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Original Article

Zooplankton communities and their relationship with water quality in eight reservoirs from the midwestern and southeastern regions of Brazil

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(With 4 figures)

Abstract

Zooplankton are widely recognised as being regulated primarily by predators and food availability. In reservoirs, the quantity and quality of food resources are generally affected by the characteristics of the water, which in turn are controlled by the flow pulse generated by operation of the dams. In this study, we investigated the relationship between zooplankton, water quality and food availability (phytoplankton) in eight hydroelectric reservoirs located in Brazil. Samples were collected during the rainy and dry periods between 2008 and 2009. In general, the reservoirs exhibited mesotrophic conditions and Cyanobacteria were the predominant phytoplankton. The results showed that the rotifers *Kellicottia bostoniensis*, *Hexarthra mira*, *Keratella* spp., and *Polyarthra vulgaris* were present, indicating nutrient-rich environments. In addition, the copepod *Thermocyclops decipiens* occurred in eutrophic environments. In contrast, the cladoceran *Daphnia gessneri* and copepod *Notodiaptomus henseni* were considered indicators of more desirable water quality, owing to their relationship with waters with lower levels of nutrients and suspended solids. The results support the use of these organisms as a useful tool for understanding changes in water quality and in the ecosystem processes involved.

Keywords: Cyanobacteria, nutrients content, plankton communities, trophic state, water quality indicator.

Comunidades de zooplâncton e sua relação com a qualidade da água em oito reservatórios das regiões Centro-Oeste e Sudeste do Brasil

Resumo

O zooplâncton é amplamente reconhecido como sendo regulado principalmente por predadores e pela disponibilidade de alimento. Em reservatórios, a quantidade e a qualidade de recursos alimentares são afetadas pelas características da água que, por sua vez, são controladas pelo pulso de fluxo gerado pela operação das barragens. Neste estudo, investigamos a relação entre o zooplâncton, qualidade d'água e a disponibilidade de alimento (fitoplâncton) em oito reservatórios hidrelétricos localizados no Brasil. Amostras foram coletadas durante os períodos chuvoso e seco, entre os anos de 2008 e 2009. Em geral, os reservatórios exibiram condições mesotróficas e Cyanobacteria foi o fitoplâncton predominante. Os resultados mostraram que os rotíferos *Kellicottia bostoniensis*, *Hexarthra mira*, *Keratella* spp. e *Polyarthra vulgaris* foram indicadores de ambientes ricos em nutrientes. Além disso, o copépode *Thermocyclops decipiens* ocorreu em ambientes eutróficos. Por outro lado, o cladócero *Daphnia gessneri* e o copépode *Notodiaptomus henseni* foram considerados indicadores de melhor qualidade da água, devido a sua relação com águas com baixos níveis de nutrientes e sólidos em suspensão. Os resultados suportam o uso desses organismos como uma ferramenta útil para o entendimento das mudanças na qualidade d'água e nos processos ecossistêmicos envolvidos.

Palavras-chave: Cyanobacteria, teor de nutrientes, comunidades planctônicas, estado trófico, indicador de qualidade da água.

1. Introduction

Reservoirs are now inseparable components of the Brazilian landscape and are present in all the main hydrographic basins as a result of the choice made by the country to generate hydroelectricity (Takahashi et al., 2009; Simões et al., 2015). There has been an increased proliferation of these engineering works, which are important for the national energy matrix (Agostinho et al., 2007). In addition, they are considered of extreme importance for regional socio-economic development due to their multiple uses, including water supply, irrigation, aquaculture, and recreation, which increases the importance of studying these systems (Soares et al., 2008). Dams significantly alters riverside ecosystems because the creating of a reservoir blocks the free flow of the river and creates a semi-lentic or lentic habitat. Thus, important factors such as the quantity and quality of water, habitats, and nutrient transport can change dramatically (Baumgartner et al., 2017; Loken et al., 2018). In addition, artificial variations in the water level can directly and indirectly affect zooplankton communities.

Due to their short life cycle and the sensitivity of some species to environmental changes, zooplankton organisms are considered bioindicators in aquatic ecosystems (De-Carli et al., 2018). Zooplankton play an important role in energy transfer in these ecosystems, as well as in the maintenance and orientation of trophic nets (Eskinazi-Sant'Anna et al., 2013). In addition, due to its position in the food chain with close links with primary producers, changes in the phytoplankton community are quickly reflected in the structure of zooplankton (e.g., in their abundance, body size, and productivity) (Bonecker and Aoyagui, 2005; Serafim-Júnior et al., 2010; Brito et al., 2016).

A recurring problem in Brazilian reservoirs is the eutrophication process, attributed mainly to industrialisation, urbanisation, and the extensive use of the reservoir basins for livestock and agriculture, all of which compromises water quality (Brito et al., 2011). In the long term, eutrophication will cause drastic changes to community structures and aquatic food chains, leading to a loss of biodiversity and reducing the utility of reservoirs as well as their fish stocks (Agostinho et al., 2007). One of the effects associated with eutrophication is the dominance of phytoplankton by Cyanobacteria (Soares et al., 2009; Silva et al., 2014). During flowering events, Cyanobacteria can form large colonies or clusters that may interfere directly with the filtration apparatus of zooplankton (De-Mott et al., 2001). In this way, powerful mechanisms, such as the predominance of Cyanobacteria, can affect the structure of zooplankton communities, making zooplankton key to understanding changes in aquatic ecosystems, especially in understanding how these changes are propagated along the food chain (Silva et al., 2014; Perbiche-Neves et al., 2016).

In this context, we aim to identify the main factors that influence the quantitative structure of the zooplankton community in eight Brazilian hydroelectric reservoirs. Therefore, we aim to answer the following questions: (i) what are the seasonal dynamics of zooplankton in the different reservoirs? (ii) Do the quality and availability of food (phytoplankton) and limnological conditions influence the characterisation of zooplankton in the different reservoirs?

2. Material and Methods

2.1. Study area

This study was conducted at eight hydroelectric reservoirs located in the midwestern and southeastern regions of Brazil: midwestern region, Corumbá (COR) and Itumbiara (ITU); southeastern region, Funil (FUN), Furnas (FUR), Luiz Carlos Barreto de Carvalho (LBC), Marimbondo (MAR), Mascarenhas de Moraes (MSM), and Porto Colômbia (PCO) (Table 1; Figure 1). The COR (17°59′S; 48°31′W) and ITU (18°24′S; 49°05′W) reservoirs lie in the Paraná–Paraguay basin, and began operations in 1997 and 1980, respectively. The MAR (20°18′S; 49°11′W), PCO (20°07′S; 48°34′W), LBC (20°09′S; 47°16′W), MSM (20°16′S; 47°03′W), and FUR (20°39′S; 46°18′W) reservoirs are located along the Grande River, also lie in the Paraná–Paraguay basin, and began operations in 1975, 1973, 1969, 1957, and 1963, respectively. The FUN reservoir (22°35′S; 44°35′W) is located on a river that drains waste from a densely populated and industrialised area in the Paraíba do Sul River basin, and began operation in 1969 (Soares et al., 2008).

Table 1. Characteristics of the eight Brazilian hydroelectric reservoirs.

Reservoirs	Abbreviation	River	Area (km^2)	Volume (km^3)	Z_{max} (m)	Discharge (m^3s^{-1})	WRT (days)
Corumbá	COR	Corumbá	55	1.2	60	475	51.1
Funil	FUN	Paraíba do Sul	27	0.5	45	202	32.9
Furnas	FUR	Grande	1,322	20.2	127	910	405.4
Itumbiara	ITU	Paranaíba	684	15.1	93	1,487	127.8
Luiz Carlos Barreto de Carvalho	LBC	Grande	45	1.3	57	951	1.8
Marimbondo	MAR	Grande	438	6.2	90	1,502	37.2
Mascarenhas de Moraes	MSM	Grande	248	3.7	55	967	51.1
Porto Colômbia	PCO	Grande	143	1.5	35	777	13.9

Abbreviations: Z_{max} = maximum depth, WRT = water residence time.

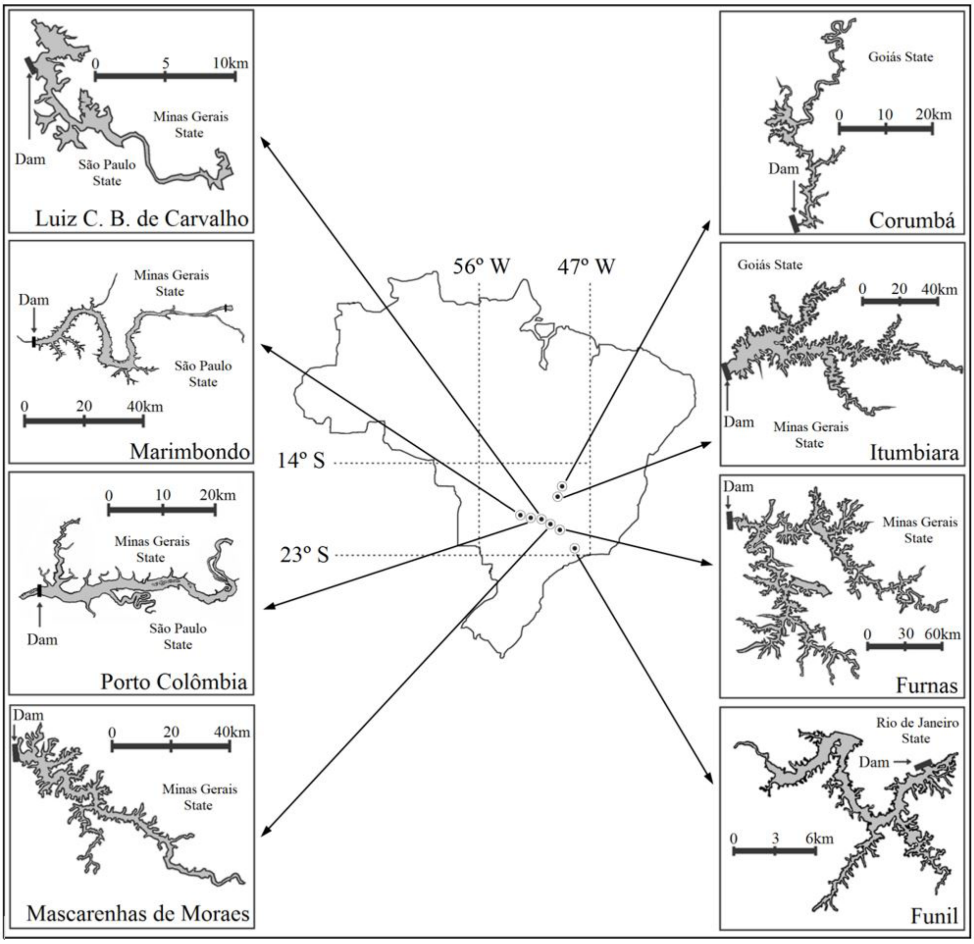

Figure 1. Map of Brazil showing the locations of the eight hydroelectric reservoirs.

2.2. Sampling and data collection

All reservoirs were sampled along the fluvial, transitional, and lacustrine zones for two months for each hydrological period (rainy and dry) between 2008 and 2009. The rainy period (December and February) was the hottest and covered the beginning and end of the rainy season, and the dry period (June and August) corresponded with mild temperatures. The study was repeated twice, spaced two months apart, to reduce the disturbance effects of sampling. Water samples were collected from the subsurface for the analysis of limnological variables: total phosphorus (TP, mg L^{-1}), total nitrogen (TN, mg L^{-1}), total suspended solids (TSS, mg L^{-1}), and chlorophyll *a* (Chl-*a*, µg L^{-1}) concentrations. Water temperature (Temp, °C), dissolved oxygen (O_2, mg L^{-1}), electrical conductivity (Cond, µS cm^{-1}), and pH data were obtained using a multiparameter probe. For phytoplankton, 250 mL of water was sampled from the subsurface with a polypropylene flask, and the material was fixed with Lugol's solution. Quantitative zooplankton samples were collected on the subsurface using a motorised pump to filter 200 L of water per sample, with a conical-cylindrical net (63 µm mesh). The collected material was packed in polyethylene flasks (500 mL), labelled, and fixed in 4% formaldehyde buffered with sodium borate (Na_3BO_3).

2.3 Sample analysis

The preserved water samples were analysed for their Chl-*a*, TP, TN, and TSS concentrations according to Apha (2005). Phytoplankton (Cyanobacteria + algae, cells mL^{-1}) were quantified in random fields using the settling technique (Utermöhl, 1958). The units (cells, colonies, and filaments) were quantified for at least 100 specimens of the most frequent species (Lund et al., 1958) under an inverted microscope at 400× magnification. The zooplankton (individuals m^{-3}) were quantified in a Sedgewick-Rafter counting chamber. Aliquots for counting were removed from the samples with a standardised volume (50 mL) using a Hensen-Stempel pipette (2.5 mL). At least 50 individual rotifers, cladocerans, and juvenile (nauplii and copepodites) and adult copepods were counted (adapted from Bottrell et al., 1976) under a microscope, with a magnification range of 10× to 100×. The species were identified according to Koste (1978), Reid (1985), Matsumura-Tundisi (1986), and Elmoor-Loureiro (1997).

2.4 Data analysis

The Trophic State Index (TSI) was calculated according to Equation 1, 2 and 3 (modified by Lamparelli, 2004), considering the Chl-*a* and TP values (Table 2):

$$TSI(Chl-a)=10\times\{6-[(0.92-0.34)\times(lnChl-a)]\}/ln2 \quad (1)$$

$$TSI(TP)=10\times\left\{6-\left[(1.77-0.42)\times(lnTP)\right]\right\}/ln2 \quad (2)$$

$$TSI=[TSI(Chl-a)+TSI(TP)]/2 \quad (3)$$

A one-way analysis of variance (ANOVA) was used, with a significance level of $p < 0.05$, to investigate the differences in limnological variables, phytoplankton, and zooplankton abundance between periods (rainy and dry). For this analysis, data from the three environments of each reservoir were grouped. Normality and homoscedasticity (homogeneity of variance) were initially verified using the Shapiro–Wilk and Levene tests, respectively. The relationship between the limnological variables, phytoplankton, and zooplankton taxa was explored using canonical correspondence analysis (CCA) for each hydrological period. The statistical significance of the eigenvalues and the species–environment correlations for the axes generated by the CCA were tested by the Monte Carlo method based on 999 permutations (Legendre et al., 2011), with a significance level of $p < 0.05$.

All data (except pH) were log $(x + 1)$ transformed prior to analysis to reduce the influence of outliers. Statistical analyses were performed in R version 3.0.2 (R Development Core Team, 2011) using the Vegan R package version 2.0-6 (Oksanen et al., 2012).

3. Results

3.1. Limnological variables

The concentrations of Chl-*a* (COR and FUN), TSS (FUN and PCO), TN (COR and ITU), and TP (FUN and MAR) presented seasonal differences (ANOVA, $p < 0.05$). In contrast, O_2 and conductivity did not show any temporal differences. The pH values fluctuated markedly (ANOVA, $p < 0.05$) in the waters of the LBC reservoir, which presented increased alkalinity during the rainy season (pH 7.1 to 7.4). Except for in MSM, the temperature showed a clear seasonal fluctuation (ANOVA, $p < 0.05$) in the reservoirs, with the higher values always being recorded in the rainy season. Overall, the temperature in the reservoirs did not exceed 30°C. Finally, the reservoirs were classified as mesotrophic, eutrophic, and supereutrophic according to the TSI. In addition, there were seasonal differences in the trophic condition only in the FUN and MAR reservoirs (Table 3).

3.2. Phytoplankton community

There was no change in the phytoplankton abundance between the rainy and dry periods for all reservoirs (ANOVA, $p > 0.05$) (Figure 2a). Cyanobacteria were the predominant phytoplankton in most of the reservoirs, except for the LBC reservoir, where Bacillariophyceae and Cyanobacteria were equally abundant in the rainy season, and Chlorophyceae, Bacillariophyceae, and other groups were predominant in the dry season. Other groups and Cyanobacteria were predominant in the dry season in the FUR reservoir. Finally, in the PCO reservoir, Bacillariophyceae were the predominant phytoplankton in the dry season (Figure 2b).

3.3. Zooplankton community

We identified a total of 99 species in this study, and rotifers were the richest group (62 species), followed by Cladocera (27 species) and Copepoda (10 species). The most common taxa of zooplankton in reservoirs were: rotifers, *Keratella cochlearis* (Gosse, 1851), *Conochilus unicornis* Rousselet, 1892, *Hexarthra mira* (Hudson, 1871) and *Polyarthra vulgaris* (Carlin, 1943); cladocerans, *Bosmina hagmanni* Stingelin, 1904, *Bosminopsis deitersi* Richard, 1895, *Ceriodaphnia cornuta* Sars, 1886, *Ceriodaphnia silvestrii* Dadayi, 1902, *Daphnia gessneri* Herbst, 1967, *Diaphanosoma spinulosum* Herbst, 1975 and *Moina minuta* Hansen, 1899; copepods, juvenile forms (nauplii and copepodites) and the species *Thermocyclops decipiens* (Kiefer, 1929) (Table 4).

Cladocerans and copepods (especially nauplii and copepodites) were the most abundant zooplankton groups in all of the reservoirs (Figure 3); the exception was MAR, which presented a predominance of rotifers in the rainy season (Figure 3a). Only the abundance of microcrustaceans was significantly different (ANOVA, $p < 0.05$) between the rainy and dry seasons. The highest average values were always recorded in the dry period, and were observed for Cladocera in the ITU reservoir (Figure 3b); Cyclopoida in the COR, ITU, and PCO reservoirs (Figure 3c); and Calanoida in the COR and ITU reservoirs (Figure 3d).

Table 2. Classification of trophic states modified by Lamparelli (2004) for reservoirs.

Trophic State	Criteria	TP (mg m^{-3})	Chl-a (mg m^{-3})
Ultraoligotrophic	TSI <47	TP ≤8	Chl-a ≤1.17
Oligotrophic	47< TSI <52	8< TP ≤19	1.17< Chl-a ≤3.24
Mesotrophic	52< TSI <59	19< TP ≤52	3.24< Chl-a ≤11.03
Eutrophic	59< TSI <63	52< TP ≤120	11.03< Chl-a ≤30.55
Supereutrophic	63< TSI <67	120< TP ≤233	30.55< Chl-a 69.05
Hypereutrophic	TSI >67	233< TP	69.0< Chl-a

Abbreviations: Chl-*a* = chlorophyll *a*, TP = total phosphorus, TSI = Trophic State Index.

Table 3. Mean values (± standard deviation) of limnological variables and Trophic State Index (TSI) of the eight hydroelectric reservoirs during the rainy and dry periods.

Variables	Reservoirs							
	COR	**FUN**	**FUR**	**ITU**	**LBC**	**MAR**	**MSM**	**PCO**
Rainy								
Chl-*a* (µg L^{-1})	3.09(±1.65)	13.98(±8.31)	1.58(±0.99)	1.45(±0.29)	0.49(±0.32)	3.24(±2.37)	0.80(±0.27)	2.08(±0.82)
O$_2$ (mg L^{-1})	8.01(±1.64)	9.73(±2.69)	9.77(±1.14)	7.44(±1.38)	8.02(±1.63)	7.72(±0.90)	6.82(±1.41)	8.28(±0.47)
Cond (µS cm^{-1})	43.00(±2.76)	68.50(±13.69)	30.83(±2.56)	29.17(±2.86)	35.00(±0.89)	45.67(±2.66)	34.17(±0.75)	40.67(±8.71)
pH	7.87(±0.44)	7.65(±1.11)	6.95(±0.41)	8.18(±0.66)	7.23(±0.18)	7.10(±0.58)	7.57(±0.55)	7.05(±0.35)
TSS (mg L^{-1})	7.01(±3.91)	7.87(±3.61)	1.63(±1.04)	1.53(±0.73)	1.47(±0.81)	5.82(±2.91)	2.42(±2.13)	1.53(±0.96)
TN (mg L^{-1})	0.53(±0.05)	0.58(±0.15)	0.48(±0.21)	0.64(±0.29)	0.53(±0.14)	0.45(±0.19)	0.52(±0.31)	0.42(±0.19)
TP (mg L^{-1})	0.03(±0.01)	0.04(±0.01)	0.01(±0.00)	0.01(±0.00)	0.01(±0.00)	0.04(±0.01)	0.01(±0.00)	0.01(±0.00)
Temp (°C)	28.62(±1.75)	24.81(±0.28)	26.15(±0.34)	28.47(±0.97)	26.40(±0.84)	28.40(±1.67)	25.78(±1.41)	28.39(±1.55)
TSI	58.67(±2.50)	63.67(±2.5)	55.00(±2.00)	54.83(±1.60)	50.83(±1.72)	59.83(±2.48)	52.67(±0.82)	55.67(±1.21)
Class	meso	super	meso	meso	meso	eu	meso	meso
Dry								
Chl-*a* (µg L^{-1})	1.23(±0.66)	5.13(±2.27)	1.04(±0.73)	1.22(±1.05)	0.46(±0.15)	2.78(±1.62)	0.50(±0.23)	1.05(±0.85)
O$_2$ (mg L^{-1})	7.54(±0.95)	7.91(±0.92)	9.05(±0.22)	7.31(±0.43)	7.63(±0.64)	7.93(±0.98)	8.37(±1.69)	8.74(±1.44)
Cond (µS cm^{-1})	39.33(±3.88)	66.50(±5.86)	35.00(±3.10)	34.67(±5.05)	36.00(±2.19)	47.17(±1.94)	34.83(±2.40)	37.33(±1.37)
pH	7.68(±0.22)	7.13(±0.68)	6.51(±0.21)	7.46(±0.21)	6.70(±0.37)	6.92(±0.54)	6.85(±0.41)	7.17(±0.45)
TSS (mg L^{-1})	5.02(±4.50)	2.32(±1.25)	1.40(±0.51)	1.39(±0.36)	1.32(±0.46)	2.40(±1.91)	1.25(±0.48)	0.50(±0.09)
TN (mg L^{-1})	0.43(±0.10)	0.65(±0.23)	0.27(±0.05)	0.41(±0.10)	0.55(±0.23)	0.72(±0.23)	0.52(±0.10)	0.58(±0.17)
TP (mg L^{-1})	0.02(±0.00)	0.03(±0.01)	0.01(±0.00)	0.01(±0.00)	0.01(±0.00)	0.02(±0.01)	0.01(±0.00)	0.01(±0.01)
Temp (°C)	25.12(±1.67)	23.53(±3.64)	22.63(±0.61)	25.85(±1.98)	23.22(±1.23)	23.88(±1.72)	23.30(±1.35)	24.72(±1.65)
TSI	55.33(±1.86)	60.67(±2.34)	54.33(±2.34)	53.00(±2.28)	52.17(±0.75)	57.67(±2.34)	52.67(±1.86)	53.83(±1.47)
Class	meso	eu	meso	meso	meso	meso	meso	meso

Abbreviations: Chl-*a* = chlorophyll *a*, O$_2$ = dissolved oxygen, cond = electrical conductivity, pH = potential of hydrogen, TSS = total suspended solids, TN = total nitrogen, TP = total phosphorus, Temp = water temperature, TSI = Trophic State Index, Class = reservoir classification, meso = mesotrophic, eu = eutrophic, super = supereutrophic. Reservoir abbreviations as in Table 1.

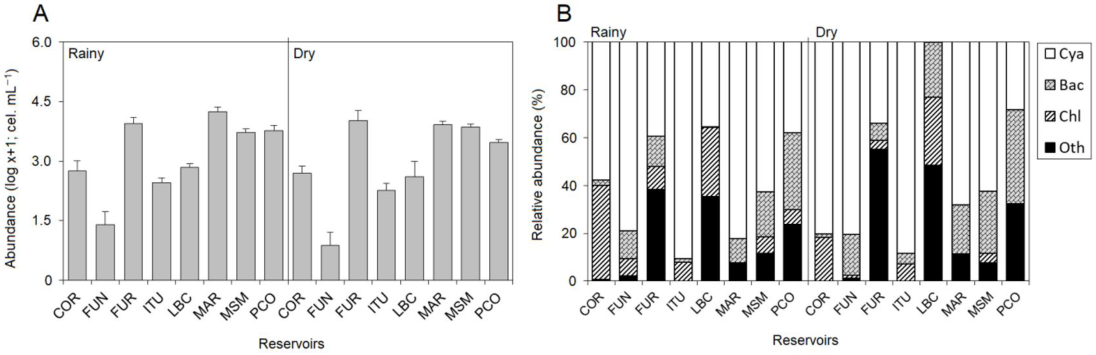

Figure 2. Mean values (± standard error) of phytoplankton abundance (A) and relative abundance (%) (B) of the different phytoplankton taxonomic classes in the eight hydroelectric reservoirs during the rainy and dry periods. Abbreviations: Cya = Cyanobacteria, Bac = Bacillariophyceae, Chl = Chlorophyceae, Oth = Others. Reservoir abbreviations as in Table 1.

Table 4. Composition and mean abundance (ind. m^{-3}) of zooplankton in the eight reservoirs.

Taxa	Reservoirs							
	COR	FUN	FUR	ITU	LBC	MAR	MSM	PCO
	Rainy / Dry							
ROTIFERA								
Anuraeopsis fissa Gosse, 1851							•/	
Ascomorpha ecaudis Perty, 1850	•/•	/•	•/		/•	•/•		•/•
Ascomorpha ovalis (Bergendahl, 1892)	•/		•/•		•/		•/•	
Asplanchna sieboldii (Leydig, 1854)			•/			/•	•/	
Brachionus calyciflorus Pallas, 1776		•/				○/		•/
Brachionus caudatus Barrois and Daday, 1894	/•							
Brachionus dolabratus Harring, 1914	/•	•/	•/		•/	●/	•/	•/
Brachionus falcatus Zacharias, 1898	/•		•/			/•	•/	
Brachionus forficula Wierzejski, 1891						•/		
Cephalodella sp.	•/							
Collotheca sp.	•/•	/•			•/•		/•	
Conochilus coenobasis (Skorikow, 1914)	•/•	•/•	•/○		•/•	•/•	•/•	•/•
Conochilus dossuarius Hudson, 1885							/•	
Conochilus unicornis Rousselet, 1892	•/○	○/●	•/●	●/●	•/•	○/●	•/○	•/
Dissotrocha sp.								•/
Euchlanis dilatata Ehrenberg, 1832		•/•	/○			•/•	/•	•/
Filinia longiseta (Ehrenberg, 1834)	•/•	•/•					/•	
Filinia opoliensis (Zacharias, 1898)		•/	•/•		•/•	•/	•/•	
Filinia terminalis (Plate, 1886)	•/•	•/	•/				•/	
Floscularia sp.			•/					
Hexarthra intermedia Wiszniewski, 1929	•/							•/
Hexarthra mira (Hudson, 1871)	•/	/•	•/	•/	•/•	•/	•/•	•/•
Hexarthra sp.	•/							
Kellicottia bostoniensis (Rousselet, 1908)	•/•	•/•	•/•	/•	/•		•/•	/•
Keratella americana Carlin, 1943	•/•	•/	•/○	•/•	•/	•/	•/•	
Keratella cochlearis (Gosse, 1851)	•/•	•/•	•/●	•/•	•/•	○/•	•/•	•/
Keratella lenzi (Hauer, 1953)				•/		○/•		
Keratella tropica (Apstein, 1907)	•/•	•/	•/•		•/		•/	
Lacinularia elliptica Shephard, 1897		•/○	●/○		•/•	●/•	○/•	○/
Lecane bulla (Gosse, 1851)	•/•				/•		•/	•/
Lecane cornuta (Müller, 1786)	/•							
Lecane ludwigi (Eckstein, 1883)	•/•	/•						

Symbols indicate men values during rainy (left of the slash) and dry (right of the slash) periods (● = >150 ind. m^{-3}; ○ = <150 to >50 ind. m^{-3}; • = <50 ind. m^{-3}; no symbol = absent). Reservoir abbreviations as in Table 1.

Table 4. Continued...

Taxa	Reservoirs							
	COR	FUN	FUR	ITU	LBC	MAR	MSM	PCO
	Rainy / Dry							
Lecane luna (Müller, 1776)	•/•				•/		•/•	•/
Lecane lunaris (Ehrenberg, 1832)	/•	•/						
Lecane monostyla (Daday, 1897)							•/	
Lecane proiecta Hauer, 1956			•/			•/		
Lecane signifera (Jennings, 1896)					/•			
Lecane stenroosi (Meissner, 1908)					/•			
Lepadella ovalis (Müller, 1786)							•/	
Lepadella patella (Müller, 1773)							•/	
Mytilina macrocera (Jennings, 1894)							•/	
Notommata sp.							•/	
Plationus patulus (Müller, 1786)	•/•	•/					•/	
Platyias quadricornis (Ehrenberg, 1832)					•/		•/	
Ploesoma hudsoni (Imhof, 1891)					/•	•/•		
Ploesoma truncatum (Levander, 1894)				•/				
Polyarthra dolichoptera Idelson, 1925	•/		•/					
Polyarthra vulgaris (Carlin, 1943)	•/•	•/	•/○	•/	•/•	○/○	•/•	/•
Pompholyx triloba Pejler, 1957			/•				•/	
Ptygura sp.	•/•		•/•		•/•		○/•	/•
Sinantherina ariprepes Edmondson, 1939		•/●	○/●		●/	○/•	•/	/•
Stephanoceros fimbriatus (Goldfusz, 1820)					○/○		•/•	•/•
Synchaeta stylata Wierzejski, 1893	○/○	/•	•/•	•/		○/●	•/•	•/•
Testudinella mucronata (Gosse, 1886)							•/	
Testudinella patina (Hermann, 1783)	/•						•/	•/
Trichocerca bidens (Lucks, 1912)	•/							
Trichocerca cylindrica (Imhof, 1891)	•/•		•/○		•/•	•/•	•/•	•/•
Trichocerca insignis (Herrick, 1885)	•/							•/•
Trichocerca insulana (Hauer, 1937)	/•							
Trichocerca similis (Wierzejski, 1893)							•/	
Trichocerca sp.							/•	
Trichotria tetractis (Ehrenberg, 1830)	/•						/•	
CLADOCERA								
Alona guttata Sars, 1862		/•						
Alonella dadayi Birge, 1910	/•		/○				•/	
Bosmina freyi Melo and Hebert, 1994					○/	○/○	/•	
Bosmina hagmanni Stingelin, 1904	•/•	•/○	○/●	•/○	●/○	●/○	●/○	•/○
Bosmina longirostris (Müller, 1785)				/•				
Bosminopsis deitersi Richard, 1895	•/○	•/●	•/●	•/•	•/○	○/●	•/○	•/•
Camptocercus australis Sars, 1896					/•			
Ceriodaphnia cornuta Sars, 1886	•/○	•/○	○/●	•/○	●/●	●/●	○/○	●/●
Ceriodaphnia silvestrii Dadayi, 1902	•/○	•/○	●/●	•/•	●/●	●/●	○/○	●/●
Coronatella poppei (Richard, 1897)					/•	•/•		
Daphnia gessneri Herbst, 1967	•/•	●/●	•/●	•/○	●/○	●/●	•/○	○/●
Diaphanosoma birgei Korineck, 1981	•/•		•/•	•/•	●/○		•/	/•
Diaphanosoma brevireme Sars, 1901				•/○	●/○	•/•		○/•
Diaphanosoma polyspina Korovchinsky, 1982					•/			
Diaphanosoma sp.				•/•				
Diaphanosoma spinulosum Herbst, 1975	○/●	●/○	●/●	•/○	○/•	○/•	●/●	●/○
Disparalona leptorhyncha Smirnov, 1996	/•							
Ilyocryptus spinifer Herrick, 1882	/•		•/			•/		
Leberis davidi (Richard, 1895)	/•							

Symbols indicate men values during rainy (left of the slash) and dry (right of the slash) periods (● = >150 ind. m^{-3}; ○ = <150 to >50 ind. m^{-3}; • = <50 ind. m^{-3}; no symbol = absent). Reservoir abbreviations as in Table 1.

Table 4. Continued...

Taxa	Reservoirs							
	COR	**FUN**	**FUR**	**ITU**	**LBC**	**MAR**	**MSM**	**PCO**
	Rainy / Dry							
Leydigia ipojucae Brehm, 1938		•/•						
Leydigia schubarti Brehm and Thomsen, 1936		•/						
Macrothrix laticornis (Jurine, 1820)							•/	
Moina micrura Kurz, 1874			•/○					
Moina minuta Hansen, 1899	•/•	•/	●/●	/•	●/•	●/○	○/○	•/•
Ovalona glabra (Sars, 1901)						/•		
Simocephalus serrulatus (Koch, 1841)				/•				
Simocephalus sp.	•/•		/•					
COPEPODA								
CYCLOPOIDA								
Nauplii	○/●	●/●	●/●	○/●	●/●	●/●	●/●	○/●
Copepodite	○/●	●/●	●/●	○/●	●/●	●/●	●/●	●/●
Mesocyclops meridianus (Kiefer, 1926)		•/•			•/	/•	•/	•/•
Thermocyclops decipiens (Kiefer, 1929)	•/○	●/•	●/●	/•	•/•	•/•	•/•	•/○
Thermocyclops minutus (Lowndes, 1934)	/•	•/•	•/•		•/○	•/•	•/•	•/•
CALANOIDA								
Nauplii	•/○	•/●	○/●	•/●	●/○	●/●	●/○	○/●
Copepodite	●/●	●/●	●/●	○/●	●/●	●/●	●/●	●/●
Argyrodiaptomus azevedoi (Wright, 1935)	•/	•/•		/•				
Argyrodiaptomus furcatus (Sars, 1901)				/•				
Argyrodiaptomus sp.				•/○				
Notodiaptomus cearensis (Wright, 1936)	•/○	●/○	○/●	•/•			•/	
Notodiaptomus henseni (Dahl, 1894)		•/•		•/●	●/●	●/●	•/○	●/●
Notodiaptomus iheringi (Wright, 1935)					•/•	•/•		
Notodiaptomus sp.				•/•				

Symbols indicate men values during rainy (left of the slash) and dry (right of the slash) periods (● = >150 ind. m^{-3}; ○ = <150 to >50 ind. m^{-3}; • = <50 ind. m^{-3}; no symbol = absent). Reservoir abbreviations as in Table 1.

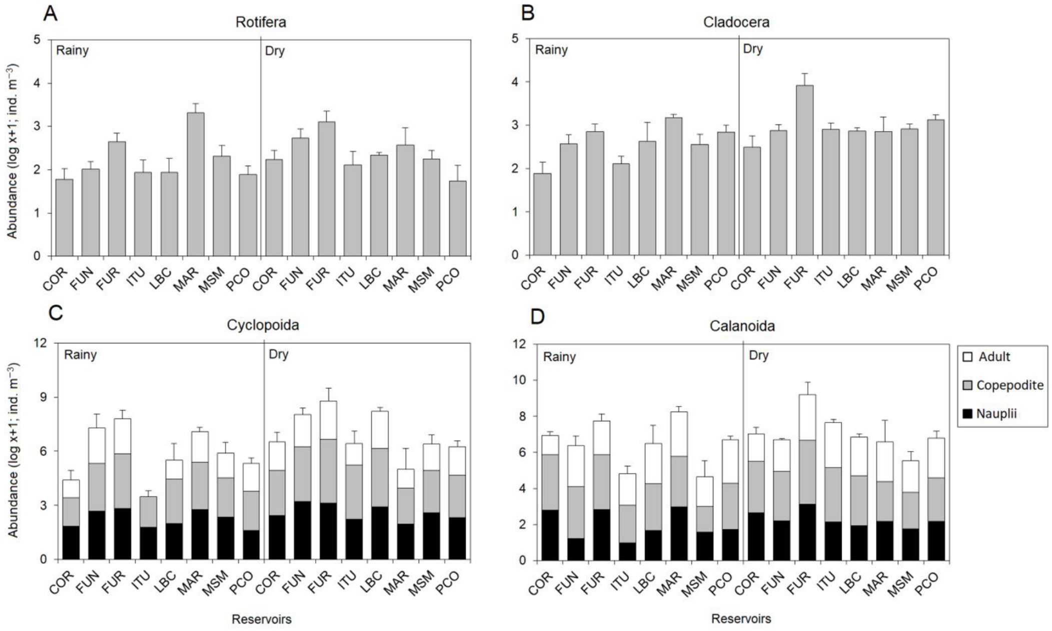

Figure 3. Mean values (± standard error) of abundance of Rotifera (A), Cladocera (B), and copepods of Cyclopoida (C) and Calanoida (D) in its different developmental phases, in the eight hydroelectric reservoirs during the rainy and dry periods. Bars = standard errors. Reservoir abbreviations as in Table 1.

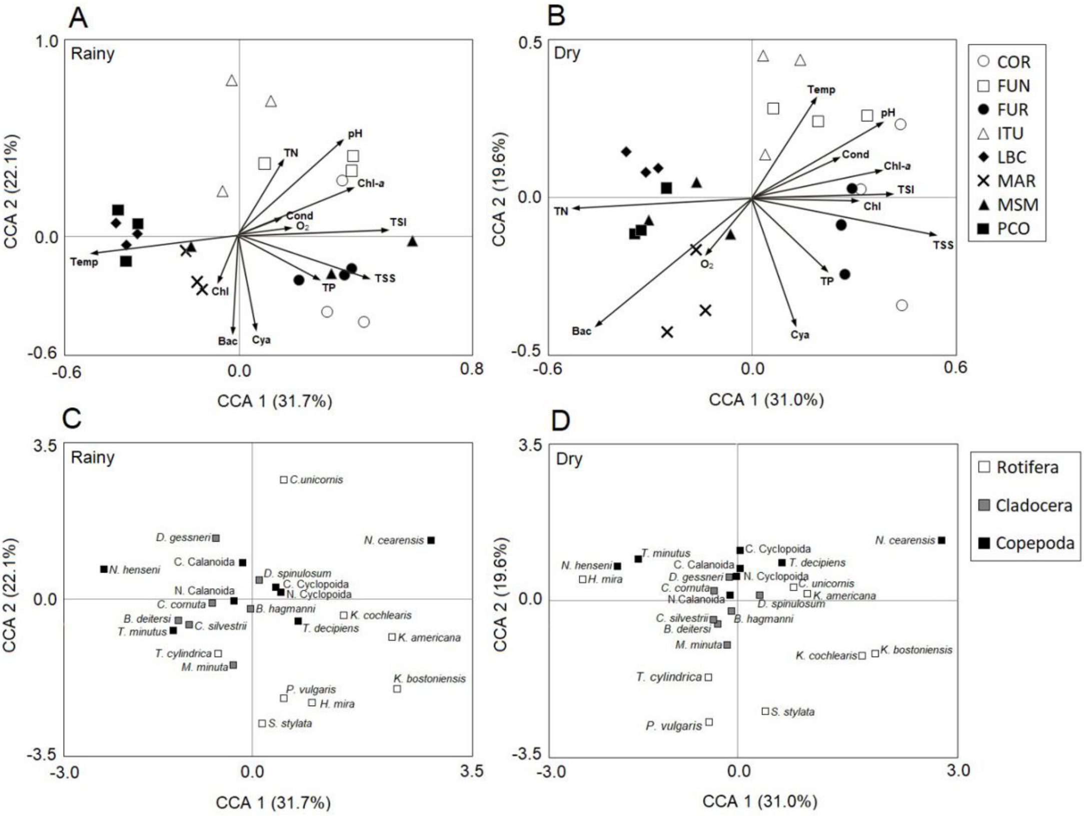

Figure 4. The canonical correspondence analysis (CCA) shows the relationships among the environmental variables and environments of the reservoirs (A, B) and zooplankton taxa (C, D) during the rainy and dry periods. Abbreviations: Cya = Cyanobacteria, Bac = Bacillariophyceae, Chl = Chlorophyceae, Chl-*a* = chlorophyll *a*, O_2 = dissolved oxygen, cond = electrical conductivity, TSS = total suspended solids, TN = total nitrogen, TP = total phosphorus, Temp = water temperature, TSI = Trophic State Index. Reservoir abbreviations as in Table 1.

3.4. Relationships between the zooplankton community dynamics and environmental variables

According to the CCAs, the abundance of zooplankton was correlated with the environmental variables, as well as with the reservoirs in both of the analysed hydrological periods (Permutest, $p = 0.001$). Furthermore, the analysis results illustrated that the environmental variables influenced 53.9% and 50.6% of the variations in abundance during the rainy and dry periods, respectively. Some species had an association with environmental variables during the analysed periods. The correlations for the rainy period are as follows: *D. gessneri* and *Notodiaptomus henseni* (Dahl, 1894) were negatively correlated with the TSS and TP concentrations, and Cyanobacteria abundance; *B. deitersi*, *C. silvestrii*, and *Thermocyclops minutus* (Lowdes, 1934) were positively correlated with the temperature and Bacillariophyta abundance; *C. unicornis* and *Notodiaptomus cearensis* (Wright, 1953) were positively correlated with the TSI, pH, and Chl-*a* concentrations; and *Kellicottia bostoniensis* (Rousselet, 1908), *K. cochlearis*, *H. mira*, and *P. vulgaris* were positively correlated with the TSS and TP concentrations (Figure 4a, 4c). The correlations for the dry period are as follows: *H. mira*, *T. minutus*, and *N. henseni* were negatively correlated with the TSS and TP concentrations and Cyanobacteria abundances; *Trichocerca cylindrica* (Imhof, 1891), *P. vulgaris*, and *M. minuta* were positively correlated with the TN concentration and Bacillariophyta abundance; *Keratella americana* Carlin, 1943, *T. decipiens*, and *N. cearensis* were positively correlated with the TSI, pH, and Chl-*a* concentrations; and *K. bostoniensis*, *K. cochlearis*, and *Synchaeta stylata* Wierzejski, 1893 were positively correlated with the TSS concentration (Figure 4b, 4d).

4. Discussion

Most of the reservoirs studied exhibited mesotrophic conditions, with the exception of the FUN and MAR reservoirs, which were experiencing eutrophication at the time of study. These reservoirs differ in many morphofunctional parameters, such as size, water residence time (WRT), and depth. Thus, both the trophic variation and morphofunctional characteristics of the reservoirs can affect zooplankton population dynamics differently (Perbiche-Neves et al., 2013).

Rotifers were the organisms that most contributed to the total species richness of the zooplankton. The high diversity of this group in reservoirs has been a recurring pattern in Brazil and is mainly attributed to the opportunistic characteristics of this group (e.g., wide food spectrum, high population turnover) (Takahashi et al., 2009; De-Carli et al., 2018; Picapedra et al., 2020). In turn, great occurrences and abundances of cladocerans (especially *B. hagmanni* and *C. cornuta*) and juvenile copepods can be an important indicator of the beginning of the eutrophication process in these reservoirs. Although most reservoirs are predominantly mesotrophic, the predominance of Cyanobacteria indicates the enrichment of nutrients in these systems. Higher concentrations of detritus and nutrients favour the growth of bacteria and protozoa, an important source of food for small filter feeders such as nauplii and small cladocerans (e.g., bosminids) (Brito et al., 2011). In addition, the great contribution of juvenile stages of copepods in relation to adults is often found in Brazilian reservoirs. The production of a large number of larval stages can be considered a reproductive strategy of this group to compensate for high mortality before they reach the final stage (Bonecker et al., 2001; Lansac-Tôha et al., 2005; De-Carli et al., 2018).

In this study, seasonal changes in abundance were observed for microcrustaceans (cladocerans and copepods) in the COR, ITU, and PCO reservoirs, with lower values in the rainy season. These decreases in abundance may have resulted from the dilution effect of a higher volume of rainwater, and partially by the removal of these populations at the outlets downstream of these reservoirs (Gazonato-Neto et al., 2014). Some authors (Bonecker et al., 2001; Takahashi et al., 2009) also observed a lower abundance of microcrustaceans during the rainy period in the COR reservoir.

The use of zooplankton species as biological indicators can provide important information on current and past processes, such as changes in biological relationships and in the physical and chemical properties of water (Perbiche-Neves et al., 2019). In this study, the TP and TSS concentrations and phytoplankton abundance were most associated with the fluctuation of zooplankton in the reservoirs. For example, the cladoceran *D. gessneri* and the copepod *N. henseni* were abundant during the rainy and dry periods in the LBC and PCO reservoirs, which had lower TSS concentrations and Cyanobacteria abundances. For some species of zooplankton, the food efficiency may decrease when food is mixed with suspended particles, even if phytoplankton are abundant in the water (Arruda et al., 1983).

The suspension of matter can have a negative effect on zooplankton, causing mechanical disturbances (obstruction and/or clogging) within the filtering apparatus, reducing the feeding and growth rates of these organisms and compromising important biological interactions (Claps et al., 2011; José de Paggi and Paggi, 2014). In addition, cyanobacterial filaments or mucilages can also interfere with the filtration apparatus of large cladocerans and calanoid copepods, which leads to the decline and replacement of these populations by small rotifers (Sendacz et al., 2006; Eskinazi-Sant'Anna et al., 2013), as observed in the FUR and COR reservoirs.

In the MAR reservoir, the variation in the abundance of some species of cladocerans (e.g., *B. hagmanni*, *M. minuta*, and *B. deitersi*) and the rotifer *T. cylindrica* were associated with the abundance of diatoms (Bacillariophyceae) during the rainy and dry periods. According to Eskinazi-Sant'Anna et al. (2013), diatoms algae are more palatable and nutritious than Cyanobacteria, and possibly favoured the development of these populations. In contrast, it was observed that the rotifers *K. bostoniensis* (invasive species), *Keratella* spp., *H. mira*, and *P. vulgaris* occurred in environments with a high abundance of Cyanobacteria and high levels of TP and TSS in the FUR (rainy and dry periods), MSM (rainy period) and COR (rainy period) reservoirs, and *C. unicornis* occurred in eutrophic environments in the FUN (rainy and dry periods) reservoir. These species are typical of meso-eutrophic environments and feed on solid suspended particles and colloids derived from bacteria that decompose organic material (Branco et al., 2002; Sousa et al. 2008; De-Carli et al. 2018). However, even with the trend observed in this study, the use of rotifers as bioindicators must be performed with care, as contrasting results can be found in the literature. For example, Nogueira (2001) and Sampaio et al. (2002) found high frequencies of *C. unicornis*, *K. americana*, *K. cochlearis*, and *P. vulgaris* in oligotrophic reservoirs on the Paranapanema River.

In relation to copepods, the co-occurrence of *T. minutus* and *T. decipiens*, with a higher occurrence of *T. decipiens*, may indicate a transition between mesotrophic and eutrophic conditions in reservoirs. *T. minutus* is more frequent in oligotrophic waters, whereas it is replaced by *T. decipiens* in eutrophic waters (Nogueira et al., 2002; Perbiche-Neves et al., 2016). In mesotrophic lakes, both species would be found together or in a seasonally alternating pattern (Sartori et al., 2009; Serafim-Júnior et al., 2016). *T. decipiens* was the most abundant in six of the eight reservoirs studied, mainly during the rainy season when the highest TP and TSS concentrations were observed. Pinto-Coelho (1987), studying Paranoá Lake, considered that *T. decipiens* had a greater growth capacity in environments with the recurrent introduction of allochthonous materials. In turn, *N. cearensis* was the most constant in the COR, FUN, and FUR reservoirs. This species is normally linked to environments with high electrical conductivity and productivity, and can feed on Cyanobacteria (Bouvy et al., 2001; Matsumura-Tundisi and Galizia Tundisi, 2003; Sartori et al., 2009).

Based on our results, it can be concluded that most reservoirs are mesotrophic (COR, FUR, ITU, LBC, MSM and PCO) and some are undergoing eutrophication (FUN and MAR), mainly due to the entry of nutrients from the urban and agricultural areas in the bodies of these systems. Consequently, there was a predominance of Cyanobacteria in the reservoirs, with the exception of LBC. Seasonal changes in zooplankton abundance were found only for microcrustaceans in some reservoirs, with lower values during the rainy season, possibly due to a dilution effect caused by rain. Species such as *K. bostoniensis*, *H. mira*, *Keratella* spp., and *P. vulgaris* were indicators of environments with higher levels of nutrients and a predominance of Cyanobacteria (e.g., COR and FUR). Additionally, microcrustaceans such as *T. decipiens*, *N. cearensis* and juvenile forms (nauplii and copepodites) of copepods occurred in environments that presented higher TSI values of FUN and ITU reservoirs. In contrast, the microcrustaceans *D. gessneri* and *N. henseni* can be considered indicators of more desirable water quality conditions (e.g., PCO and LBC). This study provided relevant information on the water quality of Brazilian reservoirs.

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