplankton community density of the Ibirité reservoir, in the three sampling points (P02, P03 and P04). Temporal variation (Oct/07 to Oct/08) of species richness of the three major groups of zooplankton in the three sampling stations of the Ibirité reservoir, over the study period.

Figura 5. *Variação da densidade total da comunidade zooplanctônica do reservatório de Ibirité, nos três pontos amostrais (P02, P03 e P04). Variação temporal (out/07 a out/08) da riqueza em espécies dos três principais grupos da comunidade zooplanctônica, nas três estações amostrais do reservatório de Ibirité, ao longo do período estudado.*

In general, microzooplankton (rotifers and nauplii) had higher densities during mixing period (nauplii – P04 506.7org.L^{-1}; and rotifers – P03 Jun/08 854.1org.L^{-1}). For rotifers, high densities were also recorded during the months of intense cyanobacterial blooms (P04 Oct/07 881.6org.L^{-1}), due to the *Brachionius calyciflorus* species dominance. The lowest densities were recorded in the period of highest rainfall for nauplii (P02 Apr/08 85.2org.L^{-1}) and rotifers (P02 Apr/08 0.85 org.L^{-1}). A dominance shift was observed among the species of rotifers at each sampling station and month, alternating as the dominant, indicating a low persistence of the species from this group (Figure 6).

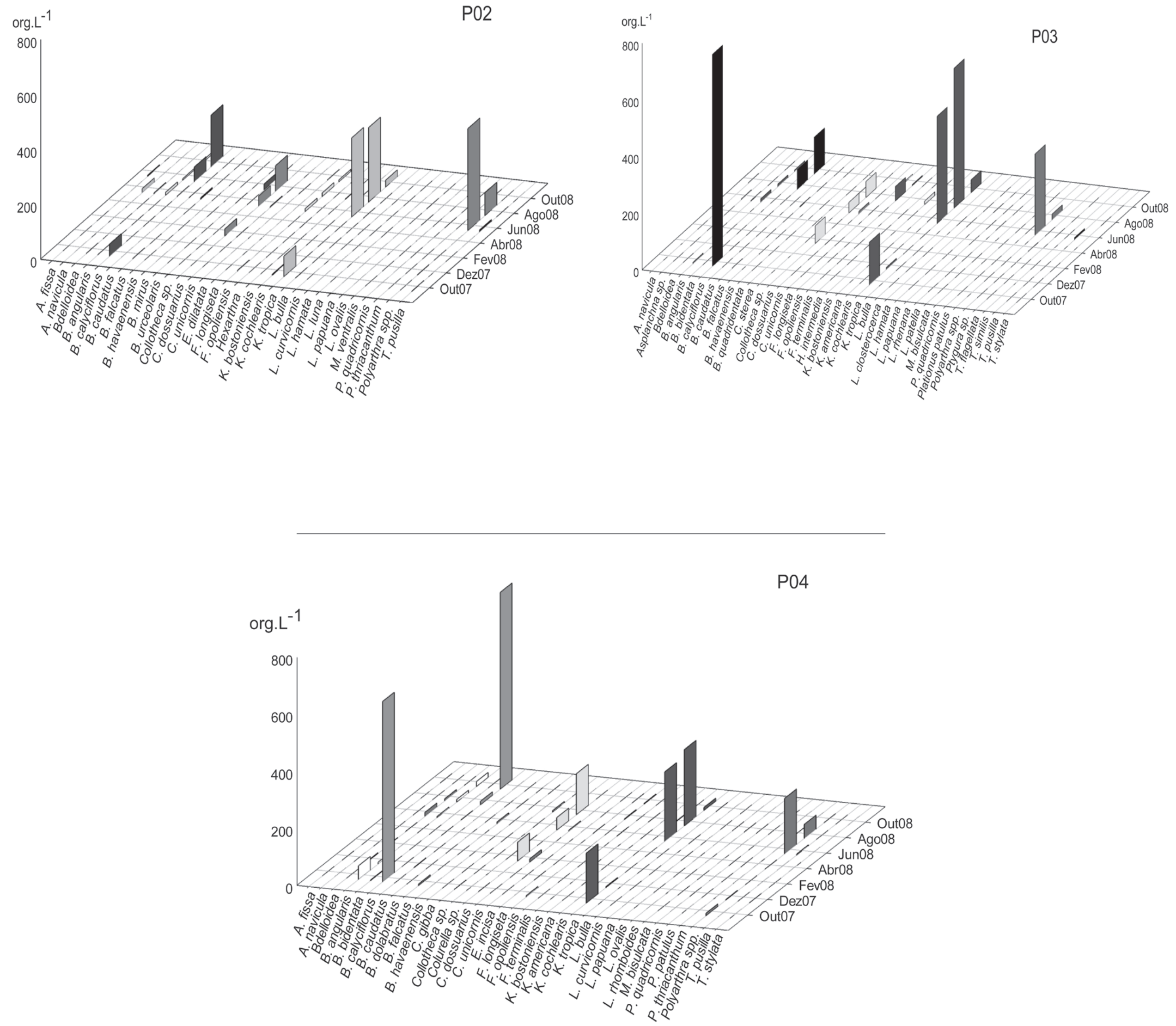

Figure 6. Densities (org.L^{-1}) of rotifer species in the three sampling stations (P02, P03 and P04) of the Ibirité reservoir over the studied period.
Figure 6*. Densidades (org.L^{-1}) das espécies de rotíferos nas três estações amostrais (P02, P03 e P04) do reservatório de Ibirité, ao longo do período estudado.*

Within the mesozooplankton fraction (> 200µm), Calanoida copepods (copepodites and adults), which were represented in the reservoir Ibirité solely by the species *Notodiaptomus cearensis*, displayed high densities only during October 2007 (P02 -75.5org.L^{-1}; P03 -179org.L^{-1}; and P04 -88org.L^{-1}). During the rest of the sampling period, this group remained at low densities ranging from 28org.L^{-1} in April/08 (P03); to 1.5org.L^{-1} in February/08 (P04). Cyclopoid copepods (copepodites and adults) had higher densities, ranging from 227 to 88org.L^{-1} in P03. The lowest numerical records occurred in April and October 2008, having the density varied between 23org.L^{-1} (P04 Oct/08) and 2org.l^{-1} (P02 Apr/08). Cladocerans displayed densities ranging from 225org.L^{-1} (P02 Oct/07) to 11org.L^{-1} (P04 Dec07), not having been recorded in some periods (Oct/08) in the P02 and P03 sampling points (Figure 7).

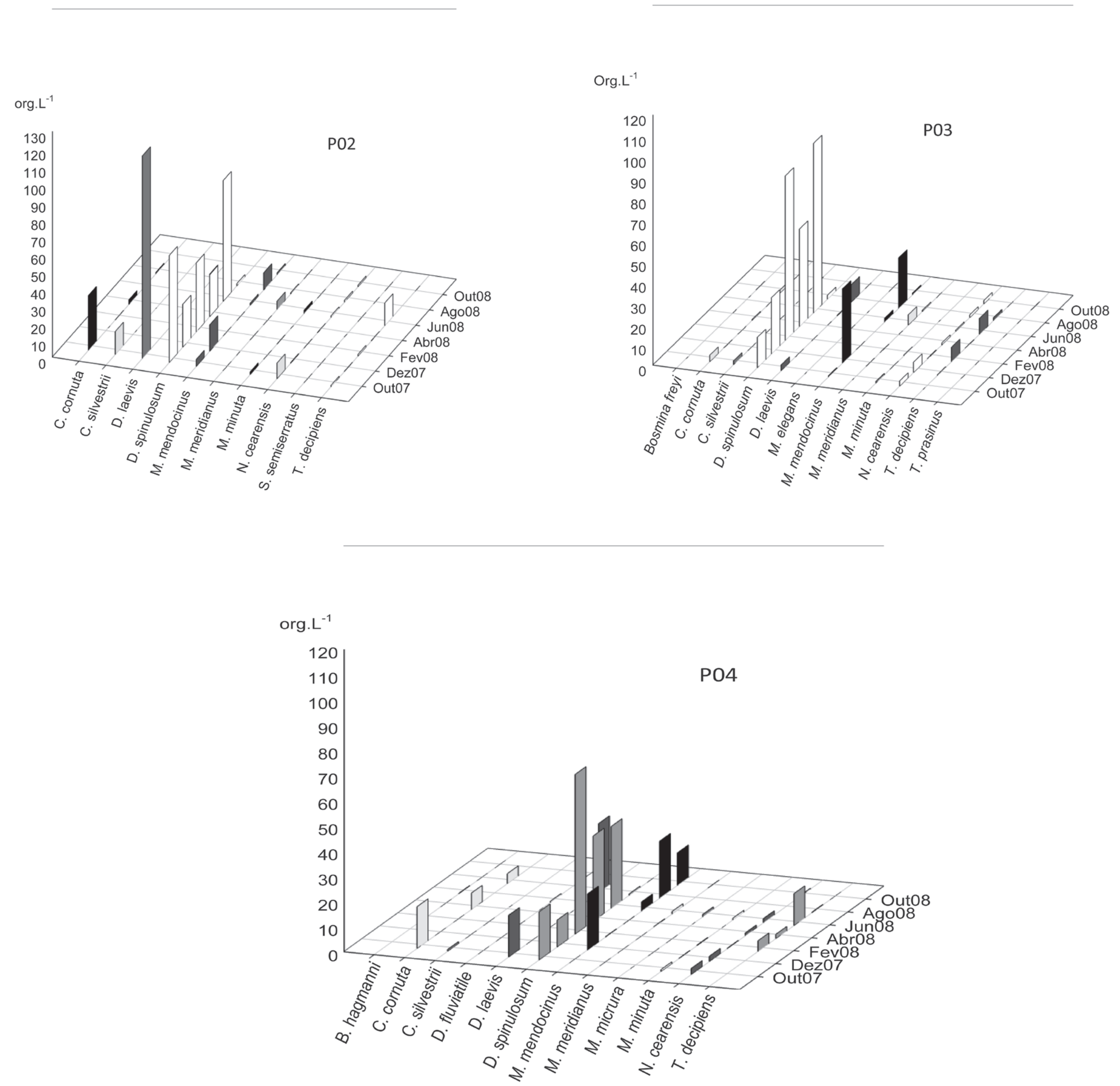

Figure 7. Microcrustacean species densities (org.L^{-1}) in three sampling points (P02, P03 and P04) of the Ibirité reservoir over the studied period.
Figura 7. *Densidades (org.L^{-1}) das espécies de microcrustáceos nos três pontos amostrais (P02, P03 e P04) do reservatório de Ibirité, ao longo do período estudado.*

Zooplankton Dynamics

Detrended Correspondence Analysis (DCA) revealed the occurrence of a temporal gradient along the studied hydrological cycle (Figure 8). The first two axes of the DCA applied to the array of biotic data [zooplankton species density (org.L^{-1})] have explained 64% of the total data variability (axis 1 = 51% and axis 2 = 13%).

The relationship between the biological variables (species density) and environmental factors [rainfall, fluctuation of reservoir level (FNR), temperature, relative stability of the water column (RWCS), chlorophyll-*a*, and water transparency (Secchi)] was detected through a canonical correspondence analysis (CCA). The first two CCA axes were significant according to a Monte Carlo test (p = 0.0010), explaining 62% of the total data variability (axis 1 = 43% and axis 2 = 19%) (Figure 9). Among the abiotic variables selected for analysis, FNR (0.880), Chl-*a* (0.823), Secchi (-0.758) and temperature (0.643) have shown the most robust correlations, thus being the most important in explaining axis 1. On axis 2, rainfall (-0.853), temperature (-0.536) and -0.535) were the most significant.

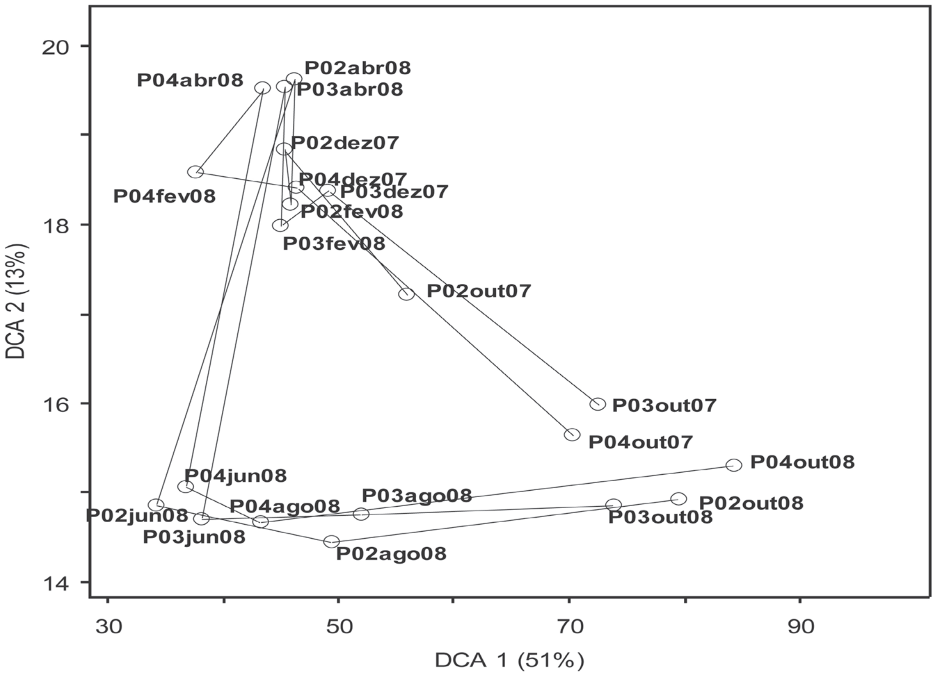

Figure 8. Score ordination of sampling units (points and month/year), according to species densities (org.L-1), which shows the temporal variation along the hydrological cycle studied (October 2007 to October 2008).

Figura 8. *Ordenação dos escores das unidades amostrais (pontos e meses/ano), de acordo com as densidades das espécies (org.L-1), evidenciando a variação temporal ao longo do ciclo hidrológico estudado (outubro 2007 a outubro de 2008).*

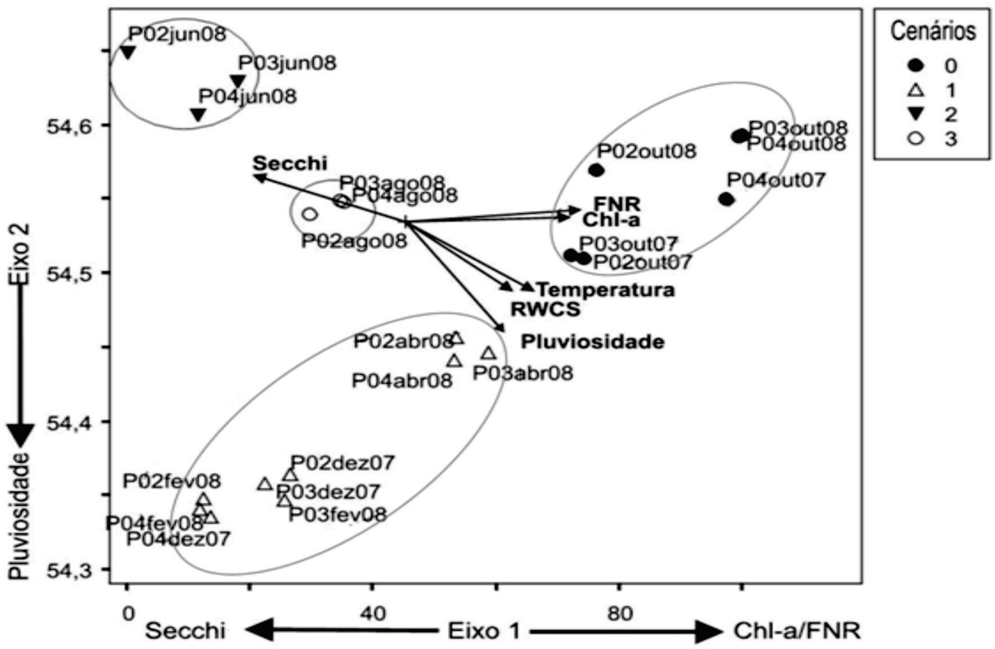

Figure 9. Score distribution of sampling units (points and month/year) resulting from canonical correlation analysis (CCA) between the densities of zooplankton species and abiotic variables [rainfall, fluctuation of reservoir level (FNR), temperature, relative stability of the column water (RWCS), chlorophyll-a and water transparency (Secchi)]. Clustering of sample units determined the four scenarios over the hydrological cycle studied, specified in the legend. Axes display the variables with greatest explanatory power of data distribution.

Figura 9. *Distribuição dos escores das unidades amostrais (pontos e meses/ano) resultante da análise de correlação canônica (CCA) entre as densidades das espécies zooplanctônicas e variáveis abióticas [pluviosidade, flutuação do nível do reservatório (FNR), temperatura, estabilidade relativa da coluna de água (RWCS), clorofila-a e transparência da água (Secchi)]. O agrupamento das unidades amostrais determinou os quatro cenários ao longo do ciclo hidrológico estudado, especificado em legenda. Eixos expondo as variáveis com maior poder de explicação na distribuição dos dados.*

Therefore, as evidenced on DCA, results obtained from CCA indicate the occurrence of a temporal gradient, becoming possible to determine four distinct scenarios throughout the hydrological cycle studied: a) Scenario 0, which comprises the months of October 2007 and 2008, related with the onset of the rains, and the apex of the algal blooming. During this period the reservoir was thermally stratified, and the water column stable, with an intense algal bloom, as evidenced by high concentrations of chlorophyll-*a*, and low water transparency (Secchi). The greatest variations in water level were recorded during this period, reflecting a probable need for bloom control through operational management of the reservoir's dam; b) Scenario 1 comprises the months of December/07, February and April 2008. During this period the highest rainfall levels were recorded and, as a consequence, there was an algal blooming dilution. The apex of this dilution occurred in February 2008, when the lowest Chl-*a* concentrations were recorded; c) In scenario 2 (June 2008), the reservoir was in the process of mixing, with low relative stability of the water column. During this period, no algal blooming occurred, and low temperatures and the lowest rainfall levels were recorded; d) Scenario 3 (August 2008) comprises the transition between the dry (Scenario 2) and rainy seasons (Scenarios 0 and 1). During this period the reservoir was partially stratified, displaying the beginning of the algal bloom.

Significant differences ($p < 0,05$) between the scenarios were verified for all the abiotic variables used in the ordination analysis (CCA) (Kruskal-Wallis) (Table 1). The applied Dunn test found that the temperature showed significant differences ($p < 0.05$) between scenarios 1 and 3 ($p = 0.03$). For RWCS significant differences occurred between scenarios 0 and 2 ($p = 0.01$). Scenarios 0 and 1, and 0 and 2 showed significant differences in the clorophyll-*a* concentration values, [0 and 1 ($p = 0.024$), and 0 and 2 ($p = 0.026$)], water transparency (Secchi) [0 and 1 ($p = 0.039$), and 0 and 2 ($p = 0.001$)] and reservoir level variation (FNR) [0 and 1 ($p = 0.002$) and 0 and 2 ($p = 0.012$)]. Rainfall amounts were different between scenarios 1 and 2 ($p = 0.001$), and 1 and 3 ($p = 0.02$).

Table 1. Results of Kruskal-Wallis test (KW-H and p) for temperature (°C), relative stability of the water column (RWCS), clorophyll-*a* ($\mu m.L^{-1}$) (Chl-*a*), Secchi (m), variation of the reservoir's water level (m) (FNR) and rainfall (mm), between scenarios. Significant differences ($p < 0,05$) in bold.

Tabela 1. *Resultados de Kruskal-Wallis (KW-H e p) para temperatura(°C), RWCS, clorofila-a ($\mu m.L^{-1}$) e Secchi (m), FNR (m) e pluviosidade (mm), entre os cenários. Diferenças significativas ($p < 0,05$) em negrito.*

Variables	KW-H	p
Temperature	12,4	**0,006**
RWCS	10,88	**0,012**
Chl-*a*	11,55	**0,0091**
Secchi	15,54	**0,0014**
FNR	16,3	**0,001**
Rainfall	18,2	**0,0004**

Species richness values showed very significant variations between scenarios (ANOVA $p = 0.00002$), and the Tukey Unequal test, applied sequentially, has determined significant differences between scenarios 0 and 2 ($p = 0.001$); 1 and 2 ($p = 0.0005$); 1 and 3 ($p = 0.015$). For the microzooplankton ($< 200\mu m$) (naupliis of Copepoda and Rotifera), differences between scenarios were also significant (variance analysis; $p < 0.05$). Therefore, Cyclopoida nauplii have shown significant differences between scenarios 1 and 2 ($p = 0.05$), and Calanoida nauplii between scenarios 0 and 1 ($p = 0.05$). For Rotifera, significant variations were found between scenarios 0 and 1 ($p = 0.0003$), 1 and 2 ($p = 0.0011$), and 1 and 3 ($p = 0.0017$). The mesozooplancton fraction ($> 200\mu m$), which comprises young and adult microcrustacea (copepods and cladocera), did not show significant variations between scenarios throughout the hydrological cycle (Table 2).

Table 2. Results of analysis of variance (one-way ANOVA or Kruskall-Wallis) for richness, Calanoida and Cyclopoida nauplii, Rotifera, copepodites and Calanoida and Cyclopoida adults, total Calanoida, Cyclopoida and Cladocera, between scenarios over the hydrological cycle studied in the Ibirité reservoir. Significant differences ($p < 0.05$) in bold.

Tabela 2. *Resultados das análises de variância (ANOVA one-way ou Kruskall-Wallis) para riqueza, náuplios de Calanoida e Cyclopoida, Rotifera, copepoditos e adultos de Calanoida e Cyclopoida, total de Calanoida e Cyclopoida e Cladocera, entre os cenários ao longo do ciclo hidrológico estudado no reservatório de Ibirité. Diferenças significativas (p < 0,05) em negrito.*

Variables	Analysis	F or H	p
Richness	ANOVA	17,2	**0,00002**
Calanoida nauplii	ANOVA	3,43	**0,04**
Cyclopoida nauplii	KW	11,3	**0,01**
Rotifera	ANOVA	21,7	**0,000005**
Copepodites and Calanoida adults	KW	4,42	0,21
Copepodite and Cyclopoida adults	ANOVA	2,62	0,08
Cladocera	KW	4	0,25

Relationships between the abiotic variables used in the canonical correspondence analysis (CCA) and the biotic variables, tested through Spearman's correlation, are shown in Table 3.

Table 3. Spearman's correlation between the abiotic and biotic variables. Significant correlations in bold ($p < 0.05$). Chl-a = clorophyll-a; RWCS = relative stability of the water column; FNR = reservoir's water level variation

Tabela 3. *Correlação de Spearman entre as variáveis abióticas e bióticas. Correlações significativas em negrito (p < 0,05).*

	Chl-*a*	Temperature	Secchi	RWCS	FNR	Precipitation
Richness	r = -0,1850	**r = -0,6925**	**r = 0,4505**	**r = -0,6457**	r = -0,1017	**r = -0,7933**
	p = 0,422	**p = 0,001**	**p = 0,040**	**p = 0,002**	p = 0,661	**p = 0,00001**
Rotifera	r = 0,1640	**r = -0,4659**	r = 0,0730	r = -0,2806	r = 0,3671	r = **-0,6960**
	p = 0,477	**p = 0,033**	p = 0,753	p = 0,218	p = 0,102	**p = 0,00001**
Calanoida nauplii	r = 0,0697	r = -0,0040	r = 0,0459	r = 0,0728	r = 0,3630	r = -0,3342
	p = 0,764	p = 0,986	p = 0,843	p = 0,754	p = 0,106	p = 0,139
Cyclopoida nauplii	r = -0,4008	**r = -0,4534**	r = 0,3714	**r = -0,4358**	r = -0,2042	r = -0,0833
	p = 0,072	**p = 0,039**	p = 0,097	**p = 0,048**	p = 0,375	p = 0,720
Cladocera	**r = -0,5527**	r = -0,1385	r = 0,4120	r = -0,3433	r = -0,3892	r = 0,1117
	p = 0,009	p = 0,550	p = 0,063	p = 0,128	p = 0,081	p = 0,630
Copepodites and Calanoida adults	r = 0,3796	r = 0,0932	r = -0,4288	r = 0,1934	**r = 0,5820**	r = 0,1961
	p = 0,090	p = 0,688	p = 0,052	p = 0,401	**p = 0,006**	p = 0,394
Copepodites and Cyclopoida adults	r = 0,1133	**r = -0,6059**	r = 0,0329	r = -0,2030	r = 0,0542	r = -0,2391
	p = 0,625	**p = 0,004**	p = 0,887	p = 0,377	p = 0,815	p = 0,296

Of the 71 taxa (with numbered records) used in the Indicator Species Analysis (ISA), 15 were considered significant ($p < 0.05$), according to the Monte Carlo test. The analysis has found that scenario 2 had the highest number of species (eight) associated to that period, being one cladoceran, two copepods and five rotifers.

Table 4. Significant species ($p < 0.05$), resulting from indicator species analysis using the scenarios determined by multivariate analysis. Indicator value (IV) ranging from 100 (excellent indicator) to 0 (not an indicator).

Tabela 4. *Espécies significantes (p < 0,05), resultado da análise de espécies indicadoras utilizando os cenários determinados através de análises multivariadas. Valor de indicação (VI) variando de 100 (Excelente indicador) a zero (não indicador).*

Species	Scenario	IV	p	Taxonomic group
Brachionus calyciflorus	0	89.6	0.0030	Rotifera
Diaphanosoma spinulosum	2	52.2	0.0080	Cladocera
Mesocyclops meridianus	2	87.3	0.0140	Copepoda
Thermocyclops decipiens	2	82.4	0.0010	Copepoda
Anuraeopsis navícula	2	57.7	0.0490	Rotifera
Brachionus falcatus	2	71.0	0.0150	Rotifera
Conochilus unicornis	2	78.4	0.0110	Rotifera
Polyarthra sp.	2	84.2	0.0100	Rotifera
Trichocerca pussila	2	92.5	0.0010	Rotifera
Metacyclops mendocinus	3	57.9	0.0500	Copepoda
Collotheca sp.	3	96.8	0.0010	Rotifera
Conochilus dossuarius	3	63.2	0.0080	Rotifera
Filinia opoliensis	3	75.0	0.0310	Rotifera
Kellicottia bostoniensis	3	100.0	0.0010	Rotifera
Lecane papuana	3	64.5	0.0120	Rotifera

DISCUSSION

Variations in the environment can promote cyclical or erratic changes in the activities of organisms, short and long fluctuations in the populations' abundance, or species replacements (Panarelli *et al.* 2001). The hypothesis of a temporal gradient along the hydrological cycle, with periods of different environmental conditions influencing the zooplanktonic community structure was confirmed. In this temporal gradient, it was possible to determine four scenarios with different environmental conditions that influenced the zooplankton community structure (Figure 10).

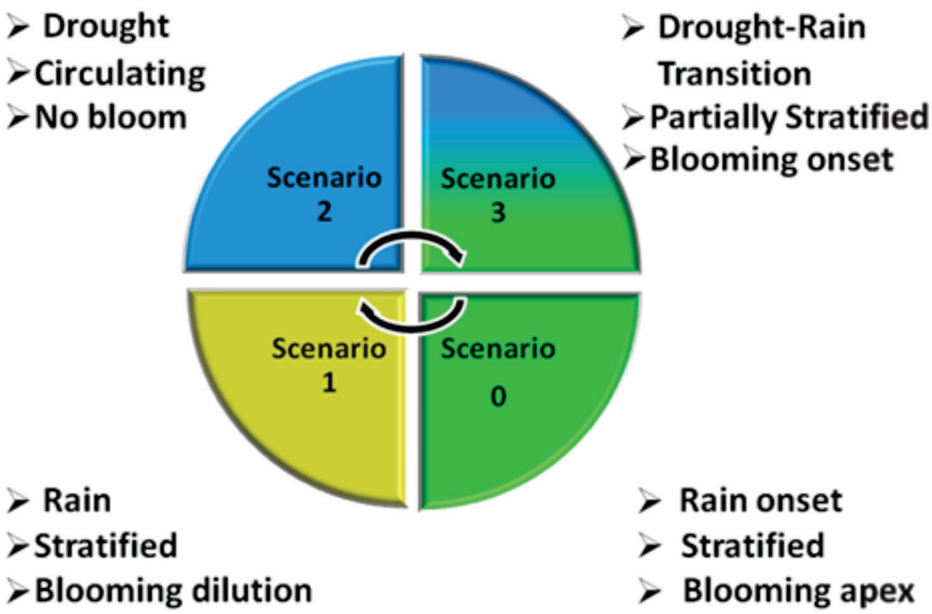

Figure 10. Outline of four scenarios along the hydrological cycle studied (Oct/07 to Oct/08) in Ibirité reservoir.
Figura 10. *Esquema dos quatro cenários ao longo do ciclo hidrológico estudado (out/07 a out/08) no reservatório de Ibirité.*

Environmental factors, such as climatological pulses (ex. rainfall and temperature), stability of the water column (seasonal pulses), variations in the reservoir level (artificial pulses) and algal bloom events were decisive for the constitution of the scenarios along the studied hydrological cycle. Levels of phytoplankton biomass in reservoirs are dependent on interrelated factors of physical, chemical and biological nature, such as: climatic and hydrological regimes functions, size, nature and morphology of the drainage basin, nature and volume of the tributaries, and food chain structure of the reservoir (Thornton *et al.* 1990).

Algal blooms that occurred were mainly composed of cyanobacteria (Brandes *et al.* unpublished data). Cyanobacterial blooms are related to eutrophic conditions (high loads of nutrients, particularly phosphorus), and have been favored by factors such as: stability of the water column, high temperature, longer retention, alkaline conditions, low luminosity (Reynolds 1998, Naselli-Flores & Barone 2003, Padisak *et. al.* 2003) and moderate rainfall levels (An & Jones 2000).

Because of the fact that the Ibirité reservoir is situated in a tropical climate region (hot/humid summer, and cold/dry winter), and present a warm monomitic mixing pattern, algal bloom persistence was directly affected by higher volumes of rain during the Summer months, and by the instability of the water column during the winter months, with temperature (>22ºC) and nutrients (eutrophic conditions) not being a limiting factor to cyanobacteria in this environment. In eutrophic environments with the recurrence of cyanobacterial blooms, zooplanktonic structure tends to be composed mainly of small size organisms (Saunders & Lewis 1988, Matsumura-Tundisi & Tundisi 2005), being efficient consumers of detritus and bacteria (Pejler 1983, Pace 1986), and cyanobacteria, despite its low nutritional value (Work & Havens 2003).

According to Matsumura-Tundisi (1999), reservoirs are unstable environments, which favor the establishment of *r*-strategist species, such as rotifers, opportunistic organisms able to quickly colonize environments. Such a capacity helps to explain why this group is the most representative regarding species richness. The high species richness of rotifers in Brazilian reservoirs was found in several studies (Sendacz 1997, Lansac-Tôha *et al.* 1999**,** Nogueira 2001**,** Lansac-Tôha *et al.* 2005).

Among the scenarios identified during the hydrological cycle studied, scenario 0 (October 2007 and October 2008) was the moment with the best conditions for cyanobacterial blooming. The first rains (low intensity) occurred in this period, after the dry season, increasing the allochthonous nutrients contribution. Moreover, factors such as high temperatures [between 25 and 27^{o}C, whilst the maximum cyanobacteria growth rate occurs at temperatures >25^{o}C (Chorus & Bartram, 1999)] and, consequently, the greater stability of the water column, favored algal blooms. For Reynolds (1999), *Microcystis* spp. populations are established only after the environment becomes stratified.

In this scenario, the greatest water level fluctuations in the Ibirité reservoir were recorded. Such variations during the sampling period were not as extreme (maximum oscillation of 1.2 m) as to breakdown water column stability. In the Ibirité reservoir, water level fluctuation (FNR) was associated to chloropyll-*a* concentration levels (r = 0.8, p = 0.000009), indicating that probably the algal blooms were controlled through operational management of the dam for the studied period.

The number of species recorded for the total zooplankton had negative, but not significant, correlation with chloropyll-*a* (r= -0.18; p= 0.42). Among the microzooplankton fraction (nauplii and rotifers), Rotifera numerically dominated this period (*Brachionus calyciflorus*), and indicator species analysis has showed that only this species of rotifer is associated to scenario 0, with a high indication value (IV = 89.6) and significance (p= 0.003). According to literature data (Fulton & Pearl 1987**,** Branco & Cavalcanti 1999, Work & Havens 2003), *B. calyciflorus* is a potential consumer of colonial bacteria and cyanobacteria, which may explain the association of this species with the blooming period. According to Azevedo (unpublished data), the cyanobacteria which caused the blooms in the Ibirité reservoir had no toxic strains.

Scenario 1 (December 2007 February and April 2008) was characterized by bloom dilution due to heavy rains that occurred during this period. In spite of favorable factors for cyanobacterial blooms, such as allochthonous input of nutrients, high temperatures and stability of the water column, high rainfall amounts during this period did not allow the persistence of blooming, which was diluted and / or carried by the water in a washout effect. In this scenario, it is likely that the retention time of the reservoir was lower than in other scenarios, due to increased effluent discharge caused by heavy rains. The zooplankton community showed a decline in species richness and abundance, a behavior also recorded in other eutrophic reservoirs (Sendacz *et al*. 2006). The zooplankton species richness showed a strong, negative and significant correlation with rainfall (r= -0.79, p= 0.00001) and temperature (r= -0.7, p= 0.001).

The next stage of the temporal gradient, scenario 2 (June 2008), was characterized by the dry season. In this period, the lowest volumes of precipitation were recorded, with low temperatures and isothermia in the water column, resulting in a process of mixing of the water column in the reservoir. The instability of the water column, coupled with the low temperatures were unfavorable factors for cyanobacteria bloomng, and because of this, there were low concentrations of Chl-*a* during this period. According to Reynolds (1999), the water column circulation (induced or not) produces a reducing effect on the formation of cyanobacterial blooms. In this scenario, the highest water transparency was found, this variable being negatively correlated with chlorophyll-*a* concentration (r= -0.84, p= 0.000001).

In zooplanktonic community, the highest values of species richness and density were found in this scenario, mainly cladocerans and rotifers. The relative instability of the water column in this scenario is a factor that favors Rotifera (Matsumura-Tundisi 1999).Another factor that may have favored the increase of zooplankton was the reduction of predation by vertebrates, due to fish mortality, mostly *Oreochromis niloticus* (Nile tilapia), observed during this period and caused by hypoxia (CETEC 2008). *O. niloticus* is an omnivorous species, potential consumer of phyto and zooplankton, with possible influence on zooplankton population control (Elhigzi *et al.* 1995, Njiru *et al.* 2004).

The indicator species analysis showed that two larger species of cyclopoid copepods, *Mesocyclops meridianus* and *Thermocyclops decipiens*, were associated with this scenario, showing significant indication values (IV= 87.3 and IV= 82.4, respectively). These species of Cyclopoida are raptorial and have omnivorous (*T. decipiens*) and carnivorous (*M. meridianus*) feeding habits (Moriarty *et al.* 1973, Matsumura-Tundisi *et al.* 1990). The increased density of potential prey (cladocerans and rotifers) for these predators may explain the association with this scenario, observed in the analysis (Figure 11).

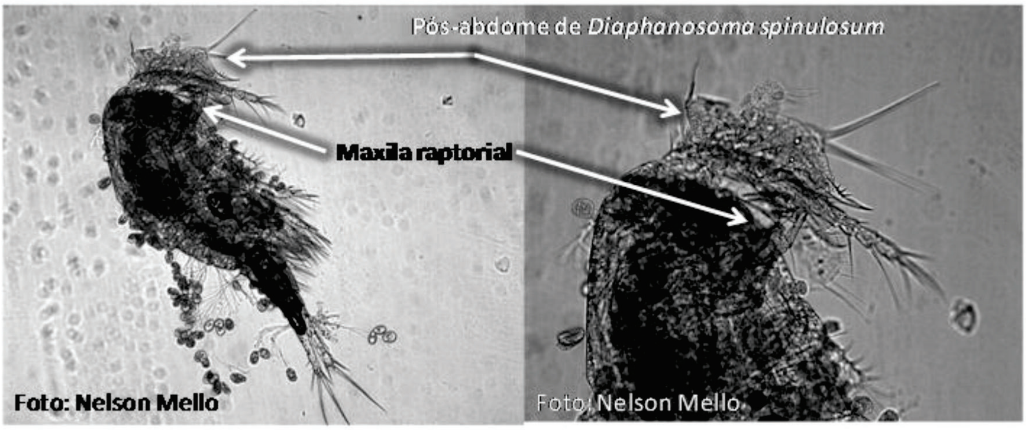

Figure 11. Metacyclops mendocinus preying on juvenile Diaphanosoma spinulosum in a Ibirité reservoir's sample.
Figura 11. *Metacyclops mendocinus predando juvenil de Diaphanosoma spinulosum em amostra do reservatório de Ibirité.*

Scenario 3 (August 2008) represented a transition between the dry-cold season (scenario 2), and the beginning of the warm-rainy season (scenario 0). During this period there was a greater relative stability of the water column, in comparison with the previous scenario. Such conditions have led to the reappearance of cyanobacterial blooms. According to Dokulil & Mayer (1996), cyanobacteria are highly resilient, quickly recovering phytoplankton dominance. As a consequence, greater fluctuations of the reservoir's level and lower water transparency were recorded, in comparison with the previous scenario. A decrease in species richness was observed in this scenario, when compared to the previous period, but not statistically significant ($p > 0.05$).

In this period, the presence of the invasive rotifer *Kellicottia bostoniensis* was recorded for the first time. This species of planktonic rotifer is common in temperate environments, with high adaptability in tropical environments (Bezerra-Neto *et al.* 2004, Peixoto *et al.* 2010). *K. bostoniensis* had the highest indication value (IV = 100, $p = 0.001$) in the indicator species analysis, and is strongly associated with the conditions of this scenario. *Metacyclops mendocinus* was also associated with the conditions of this scenario (IV = 57.9, $p = 0.05$). According to Sendacz & Kubo (1982) and Reid (1985), this species of Cyclopoida is associated with eutrophic conditions, and may occur at times before or after algal blooms.

In conclusion, in the Ibirité reservoir, factors such as rainfall regime and changes in the conditions of water column stability have been shown to be determinant factors in structuring the zooplankton community. The structure of microzooplankton (rotifers and nauplii) were more susceptible to changes of the scenarios that the mesozooplankton (cladocerans and copepodids and adults of copepods).

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