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Original Article

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Structure and spatial distribution of the rotifer assemblages along a tropical reservoir

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Abstract

The construction of reservoirs is a common practice in the world. These systems modify the hydric landscape and alter the flow of rivers, becoming lotic environments in lentic. Here we investigated the structure and spatial distribution of rotifers along a tropical reservoir. We sampled four points in the Pedra do Cavalo Reservoir, Bahia, Brazil, bimonthly, between August 2014 and June 2015. We registered more than 70 taxa distributed in 17 families, with the majority of species belonging to the Lecanidae, Brachionidae and Trichocercidae families. The species rarefaction curve did not achieve a total asymptote, indicating that species richness in the reservoir is higher than what was registered. Based in the species frequency of occurrence, we identified 48 rare species, 16 common species, five constant species and one frequent species. The highest beta diversity values were registered in riverine P1 (0.513) and intermediate P2 (0.503), although there were no significant differences between the sampling points. Despite the high abundance values in P1, P2 and P3 no significant differences were found between the studied points. Thus, this study substantially increases the knowledge on the rotifer community in the Paraguaçu River and contributes to future studies that focus on biodiversity, ecology and conservation in the Brazilian reservoir ecosystems.

Keywords: plankton, rotifera, beta diversity, longitudinal distribution.

Estrutura e distribuição espacial da comunidade de rotíferos em um reservatório tropical

Resumo

A construção de reservatórios é uma prática comum no mundo. Esses sistemas modificam a paisagem hídrica e alteram o fluxo dos rios, tornando-se ambientes lóticos em lênticos. Aqui investigamos a estrutura e distribuição espacial de rotíferos ao longo de um reservatório tropical. Foram amostrados quatro pontos no Reservatório da Pedra do Cavalo, Bahia, Brasil, bimestralmente, entre agosto de 2014 e junho de 2015. Registramos mais de 70 táxons distribuídos em 17 famílias, com a maioria das espécies pertencentes às famílias Lecanidae, Brachionidae e Trichocercidae. A curva de rarefação das espécies não alcançou uma assíntota total, indicando que a riqueza de espécies no reservatório é superior à registrada. Com base na frequência de ocorrência das espécies, identificamos 48 espécies raras, 16 espécies comuns, cinco espécies constantes e uma espécie frequente. Os maiores valores de diversidade beta foram registrados no ribeirinho P1 (0,513) e no intermediário P2 (0,503), embora não houvesse diferenças significativas entre os pontos de amostragem. Apesar dos altos valores de abundância em P1, P2 e P3, não foram encontradas diferenças significativas entre os pontos estudados. Assim, este estudo aumenta substancialmente o conhecimento sobre a comunidade de rotíferos no rio Paraguaçu e contribui para estudos futuros que enfocam biodiversidade, ecologia e conservação nos ecossistemas de reservatórios brasileiros.

Palavras-chave: plâncton, rotifera, diversidade beta, distribuição longitudinal.

1. Introduction

The freshwater environments represent vital resources for human, also an ideals habitat for the maintenance of the biota and endemic species (Vörösmarty et al., 2010; Junk et al., 2014). These hydric systems are formed by lentic environments with slow or absence of flow (as lakes); lotic with flow (as rivers), and semilotic environments, with calm water that preserve characteristics of lotic environments (as reservoirs) (Esteves, 2011).

The construction of reservoirs is also a common practice in tropical and subtropical regions of South America, facilitated by high hydric availability, and their reasons are for electricity generation, as well urban, industrial and agricultural water supply, leisure and navigation (Rodgher et al., 2005). In Brazil, the increase in reservoir numbers started in the 1960's (Agostinho et al., 2002; Dudgeon et al., 2006), which have modified the hydric landscape and the flow of lotic environments, becoming lentic areas (Nogueira, 2006; Jorgensen et al., 2013; Schork and Zaniboni-Filho, 2018). Currently there are over 1,313 large reservoirs in operation and an enormous number of small all over the country (Dias et al., 2018).

The reduction of hydrologic flow provides favorable conditions to the development of species adapted to lentic conditions (Rocha et al., 1999). Such environments, as reservoirs, are suitable for the development of high planktonic populations, once that the plankton growing rates are elevated in these environments (Marzolf, 1990; Okulu et al., 2016). Studies have shown that high densities of zooplanktonic organisms in reservoirs may be due to the reduced water speed and low water residence time with the associated reduction in advective downstream losses (Takahashi et al., 2014; Beaver et al., 2015; Okulu et al., 2016). Besides that, the zooplankton abundance, generally, exhibited a trend similar that of the phytoplankton (Beaver et al., 2015).

Studies on the structure and functioning of the planktonic community in reservoirs provide opportunities to investigate patterns due to the cyclic variation and episodic disturbances (Nogueira, 2001; Xue et al., 2018). Reservoir shows marked changes in limnological conditions in relatively short periods (Geraldes and George, 2013). Thus, the understanding of the plankton dynamics in these systems can be used to evaluate the resilience of this type of ecosystem, once plankton are sensible to alterations in environmental characteristics and reflect the dynamics of the ecosystem (Margalef, 1983; Legendre et al., 1985; Dias et al., 2012; Silva Brito et al., 2018).

The zooplanktonic community has a fundamental role in aquatic ecosystems, due to its position in the food chain, where it regulates the structural heterogeneity of various biological communities (Lemke and Benke, 2009). Among the zooplankton, rotifers constitute the majority of the species richness, as they occupy diverse ecological niches, both in the limnetic and littoral zones (Lansac-Tôha et al., 2009; Azevêdo et al., 2015). Furthermore, because the environmental requirements their immediately respond to the environmental variations, associated with high rates of population renovation (Obertegger et al., 2007; Azevêdo et al., 2015).

In this way, characterizing the community structure of rotifers is useful both to the understanding of the growth of dependent populations and for studies aiming at conservation and biomonitoring in this region. This study aimed at investigating the structure and spatial distribution of the rotifer community along a tropical reservoir.

2. Material and Methods

2.1. Study area

This study was made in the Pedra do Cavalo Reservoir, which supply a power plant in the dam (12°35'S and 38°59'W). This lake of 55 Km^2 area is in Bahia (Brazil) in the lower part of the Paraguaçu River, which large tributary is the Jacuípe River. This river rises in Chapada Diamantina Mountain, drain and crosses the semiarid region for 500 km until the confluence with the Paraguaçu River near the Pedra do Cavalo Reservoir (Fontes et al., 2011) (Figure 1).

We performed six samplings bimonthly between August 2014 and June 2015 in four sites distributed in the littoral zone of the Pedra do Cavalo Reservoir (Table 1).

2.2. Sampling design

We sampled rotifers in the morning period, at the sub-surface of the pellagic zone, using a graduated bucket and plankton net of 68 µm mesh size. We filtered 100 liters of water per sample totalizing 6 replicated. Samples were fixed with a 4% formaldehyde solution and buffered with calcium carbonate precipitated.

2.3. Laboratory analyses

Organisms were analyzed using stereoscope and microscope. We determined rotifer species richness in each sample until species curve was stabilized, that is, until no new species were registered in the sample. The individuals were estimated by analyzing a minimum of three subsamples (Bottrell et al., 1976) in a Sedgewick-Rafter chamber, using an optical microscope, at least 50 individuals being counted. Samples with few individuals were counted integrally. Species were identified using slides and coverslips and following basic literature as Koste (1972, 1978), Koste and Roberton (1983), Paggi (1989), Nogrady et al. (1993), Nogrady and Pourriot (1995) and Segers (1995).

In order to determine the abundance of rotifers (individuals/m^3), we have taken subsamples from 0.5 to 4 ml with a graduated pipette after sample homogenization and counted in the Sedgwick-Rafter chamber under optic and stereoscopic microscope.

2.4. Data analyses

We have determined the frequency of occurrence of species considering the number of samples in which the species was present in relation to the total of samples. This was calculated according to the Formula 1:

$$C = p \times 100 \; / \; P \qquad (1)$$

where C is the constancy index, p is the number of samples where the species was present and P is the total of samples.

Then, we have classified species as constant (present in more than 80% of samples), frequent (between 50 and 80%), common (from 20 to 50%), and rare (<20%) (Castilho et al., 2016).

Through species presence and absence data, we generated a rarefaction curve to verify if the samples were sufficient to estimate the incidence of rotifer species. We calculated

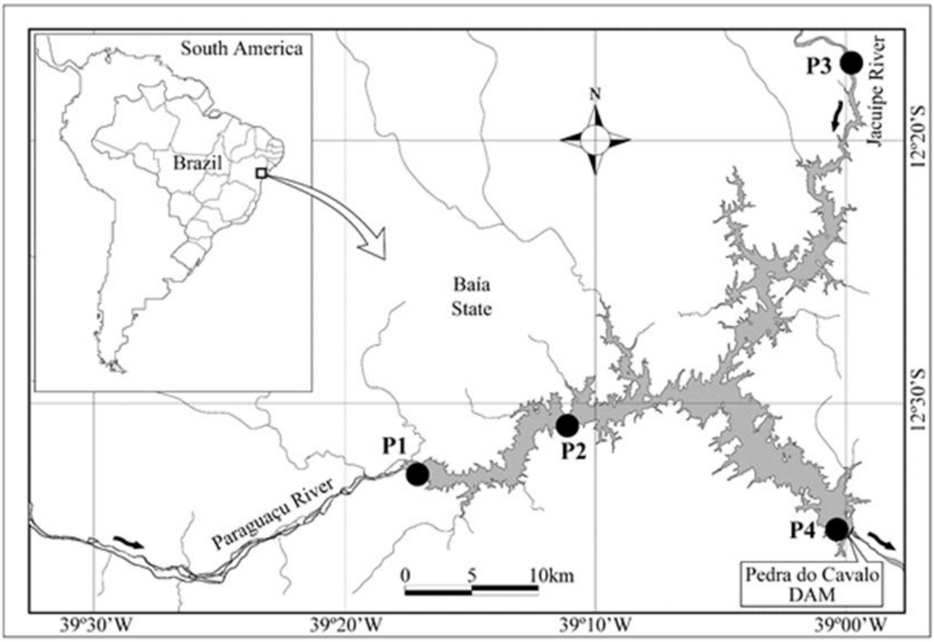

Figure 1. Study area with sampled points in the Paraguaçu River and reservoir of the Pedra do Cavalo.

Table 1. Environmental characterization of sampled points in the Pedra do Cavalo reservoir.

Sampled points	Environmental characterization
P1-Reservoir/Tupiaçu (12° 32'44.9" S; 39° 17' 05.2" W)	In the surroundings of P1, agro pastoral activities as sheep farming and okra, manioc, sugar cane, corn and tobacco plantations are common. Alkaline water (pH=8.2), lowest average value recorded for electrical conductivity (144 µS/cm^{-1}), total dissolved solids (72 mg/L).
P2-Reservoir/Balsa (12° 30'49.4" S; 39° 11'14.1" W)	Fish farming in net tanks, recreation and transport of people and automobiles by ferryboat. Possess macrophyte patches, pH=7.8, electrical conductivity (171 µS/cm^{-1}), total dissolved solids (92 mg/L).
P3-Reservoir/Feira de Santana (12° 35'31.2" S; 38° 59' 01.1 W)	Localized in the municipality of Feira de Santana (Jacuípe River), next to houses without basic sanitation, where it is possible to observe the discharge of domestic sewage. Possess macrophyte patches. pH=7.7, electrical conductivity (250 µS/cm^{-1}), total dissolved solids (134 mg/L).
P4-River Reservoir/Piscicultura (12° 41' 03.0" S; 38° 51' 36.8" W)	Next to the dam and to the catch pump of the fish farm station Rodolpho Von Ihering. Possess macrophyte patches, pH=7.4, electrical conductivity (250,1 µS/cm^{-1}),), total dissolved solids (194 mg/L).

the mean percentage of richness extrapolation according to Heck Junior et al. (1975). We have used the Jackknife 2 estimator, which bases in the removal of a sample from the total of observed samples, recalculating the estimator from the remaining values. For this, we used the programs Estimate and Statistica 5.0.

Firstly we used an analysis of variance (ANOVA) in order to test for differences in the abundance and richness of species between sampled points (P1, P2, P3 and P4). However, as the homocedasticity assumptions for the ANOVA were not achieved, we realized a non-parametric Kruskal-Wallis test (Sokal and Rohlf, 1995).

We have evaluated the variability of the composition of the rotifer community (beta diversity) through a test for homogeneity of multivariate dispersions – PERMDISP (Anderson et al., 2006) using presence/absence data. This test is based on the distances between the sample units and the centroid of the group in an Analysis of Principal Coordinates (PCoA), built using a dissimilarity measure. For this we have used the Jaccard dissimilarity measure, so that the higher the Jaccard dissimilarity means, the higher the beta diversity. PERMDISP uses an ANOVA with 999 permutations to test for significant differences ($p<0.05$). For PERMDISP and PCoA, we used the software R 3.4 (R Development Core Team, 2017), and the packages vegan (Oksanen et al., 2013) and permute (Simpson, 2016).

3. Results

The rotifer assembly was composed by 70 taxa, distributed in 17 families (Table 2). The richest families were: Lecanidae (17 taxa), Brachionidae (14 taxa), and Trichocercidae (eight taxa) (Table 2).

Table 2. Faunistic inventory of the rotifer community in the reservoir Pedra do Cavalo.

	P1	P2	P3	P4
Brachionidae				
Brachionus angularis Gosse, 1851	X	X	X	
Brachionus calyciflorus Pallas, 1766	X4	X	X	X
Brachionus caudatus Barrois & Daday, 1894	X	X		
Brachionus falcatus Zacharias, 1898	X	X		
Brachionus havanaensis Rousselet, 1911	X	X		
Brachionus quadridentatus Hermann, 1783	X		X	
Brachionus urceolaris Muller, 1773	X	X		
Brachionus mirus Daday, 1905		X		
Keratella americana Carlin, 1943	X	X	X	X
Keratella cochlearis (Gosse, 1851)	X	X	X	X
Keratella lenzi Hauer, 1953	X	X	X	X
Keratella tropica (Apstein, 1907)	X	X	X	X
Platyias quadricornis (Ehrenberg, 1832)	X	X	X	X
Plationus patulus (Muller, 1786)	X	X	X	X
Conochilidae				
Conochilus coenobasis (Skorikov, 1914)			X	
Conochilus dossuarius Hudson, 1885		X		
Conochilus cf. *unicornis* Rousselet, 1892		X		
Dicranophoridae				
Dicranophorus epicharis Harring & Myers, 1928				X
Epiphanidae				
Epiphanes clavatula (Ehrenberg, 1832)	X	X	X	X
Euchlanidae				
Dipleuchlanis propatula (Gosse, 1886)	X		X	
Euchlanis dilatata Ehrenberg, 1832		X	X	X
Euchlanis meneta Myers, 1930	X	X	X	X
Euchlanis lyra Hudson, 1886		X		
Filinidae				
Filinia longiseta (Ehrenberg, 1834)	X	X		
Gastropodidae				
Gastropus hyptopus (Ehrenberg, 1938)			X	
Lecanidae				
Lecane bulla (Gosse, 1886)	X	X	X	X
Lecane cornuta (Muller 1786)	X	X	X	X
Lecane curvicornis (Murray, 1913)	X	X	X	X
Lecane elsa Hauer, 1931	X			X
Lecane haliclysta Harring & Myers, 1926	X		X	
Lecane hastata (Murray, 1913)	X			
Lecane leontina (Turner, 1892)	X	X	X	X
Lecane ludwigii (Eckstein, 1883)	X	X	X	X
Lecane luna (Muller, 1776)	X	X	X	X
Lecane lunaris (Ehrenberg, 1832)			X	X
Lecane monostyla (Daday, 1897)	X		X	
Lecane papuana Murray, 1913			X	
Lecane quadridentata (Ehrenberg, 1830)	X	X	X	X
Lecane rhytida Harring e Myers, 1926		X		
Lecane spinulifera (Edmondson, 1935)				X

Table 2. Continued...

	P1	P2	P3	P4
Lecane stenroosi (Meissner, 1908)	X			
Lecane stichaea Hairing, 1913		X	X	
Lepadellidae				
Lepadella benjamini Harring, 1916			X	
Lepadella ovalis (Muller,1786)		X	X	X
Mytilinidae				
Mytilina mucronata Muller, 1773	X	X	X	X
Mytilina ventralis (Ehrenberg, 1832)			X	
Notommatidae				
Cephalodella gibba (Ehrenberg, 1832)		X	X	
Cephalodella tenuiseta (Burn, 1890)	X			
Notommata cerberus (Gosse, 1886)			X	
Notommata copeus Ehrenberg, 1834			X	X
Scaridiidae				
Scaridium longicaudum (Muller, 1786)				X
Synchaetidae				
Polyarthra dolichoptera Idelson, 1925				X
Polyarthra vulgaris Carlin, 1943				X
Synchaeta stylata Wierzejski, 1893		X		
Testudinellidae				
Testudinella patina (Hermann, 1783)	X	X	X	X
Trichocercidae				
Trichocerca bicristata (Gosse, 1887)	X			
Trichocerca bidens (Lucks, 1912)		X	X	
Trichocerca capucina (Wierzejski e Zacharias, 1893)			X	X
Trichocerca elongata braziliensis (Murray, 1913)			X	
Trichocerca heterodactila (Tschugunoff, 1921)			X	
Trichocerca insignis (Herrick, 1885)	X		X	
Trichocerca intermédia (Stenroos, 1898)			X	
Trichocerca pusilla (Jennings, 1903)	X	X	X	X
Trichotriidae				
Macrochaetus sericus (Thorpe, 1893)	X	X	X	X
Trichotria tetractis (Ehrenberg, 1830)	X	X	X	
Trochosphaeridae				
Horaella thomassoni Koste, 1973			X	
Bdelloidea	X	X	X	X

We found no significant differences in rotifer abundance between sampled points (p>0.05) (Figure 2A). Brachionidae, Lecanidae, and Synchaetidae were the most abundant families. Among the taxa, *Keratella cochlearis* (961.648,8 ind/m^3) and *Brachionus calyciflorus* (251.953,4 ind/m^3) presented the highest abundance peaks (Figure 2B).

We verified no significant differences in species richness between sampled points (p<0.05) (Figure 3). The frequency of occurrence indicated a higher number of rare species (48 species), followed by common species (16 species), frequent species (five species: *Keratella tropica* 73.9%, *Lecane bulla* 69.5%, *Keratella cochlearis* 69.5%, *Brachionus calyciflorus* 60.8% e *Keratella americana* 60.8%), and one constant taxa, belonging to the Bdelloidea (91.3%).

The rarefaction curve evidenced that our samplings were not enough to reach an asymptotic trend in P2, P3 and P4 (Figure 4). However more samples are needed to reach a P1 asymptote.

According to the mean percentage of richness extrapolation, rotifer data were capable of assessing 62.4% of species. The PERMDISP test, used to verify beta diversity, revealed higher values in P1 (0.513) and P2 (0.503), without significant differences between points (Figure 5).

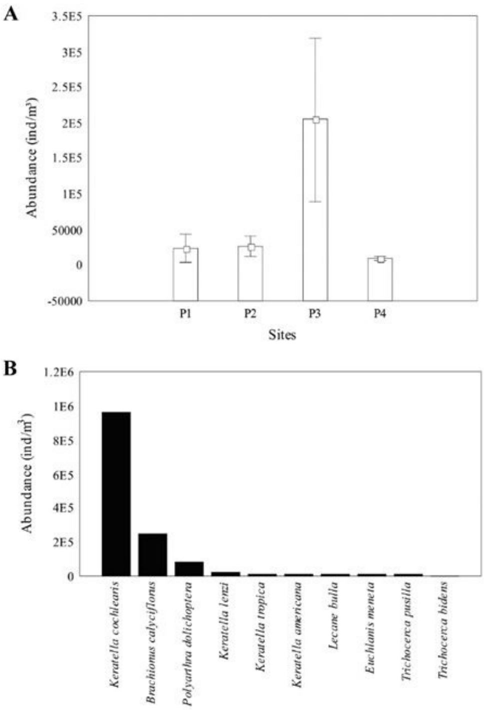

Figure 2. Abundance of the community in sampled points (A) and more abundant rotifer species (B) in the reservoir of the Pedra do Cavalo.

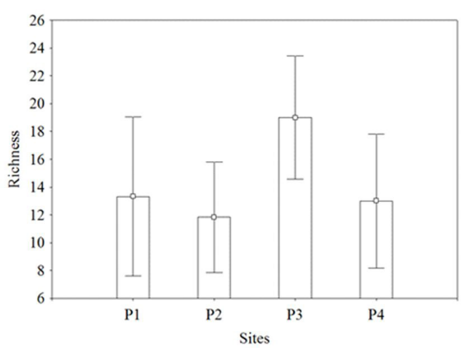

Figure 3. Mean and standard deviation of rotifer species richness in the reservoir of the Pedra do Cavalo between August 2014 and June 2015.

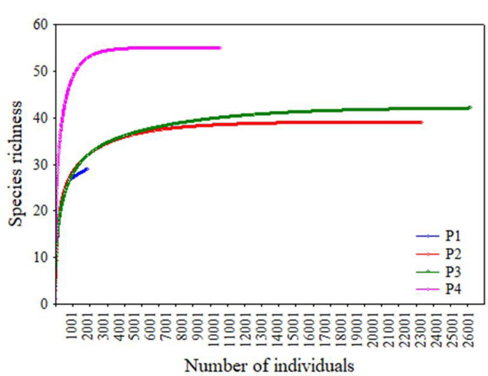

Figure 4. Rarefaction curve of rotifer species based on richness, sampled points, and richness estimator Jack 2.

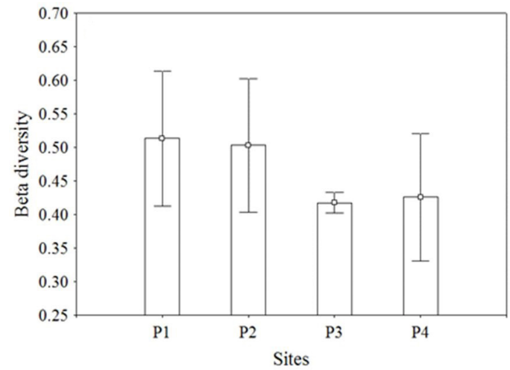

Figure 5. Principal Coordinates Analysis (PCoA) showing the similarity in species composition between the sampled points.

4. Discussion

The results obtained through the faunistic inventory of the rotifer community showed that the number of taxa may be considered relevant when compared to the values found in other studies. Sampaio et al. (2002), for example, identified 76 species of Rotifera in seven reservoirs of the Paranapanema River – SP/PR; Serafim-Junior et al. (2010) registered 52 taxa in seven sampled points in the Iraí Reservoir – PR; and Pedrozo et al. (2012) identified 57 taxa in seven sampled points in the mesotrophic Dona Francisca Reservoir – RS. Comparing with reservoirs in the same region (semi-arid region) like as Armando Ribeiro Gonçalves, Boqueirão de Parelhas, Gargalheiras, Itans, Passagem das Traíras, and Sabugi (Eskinazi-Sant'Anna et al., 2013) our study also showed a high number of taxa.

High abundances of *K. cochlearis* and *B. calyciflorus* have been commonly registered in reservoirs and are possibly related to the great tolerance of these species to eutrophic environments (Aoyagui et al., 2004; Almeida et al., 2006; Bezerra et al., 2015), especially in the studied region (Almeida et al., 2012). Some species *Keratella* are good explorers of a high range of feeding resources and are resistant to cyanobacteria toxins, which favors the development of large populations in eutrophic environments (Bezerra et al., 2015). *Brachionus calyciflorus* is tolerable to eutrophic environments with high conductivity (Serafim-Junior et al., 2010). Thus, water quality changes in reservoirs resulting from the eutrophication process may have contributed to the higher abundance of these species.

Brachionidae, Lecanidae, and Trichocercidae have been frequently registered in various studies in Brazil and others countries as the families with the highest species richness, and may correspond to 50% of the present taxa (Lansac-Tôha et al., 2004, 2009; Mantovano et al., 2015; Augustin et al., 2018; Nandini et al. 2019). The predominance of these families is considered typical of Neotropical regions (Serafim Júnior et al., 2003; Aoyagui et al., 2004).

Lecanidae presented the highest species richness and was mainly registered in P2, P3 and P4, which possess macrophyte patches. Taxa of these families are more frequent in the littoral zone, and in the benthonic and periphytic communities. They usually occur in the plankton as occasional migrants, mainly in areas with marginal vegetation and extensive macrophyte patches (Almeida et al., 2006; Melo-Junior et al., 2007; Bezerra et al., 2015). On the other hand, Brachionidae, highly endemic to South America, have in general planktonic habit and are associated with environments with great accumulation of organic matter (Almeida et al., 2006; Dantas-Silva and Dantas, 2012). Thus, the higher richness of this family in the reservoir is expected, since three sampled points present some kind of activities that could generate nutrient accumulation (see Table 1).

The highest frequency of occurrence of *Keratella tropica*, *Lecane bulla*, *Keratella cochlearis*, *Brachionus calyciflorus, Keratella americana* and Bdelloidea is commonly observed in other continental water bodies of the tropical region. As in our study, Eler et al. (2003) observed an elevated frequency of occurrence for *K. cochlearis, K. tropica* and Bdelloidea in fee fishing lakes, in the Mogi-Guaçu River Basin (SP). Serafim-Junior et al. (2006) have also registered highest frequency of occurrence for *K. cochlearis* and *L. bulla,* besides more Bdelloidea, with 100% of occurrence in the Itajaí-Açu River at Santa Catarina State. *Keratella tropica* and *K. americana* were the dominant species in the zooplankton community of some semi-arid reservoirs of the Rio Grande do Norte State (Eskinazi-Sant'Anna et al., 2007). High frequencies of *B. calyciflorus* and *K. cochlearis* have also been commonly observed in reservoirs (Zaganini et al., 2011; Dantas-Silva and Dantas, 2012; Pedrozo et al., 2012). Serafim-Junior et al. (2016), studying the effects of a reservoir construction in the Iguaçu River (PR) on zooplankton also verified an elevated frequency for *K. americana* and *K. cochlearis.*

Although the number of rotifer species is considerably high, the species rarefaction curve did not reach a total asymptote, indicating that species richness in the reservoir is higher than has been registered. According to the mean percentage of richness extrapolation, our rotifer data were capable of assessing 62.4% of species. However, Heck Junior et al. (1975) suggested that inventories that obtain 50% to 75% of the total number of species that occur in a determinate area might be considered satisfactory without loss of information, provided that common species are registered in the study.

Our results evidenced no significant differences between sampled points for beta diversity. This may be a result of the high water residence time (180 days) that the Pedra do Cavalo Reservoir presents when compared to other small and medium sized reservoirs, such as Rosana Reservoir (18.6 days) and Salto Segredo (47 days) (Julio Junior et al., 2005). Environments with low flow velocity and long residence times, such as reservoirs, favor rotifers, as they are organisms with a short life cycle (Takahashi et al., 2014).

The Paraguaçu River, with its 500 Km of extension, still remains unknown as to its planktonic species, as rotifers. In this sense, we highlight the importance of realizing a spatially integrated analysis, rich in information on local species. This study substantially amplifies the knowledge of the rotifer communities in the Paraguaçu River Basin and shows us that the trends found in the study are similar to those of other eutrophic reservoirs. It also aid in future studies that focus on biodiversity, ecology and conservation and, more broadly, contribute with studies on Brazilian reservoirs.

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