

The influence of environmental factors on the seasonal dynamics and composition of Rotifera in the Sapucaí River arm of Furnas Reservoir, MG, Brazil

Natalia Felix Negreiros^{1,4}, Maria José dos Santos-Wisniewski², Renata Martins dos Santos¹ & Odete Rocha³

¹Post-graduate Program in Ecology and Natural Resources, Federal University of São Carlos – UFSCar, São Carlos, SP, Brazil

²Department of Biology, Federal University of Alfenas, Alfenas, MG, Brazil

³Department of Ecology and Evolutionary Biology, Federal University of São Carlos – UFSCar, São Carlos, SP, Brazil

⁴Corresponding author: Natalia Felix Negreiros, e-mail: natalia_felix@yahoo.com.br

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Abstract: Seasonal fluctuations in the dynamics of the plankton rotifer populations in an oligo-mesotrophic branch of a tropical reservoir were analyzed with respect to the possible influence of environmental conditions (physical, chemical and biological), with emphasis on biological interactions. Samples were taken monthly from August 2006 to July 2007. The well-defined climatic seasons were reflected in variations of the physical and chemical properties of the water. The zooplankton community consisted mainly of Rotifera, Cladocera and Copepoda, with occasional representatives of *Chaoborus brasiliensis* (Diptera), Ostracoda, Protozoa and Turbellaria. Rotifera was the dominant group in zooplankton community in 5 of the 12 months of the study and were represented by 35 taxa. Redundancy analysis between the rotifer population abundances and the set of environmental variables showed significant ($p < 0.05$) positive correlations with the chlorophyll *a* in the rainy season. In the dry period, predation was probably the environmental factor that had the strongest effect on rotifer populations; in particular, the density of the cyclopoid *Thermocyclops decipiens* showed significant ($p < 0.05$) negative correlations with many of the rotifer population abundances. In addition, analysis of the co-occurrence of different rotifer species indicated strong competitive interactions between populations, during the rainy period ($p < 0.001$). Among the biotic environmental factors analyzed, algal biomass had an important role during the rainy period and inter-rotifer competition was also significant in these months. It was probably that predation by the cyclopoid copepod *Thermocyclops decipiens* determined the structure and dynamics of the rotifer populations in the Sapucaí arm of the Furnas reservoir, during the dry period.

Keywords: Rotifera, Furnas reservoir, intra-zooplankton predation, inter-specific competition.

NEGREIROS, N.F., SANTOS-WISNIEWSKI, M.J., SANTOS, R.M. & ROCHA, O. **Influência de fatores ambientais na composição e dinâmica sazonal de Rotifera no compartimento Rio Sapucaí, UHE de Furnas, MG, Brasil.** *Biota Neotrop.* 10(4): <http://www.biotaneotropica.org.br/v10n4/pt/abstract?article+bn03510042010>.

Resumo: Mudanças na dinâmica sazonal dos rotíferos planctônicos em uma porção oligo-mesotrófica de um reservatório tropical foram avaliadas em relação às variáveis ambientais (físicas, químicas e biológicas). As coletas foram realizadas mensalmente de agosto de 2006 a julho de 2007. As estações climáticas foram bem definidas, refletindo em variações nas características físicas e químicas da água. A comunidade zooplancônica foi representada pelos grupos: Rotifera, Cladocera, Copepoda, e ocasionalmente por *Chaoborus brasiliensis* (Diptera), Ostracoda, Protozoa e Turbellaria. Os Rotifera foram dominantes na comunidade em cinco dos 12 meses amostrados, tendo sido representados por 35 taxa. A análise de redundância entre as densidades das populações de Rotifera e as diversas variáveis ambientais indicou correlação positiva significativa ($p < 0.05$) com a concentração de clorofila *a* no período chuvoso. No período seco, provavelmente a predação foi o fator ambiental que mais influenciou estas populações, tendo sido obtida correlação negativa significativa ($p < 0.05$) entre a densidade da espécie *Thermocyclops decipiens* e a maior parte das populações de rotíferos. A análise de co-ocorrência entre as populações de rotíferos indicou fortes interações competitivas entre estas populações no período chuvoso ($p < 0.001$). Entre os fatores bióticos analisados a biomassa algal teve um papel importante durante o período chuvoso e a competição inter-específica entre os Rotifera também foi significativa neste período. No entanto, a predação pelo Copepoda Cyclopoida *Thermocyclops decipiens* foi provavelmente o que determinou a estrutura e dinâmica das populações de rotíferos no compartimento Sapucaí do reservatório de Furnas, durante o período seco.

Palavras-chave: Rotifera, reservatório de Furnas, predação intra-zooplancônica, competição interespecífica.

Introduction

Rotifera constitutes an important part of the freshwater zooplankton and have an essential role in energy transfer and the regeneration and transport of nutrients into the food web, as they are largely composed of direct consumers of phytoplankton primary production. They are generally present in great numbers and with high species richness in tropical zooplankton, being opportunistic organisms capable of colonizing a wide variety of habitats, from temporarily flooded areas (Koste & Robertson 1990, Bonecker & Lansac-Tôha, 1996, Lima et al. 1996, Garcia et al. 1998, Martínez et al. 2000, Lansac-Tôha et al. 2009) to large rivers, lakes and reservoirs (Oliveira Neto & Moreno 1999, Aoyagui & Bonecker. 2004, Sendacz et al. 2006, Corgosinho & Pinto-Coelho, 2006, Almeida et al. 2009, Borges & Pedrozo, 2009).

The representatives of this group are small and short-lived (Streble & Krauter 1987) and generally show high sensitivity, responding quickly to various types of environmental change, thus altering the total density of zooplankton and modifying the species composition and diversity of the community (Coelho-Botelho 2004). Although the freshwater zooplankton community consists mainly of rotifers, cladocerans and copepods, other groups are present at lower densities and frequencies, such as turbellarians, water acarines and dipteran larvae (Chaoboridae, Culicidae) (Tundisi et al. 1988), and biotic interactions among them can be a relevant factors.

The composition and dynamics of a community are influenced by surrounding conditions and a complex of physical, chemical and biological factors, as well as interactions among them, that can play a major part in selecting the prevailing species (Lehman 1991). While organisms numbers and relative abundance are the fundamental properties that define the structure of a community, local processes of competition, predation and heterogeneity (in time and space) of the environment are the immediate determining factors of population dynamics in a given locality (Chesson 1986). Although in some particular environments, the physical and chemical variables may be more important than biotic variables, or vice versa, both sets of factors usually operate simultaneously along a seasonal cycle.

In the present study, the most important variables controlling the abundance of rotifers in the plankton communities, according to the literature were measured during a one-year period of in the Sapucaí arm of the Furnas hydroelectric power station reservoir, and analysed regarding its effects on the structure and dynamics of the Rotifera assemblages. The main focus was upon the variables indicating biotic interactions, such as herbivory (phytoplankton biomass), competition (other filter-feeders) and intrazooplankton predation (zooplankton carnivores), that could influence the dynamics of rotifer populations.

Material and Methods

1. Study area

The reservoir serving the Furnas hydroelectric power station, situated in the Rio Grande basin in Minas Gerais State, Brazil (20° 40' S and 46° 19' W) is formed by the Grande (northern arm) and Sapucaí (southern arm) rivers. A limnetic section of this later arm (Figure 1) was sampled monthly from August 2006 to July 2007.

2. Experimental design

The following physical and chemical properties of the water were measured in situ at each collection: temperature with a mercury thermometer; electrical conductivity and pH with Quimis digital meters. Samples of water were also collected for the measurement

of dissolved oxygen (DO), total N, total P and chlorophyll *a* concentrations. DO concentration was determined by the Winkler method, modified with NaN_3 , as described by Golterman et al. (1978), and the phosphorus and nitrogen contents by the methods given in Mackereth et al. (1978). Chlorophyll *a* was determined by 90% acetone extraction (Lorenzen 1967, Golterman et al. 1978). Water transparency was measured using a Secchi disk of 30 cm of diameter.

The Trophic State Index (TSI) of Carlson (1977), modified by Toledo et al. (1983) was calculated using water transparency, chlorophyll *a* and total phosphorus concentrations.

Zooplankton was collected by vertical hauls with a 68 μm mesh plankton net through the whole water column. The volume of water filtered was estimated by multiplying the area of the net mouth by the local depth of the water. The organisms were fixed in 4% formaldehyde solution and later identified and counted under an optical Leica (DMLS) microscope (up to 1000X magnification), and specialized literature (Edmondson 1959, Koste 1978, Segers 1995, Elmoor-Loureiro 1997, Smirnov 1996, Rocha & Matsumura-Tundisi 1976, Matsumura-Tundisi 1986, Reid 1985). Cladocera and Copepoda were counted in square plastic counting dishes marked with a square 5 mm grid on the bottom, using sample aliquots of 5 mL or more and, in the case of the rare taxa, the whole sample. Rotifers were counted in a Sedgewick-Rafter cell, using sample aliquots of 1 mL and, at times, the whole sample.

3. Analysis of data

The statistical analysis was based on data from monthly samples, 19 species of rotifer and 20 environmental variables (5 physical and chemical factors, chlorophyll *a* content, 7 potential competitors and 7 potential predators). The data were subjected to redundancy analysis (RDA), employing the program CANOCO 3.12 (Ter Braak & Šmilauer 2002). Rotifer species densities were transformed by the function $\log(x+1)$ before analysis. The Monte Carlo test, with 999 random permutations, was used to test the significance of the environmental variables.

In view of the great number of rotifer species found in the samples, Principal Components Analysis (PCA) was applied to rotifer densities, in order to select those species that accounted for more than 0.8 of variance for the first two components. To avoid overvaluing some RDA results with very different number of variables in different tests, the competitors (7 variables) were grouped into taxonomic families.

The variables total P and total N were treated as unreal independent environmental variables, as their values and those of total zooplankton density are mutually dependent. Thus, these variables were excluded from the RDA calculations. The program EcoSim@ (Gotelli & Entsminger 2001) was used to verify the existence of competition among rotifer species during the period of study.

Results

During the study, the climatic periods were well defined, with the rainy season extending from October 2006 to February 2007. The dry period (August and September 2006 and March to July 2007) was marked by low temperatures and low pluviosity (Figure 2a). The Figure 2 shows the following variables: Rainfall (Figure 2a), D.O. (Figure 2b), Temperature (Figure 2c), Total N (Figure 2d), Depth (Figure 2e), Total P (Figure 2f), pH (Figure 2g), Chlorophyll (Figure 2h), Conductivity (Figure 2i), and Trophic State Index (Figure 2j).

In the Sapucaí River arm of the Furnas hydroelectric station reservoir, the water was well oxygenated and the highest D.O. content (8.52 mg.L^{-1}) was during June and the lowest (5.97 $\mu\text{g.L}^{-1}$)

in February (Figure 2b). Water temperature varied from month to month, with the highest value (27.0 °C) recorded in March and lowest (20.8 °C) in June (Figure 2c). The pH varied between slightly acid and alkaline, remaining close to neutral throughout the study period (Figure 2g). Regarding the nutrients, the greatest concentrations of nitrogen and phosphorous were recorded during the rainy period, between October and January (Figures d, f). Chlorophyll *a* values were relatively low, except in January, when a peak of 79.5 $\mu\text{g.L}^{-1}$ was registered. During the rest of the study period, little the variation was observed: average chlorophyll *a* value was $6.6 \pm 6.5 \mu\text{g.L}^{-1}$ (Figure 2h). Electrical conductivity was relatively low, with a narrow range of variation, between 14.9 $\mu\text{S.cm}^{-1}$ (January) and 28.9 $\mu\text{S.cm}^{-1}$ (November) (Figure 2i).

On the basis of the TSI employed, the Sapucaí arm of Furnas reservoir was classified as oligotrophic, except in January, when it was mesotrophic (Figure 2j).

Zooplankton community in the Sapucaí arm of the Furnas reservoir was constituted by Rotifera, Cladocera and Copepoda and, occasionally, by other taxa, such as Ostracoda, Turbellaria, the dipteran's larvae *Chaoborus brasiliensis* and Protozoa, mainly the

tecamoebae *Arcella* sp. and *Diffugia* sp. Rotifers were dominant in 5 of the 12 months, while copepods dominated during 6 months. The least abundant group was Cladocera, which was found in low densities as compared with rotifers and copepods, except during February, when their numbers exceeded those of the other two groups (Tables 1, 2 and 3).

Rotifera was represented by 35 taxa. The dominant species were *Ascomorpha ecaudis*, *A. ovalis*, *Brachionus dolabratus*, *Collotheca* sp., *Conochilus coenobasis*, *C. unicornis*, *Filinia longiseta*, *F. opoliensis*, *Hexarthra intermedia*, *Kellicottia bostoniensis*, *Keratella americana*, *K. cochlearis*, *Lecane prolecta*, *Polyarthra* aff. *vulgaris* and *Sinantherina semibullata* (Table 2). The highest density of rotifers (166,854 ind.m⁻³) was recorded in November and a single species (*C. unicornis*) was responsible for most of this peak, contributing 122,897 ind.m⁻³ (Figure 3).

Crustaceans with high abundances, comparable to rotifer densities and possibly competing with rotifer populations in this part of the reservoir were mostly the species *Bosmina freyi*, *B. hagmanni*, *B. tubicen*, *Ceriodaphnia cornuta cornuta*, *C. cornuta intermedia*, *C. cornuta rigaudi*, *C. silvestrii*; *Diaphanosoma birgei*, *D. brevireme*,

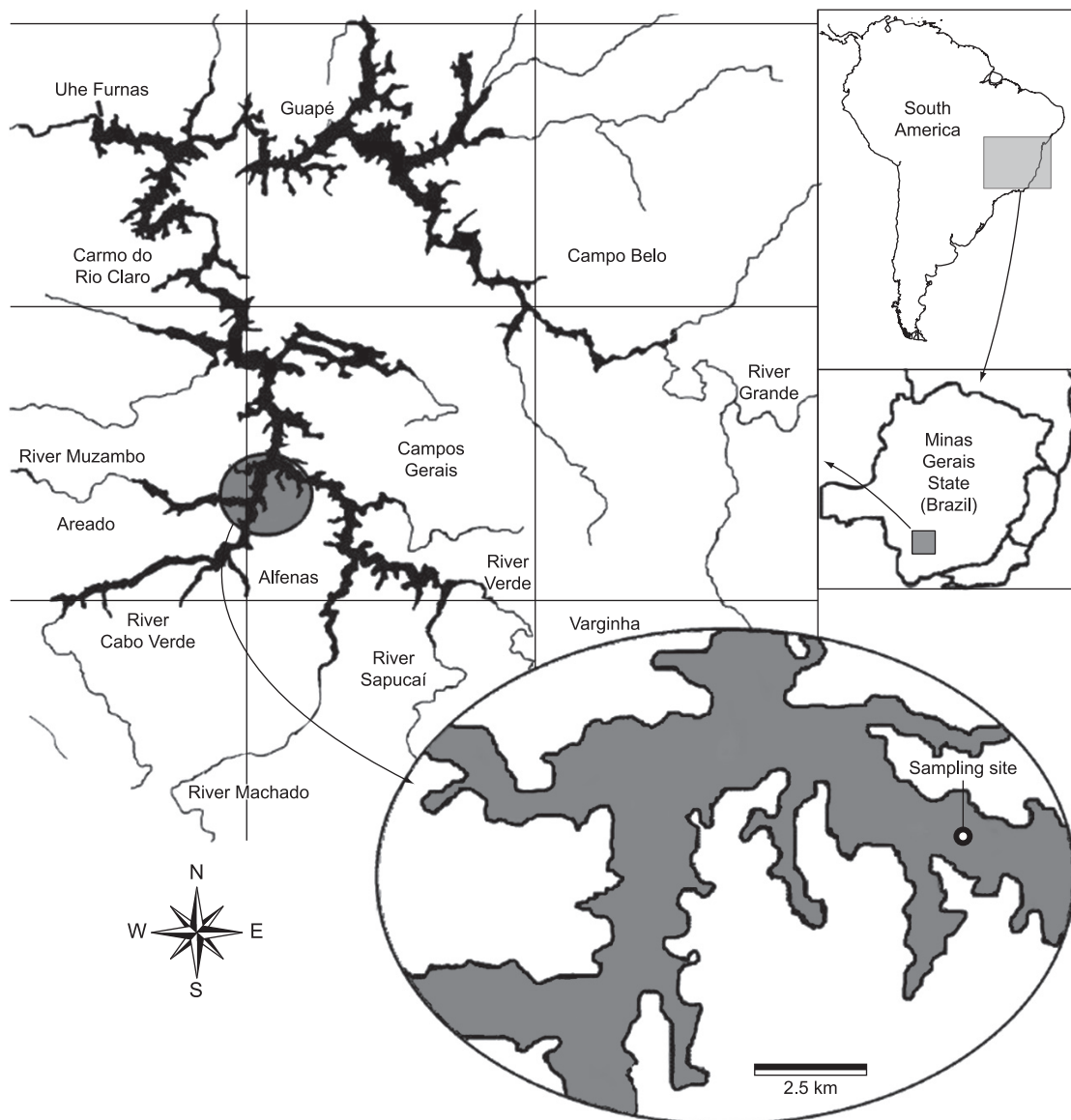


Figure 1. Map of Furnas reservoir, showing the sample site in the arm formed by the Sapucaí River.

Table 1. Values of the Rotifera species densities (ind.m⁻³) in the Sapucaí arm of the Furnas Reservoir, MG, Brazil, from August 2006 to July 2007.

Rotifera	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
<i>Ascomorpha ecaudis</i> Perty, 1850	0	0	896	1,246	1	0	1	24	1	3	0	0
<i>Ascomorpha ovalis</i> * (Bergendal, 1892)	136	45	45	2,076	153	0	18	59	76	58	184	93
<i>Brachionus angularis</i> * Gosse, 1851	0	0	0	0	0	13	0	0	0	0	0	0
<i>Brachionus calyciflorus</i> * (Pallas, 1766)	0	0	0	1,661	7	158	27	7	0	0	0	0
<i>Brachionus caudatus</i> *	0	0	0	2	0	8	0	0	0	0	0	0
<i>Brachionus dolabratus</i> * Barrois & Daday, 1894	0	0	9	913	256	0	75	12	15	6	0	0
<i>Brachionus falcatus</i> *(Zacarias, 1898)	0	0	0	1,246	51	0	9	12	15	0	0	0
<i>Brachionus mirus</i> *(Daday, 1905)	0	0	4	1,246	256	13	0	0	0	0	61	0
<i>Collotheca</i> sp.*	136	908	224	2,906	1,533	788	45	118	228	173	123	467
<i>Conochilus coenobasis</i> * (Skorikov, 1914)	27	227	224	4,152	256	197	38	59	76	116	0	0
<i>Conochilus unicornis</i> * (Rousselet, 1892)	6,954	45,639	21,066	122,897	7,156	7,884	1,763	709	3,417	809	5,390	560
<i>Euchlanis dilatata</i> * Ehrenber, 1832	0	0	0	415	256	197	18	35	76	58	61	93
<i>Filinia longiseta</i> *(Ehrenberg, 1834)	0	0	2	83	256	591	9	59	76	6	0	0
<i>Filinia opoliensis</i> (Zacarias, 1898)	0	0	45	415	511	197	38	4	15	58	61	5
<i>Hexartra intermedia</i> * (Weiszniowski, 1929)	0	2	224	3,737	0	1,183	75	47	456	12	184	93
<i>Kellicotia bostoniensis</i> (Rousselet, 1908)	136	6	11	830	13	197	38	59	228	173	551	93
<i>Keratella americana</i> (Carlin, 1943)	2	0	45	83	256	79	38	47	76	58	61	9
<i>Keratella cochlearis</i> * (Gosse, 1851)	2	227	449	1,682	263	394	0	24	76	116	245	3
<i>Keratella lenzi</i> * (Hauer, 1953)	0	0	22	83	5	0	0	0	8	0	0	0
<i>Keratella tropica</i> * (Apstein, 1907)	0	0	224	8	256	788	3	0	0	0	0	0
<i>Lecane cornuta</i> (Müller, 1786)	0	0	0	0	0	1	0	59	0	0	0	0
<i>Lecane ludwigii</i> (Eckstein, 1883)	0	0	0	0	0	0	0	0	0	1	0	0
<i>Lecane proiecta</i> * Hauer, 1956	0	0	314	17,023	16,100	591	1	24	23	58	61	0
<i>Lecane stenroosi</i> (Meissner, 1908)	0	0	0	0	0	0	0	0	0	0	0	1
<i>Plationus macracanthus</i> * (Daday, 1905)	0	0	0	0	0	8	0	0	0	0	0	0
<i>Plationus patulus</i> * (Müller, 1953)	0	11	0	0	0	197	0	0	0	58	0	93
<i>Polyarthra</i> aff. <i>vulgaris</i>	27	908	1,569	2,076	767	197	38	1	8	58	796	560
<i>Prygura</i> cf. <i>wilsonii</i> (Anderson & Shephard, 1892)	0	23	448	0	0	0	38	95	38	0	0	0
<i>Sinatherina semibullata</i> (Thorpe, 1893)	7	454	448	0	0	0	0	733	152	12	417	93
<i>Synchaeta jollyae</i> Shiel & Koste, 1993	818	0	11	1,661	767	1,774	9	0	76	0	1,764	1,866
<i>Testudinella patina</i> (Hermann, 1783)	136	0	0	0	0	197	0	0	0	0	0	0
<i>Trichocerca chattoni</i> (de Beauchamp, 1907)	27	908	1,345	12	38	0	2	59	76	0	61	47
<i>Trichocerca capucina</i> (Wierzejski & Zacharias, 1893)	7	45	896	0	0	0	0	0	0	0	0	0
<i>Trichotria tetractis</i> (Ehrenberg, 1830)	0	0	1	0	0	0	0	0	0	0	0	0
<i>Bdelloidea</i>	0	0	0	0	0	1	0	0	0	0	0	0

*Species selected by pca, which contribute eigen values ≥ 0.8 to the two principal axes.

D. fluviatile and *D. spinulosum*; *Moina minuta*; *Notodiptomus cearensis*; *N. spinuliferus*; calanoid nauplii and copepodites and cyclopoid nauplii (Table 3). Potential predators of rotifers were represented by juvenile and adult stages of cyclopoid copepods *Thermocyclops minutus*, *T. decipiens* and *Mesocyclops ogunnus*, larvae of *Chaoborus brasiliensis*, the rotifer *Asplanchna sieboldi* and turbellarians (Table 3).

When the Monte Carlo test was applied to the sets of environmental factors, it was found that chlorophyll *a*, and crustacean competitors (cladocerans of family Moinidae, predatory copepods *Thermocyclops decipiens* and *Mesocyclops ogunnus*) had significant effects on the rotifer populations (Table 4).

Redundancy Analysis (RDA) applied to rotifer populations, and physical, chemical and biological (chlorophyll *a*) variables indicated that the first two ordination axes explained 69% of the total variance in the results. Among the explanatory variables, D.O. and electrical conductivity showed the least influence on rotifer numbers. The ordination chart (Figure 4a) showed that chlorophyll *a* was the environmental factor that most strongly influenced the rotifers ($p < 0.05$) (Table 4). The chart also showed that the species *Brachionus*

angularis, *B. caudatus*, *Plationus macracanthus*, *P. patulus* and *Filinia longiseta* occurred in the rainy period and increased collinearly with phytoplankton biomass.

The RDA between Rotifera populations and potential competitor species explained 70.9% of total variance. Representatives of Chydoridae and Sididae families of Cladocera had the least influence on rotifer densities (Figure 4b). Ordination diagram indicated that representatives of Moinidae had the strongest influence upon the rotifer populations ($p < 0.05$) (Table 4), and showed that *Conochilus coenobasis*, *Brachionus falcatus*, *Lecane proiecta*, *Keratella tropica* and *B. dolabratus* occurred in the rainy period and had positive collinearity with the Moinidae cladocerans.

RDA between rotifers and predator species explained 86.2% of total variability accumulated in the two first ordination axes. Triplot ordination analysis indicated that the cyclopoid copepod *Thermocyclops minutus* was the predatory species with the least influence over the Rotifera populations, although it occurred in high densities throughout the whole study period. It further revealed that the species *Thermocyclops decipiens* ($p < 0.05$) and *Mesocyclops ogunnus* ($p < 0.001$) (Figure 4c) constituted the most important

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Table 2. Monthly densities (ind.m⁻³) of potential competitors for Rotifera recorded in the Sapucaí arm of Furnas Reservoir, MG, Brazil, from August 2006 to July 2007.

Competitors	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
<i>Bosmina freyi</i> De Melo and Hebert, 1994	55	772	762	6,726	409	355	41	2	886	142	632	1,717
<i>Bosmina hagamni</i> Stingelin, 1904	136	0	134	5,813	409	355	120	1	382	233	438	1,017
<i>Bosmina tubicen</i> Brehm, 1953	0	0	0	0	0	39	0	0	0	0	0	0
<i>Bosminopsis deitersi</i> Richard, 1895	0	0	0	83	0	355	3	0	0	0	0	0
<i>Ceriodaphnia cornuta cornuta</i> Sars, 1886	218	908	1,524	2,657	1,533	749	1,151	234	489	111	219	336
<i>Ceriodaphnia cornuta intermedia</i> Sars, 1886	45	727	1,031	1,329	664	118	278	16	191	37	30	37
<i>Ceriodaphnia c. righaudi</i> Sars, 1886	0	500	1,434	2,574	307	276	465	97	642	132	140	89
<i>Ceriodaphnia silvestrii</i> Daday, 1902	418	2,689	628	664	153	158	390	102	2,117	233	1,210	849
<i>Chydorus pubescens</i> Sars, 1901	3	0	20	0	0	13	16	0	0	0	0	0
<i>Daphnia gessneri</i> Herbst, 1967	27	0	512	1,183	226	48	0	0	321	70	2705	956
<i>Diaphanosoma birgei</i> Korineck, 1981	0	0	0	166	0	0	101	435	1,628	43	0	14
<i>Diaphanosoma brevireme</i> Sars, 1901	0	45	224	83	51	0	38	8	0	2	6	0
<i>Diaphanosoma fluviatile</i> Hansen, 1899	0	0	0	0	0	39	0	295	1,475	450	0	0
<i>Diaphanosoma spinulosum</i> Herbst, 1967	55	2,770	1,389	664	409	315	176	73	313	43	843	364
<i>Kurzia latissima</i> (Kurz, 1874)	0	0	0	0	0	0	4	0	0	0	0	0
<i>Leydigia</i> sp.	0	0	0	0	0	0	4	0	0	0	0	0
<i>Moina minuta</i> Hansen, 1899	1	318	75	1,661	2,045	631	754	24	176	10	18	65
<i>Simocephalus latirostris</i> Stingelin, 1906	0	0	0	0	0	0	98	19	0	0	0	0
<i>Simocephalus serrulatus</i> (Koch, 1841)	2	37	0	0	0	0	0	0	0	1	0	5
<i>Argyrodiaptomus furcatus</i> (Sars, 1901)	0	5	0	0	0	0	9	47	0	0	0	9
<i>Notodiptomus cearensis</i> (Wright, 1936)	136	91	403	498	26	8	18	213	30	23	0	19
<i>Notodiptomus iheringi</i> (Poppe, 1891)	0	0	90	0	13	13	9	0	15	0	49	0
<i>Notodiptomus spinuliferus</i> Dussart & Matsumura-Tundisi, 1986	382	727	493	498	26	118	54	95	152	23	221	187
Calanoida copepodid	11,04	7,765	2,017	2,989	562	434	324	1,418	1,731	486	931	2,799
Calanoida nauplii	2,045	2,498	2,241	6,228	2,556	788	38	473	152	867	245	187
Cyclopoida nauplii	2,454	13,62	13,45	20,76	12,78	2,957	900	1,773	4,936	4,914	7,963	6,531
Ostracoda	27	5	90	83	51	13	18	47	5	12	25	9

Table 3. Monthly densities (ind.m⁻³) of the potential predators of the Rotifera recorded in the Sapucaí arm of the Furnas Reservoir, MG, Brazil, from August 2006 to July 2007.

Predators	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
<i>Asplanchna sieboldi</i>	0	0	4	415	0	788	0	0	1	3	0	0
<i>Mesocyclops ogunnus</i> Onabamiro, 1957	0	0	0	332	102	0	14	24	30	23	25	0
<i>Thermocyclops decipiens</i> (Kiefer, 1929)	191	363	224	166	51	118	9	47	61	139	74	9
<i>Thermocyclops minutus</i> (Lowndes, 1934)	764	1,635	179	166	153	13	14	165	1,276	532	172	1,680
Cyclopoida copepodids	2,127	3,996	1,838	2,823	716	434	288	1,678	4,101	2,266	2,230	5,673
<i>Chaoborus brasiliensis</i>	0	0	0	0	0	39	1	0	3	0	0	1
<i>Turbellaria</i> (Theobald, 1901)	109	590	134	249	153	0	18	24	30	93	25	37

predators controlling rotifer populations. Thus, for the dry period there is a negative collinearity between *T. decipiens* densities and *Euchlanis dilatata*, *Keratella cochlearis*, *B. calyciflorus*, *F. longiseta*, *H. intermedia* and *K. tropica* densities. Conversely, there was a positive linear correlation with *M. ogunnus*, a potential predator of most of the Rotifera populations.

According to these results, obtained from the co-occurrence analysis, it could be inferred that competition among Rotifera populations occurred only from November to January (rainy period) ($p < 0.05$), with a C-score (0.18) higher than that randomly expected (0.14).

Discussion

The two well-defined climatic seasons that occur in the studied area, a dry winter and a rainy summer, resulted in significant changes in the abiotic and biotic variables observed in the reservoir arm formed by the Sapucaí River.

A majority of the rotifer species (22 out of 35) was recorded at high densities at the start of the rainy season while the occurrence of certain species - *Brachionus angularis*, *B. calyciflorus*, *B. caudatus*, *Keratella cochlearis* var. *tecta*, *K. tropica* and *Plationus patulus* - was entirely restricted to this period. Conversely, *Ptygura* cf. *wilsonii*

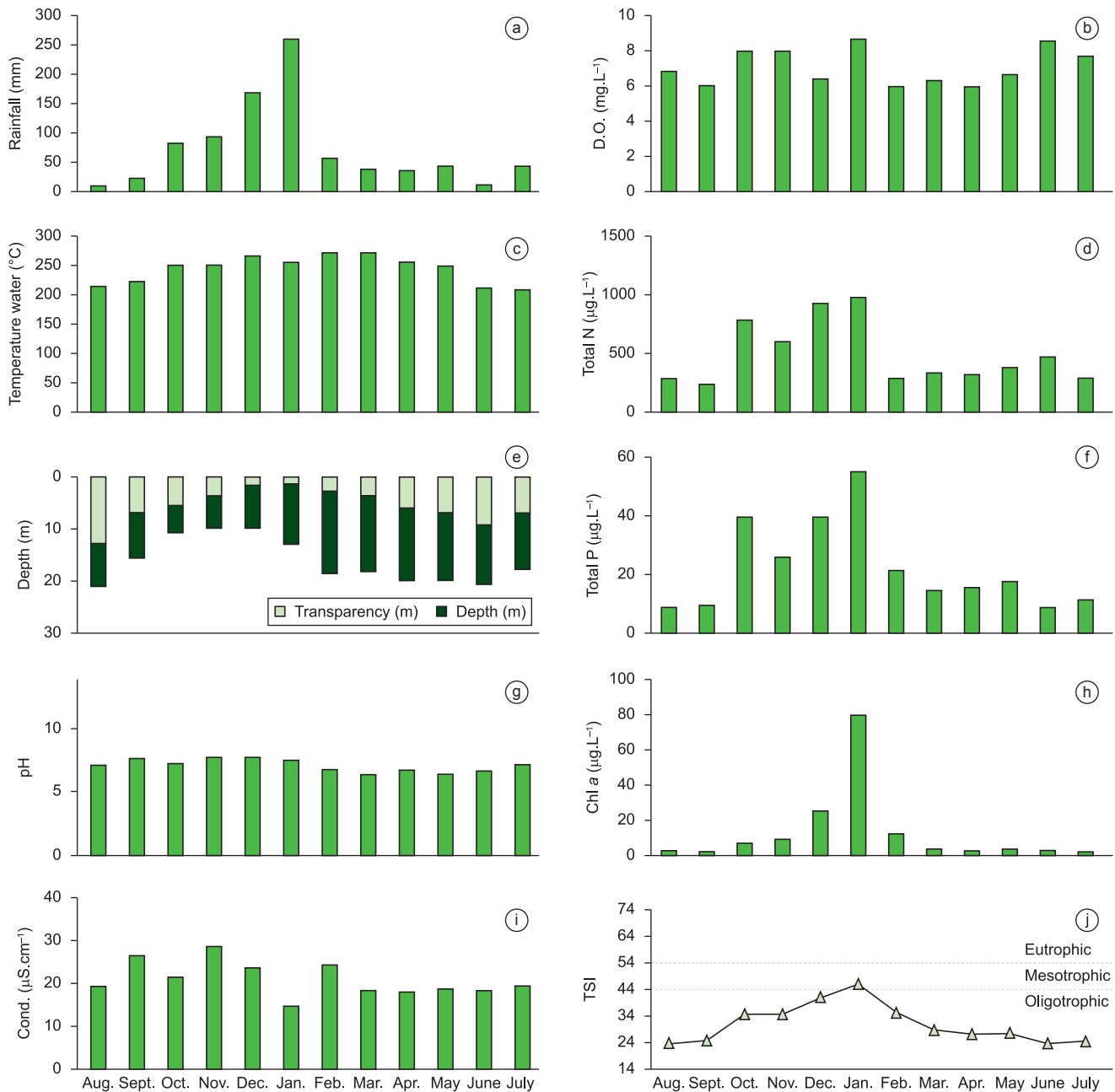


Figure 2. Monthly values of the physical, chemical and biological variables recorded in the Sapucaí arm of the Furnas Reservoir, MG, Brazil, from August 2006 to July 2007.

and *Sinantherina semibullata*, species of the family Flosculariidae, occurred not in the rainy season, but mainly in the transition from the rainy to the dry season and during the dry period.

The pH, electrical conductivity and D.O. concentrations probably had little effect on the fluctuations of the rotifer populations, since the whole ranges of variation of the variables observed were inside the range considered adequate for most zooplankton species (Sipaúba-Tavares & Rocha 2003). Eventhough the electrical conductivity did not contribute significantly to the correlations revealed by the RDA, the highest value recorded ($28.9 \mu\text{S}\cdot\text{cm}^{-1}$) coincided with the peak in the total rotifer densities, in November. Toledo et al. (2003) have pointed out that moderate electrical conductivities (around $40 \mu\text{S}\cdot\text{cm}^{-1}$) can favor the growth and even the dominance of Rotifera in tropical waters.

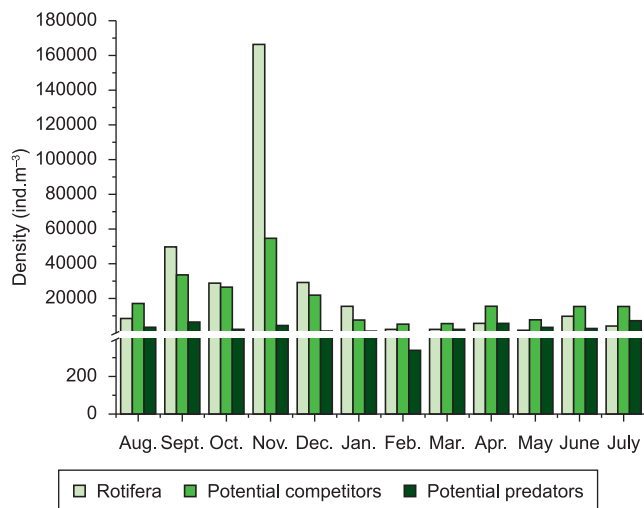
Light penetration in the water column was limited in Furnas reservoir. This is a common fact in tropical reservoirs because heavy rainfall usually carries large quantities of inorganic matter from neighboring lands into streams flowing to the reservoirs (Payne 1986).

Positive correlation was found between rotifer density and chlorophyll *a* concentrations, evidencing the importance of food, noticeably for *Brachionus caudatus*. Food availability is a biotic factor frequently related to rotifer population densities and diversity (Bonecker et al. 2005, Deveter & Sed'a 2005, Duggan et al. 2001).

In the Sapucaí arm of the reservoir, cladocerans were represented chiefly by the genera *Bosmina*, *Ceriodaphnia*, *Diaphanosoma* and *Moina*. As a rule, both rotifers and cladocerans prefer to filter algal cells lesser than $50 \mu\text{m}$ of size (MacIsaac & Gilbert

Table 4. Significance (*p* value) for each environmental variable, tested by RDA method.

Type of environmental factors	Variable	Significance (<i>p</i> value)	F value
Physical and chemical	Temperature	0.36	1.08
	Dissolved Oxygen	0.42	1.04
	Transparency	0.09	2.00
	Conductivity	0.74	0.54
	pH	0.059	2.20
Phytoplankton biomass	Chlorophyll <i>a</i>	0.02*	3.88
Crustacean competitors	Bosminidae	0.18	1.65
	Chydoridae	0.49	0.89
	Daphnidae	0.49	0.67
	Moinidae	0.01*	3.84
	Sididae	0.56	0.68
	Calanoida/Nauplii Copepoda	0.07	1.77
	Ostracoda	0.4	0.90
	Invertebrate predators	<i>Asplanchna sieboldi</i>	0.18
<i>Mesocyclops ogunnus</i>		0.006*	4.64
<i>Thermocyclops decipiens</i>		0.01*	2.31
<i>Thermocyclops minutus</i>		0.17	1.54
Cyclopoida copepodid		0.14	1.77
<i>Chaoborus brasiliensis</i>		0.07	6.39
Turbellaria		0.88	0.38

*Significant results ($p < 0.05$)**Figure 3.** Value of the Rotifera, potential competitor and potential predator densities (ind.m⁻³) in the Sapucaí arm of the Furnas Reservoir, MG, Brazil, from August 2006 to July 2007.

1989, Jaramillo-Londino & Pinto-Coelho 2010). Kirk (1997) suggests that when algal biomass acts as a limiting factor, rotifers could be at disadvantage in the competition for food, since they are less resistant to starvation. Hurtado-Bocanegra et al. (2002) found that the population growth of *B. patulus* was negatively influenced by the presence of *Ceriodaphnia dubia* and *M. macrocopa* and that there is a complex interaction between rotifers and cladocerans.

Results of the RDA indicated positive collinearity between Moinidae density (mainly *Moina minuta*) and that of rotifers *Conochilus coenobasis*, *Brachionus falcatus*, *Lecane prolecta*, *Keratella tropica* and *B. dolabratus*. In general survival strategies of *Moina* species are similar to those of rotifers, which have high

rates of population growth and short life cycles (Nandini & Sarma 2000). In the present study *Moina minuta* population probably had no prejudicial effect on rotifers, since the latter were found at far higher densities (around 800 – fold higher) throughout the period of study. Even though clearance rates of *Moina* are around 25 times greater than rotifer clearance rates - (235 $\mu\text{L ind.}^{-1}/\text{hour}$ - for *Moina micrura* (Macedo & Pinto-Coelho 2000), and 9 $\mu\text{L ind.}^{-1}/\text{hour}$ - for *Keratella cochlearis*, *Polyarthra vulgaris* and *P. dolychoptera* (Bogdan & Gilbert 1982).

Analysis of the co-occurrences indicated that in the rainy period (November to January), competitive interactions were strong among rotifer populations ($p < 0.001$). This fact is consistent with the high species diversity and high densities of rotifers observed in the Sapucaí arm during the period of study. In natural environments herbivore communities can compete strongly by limiting resources leading to coexistence or exclusion of species (DeMott & Kerfoot 1982).

Although the food niches of rotifers are more specialized than those of cladocerans (Bogdan & Gilbert 1982), limiting resources can lead to inter-specific competition depending on rotifer sizes, food concentration and the initial densities of the competing species (Sarma et al. 2008).

Predators with most of rotifers observed in Furnas reservoir were the copepodites and adults of Cyclopoida (*Mesocyclops ogunnus*, *Thermocyclops decipiens* and *T. minutus*), the larvae of the dipteran *Chaoborus brasiliensis*, the rotifer *Asplanchna sieboldi* and turbellarians. In the rainy season, *Mesocyclops ogunnus* numbers showed significant positive correlation ($p < 0.001$) with most rotifers and, due to the low *Mesocyclops* densities, this copepod probably had no negative effect on the rotifer populations. In the dry season, adults of *Thermocyclops decipiens* were recorded at high densities and showed negative collinearity ($p < 0.05$) with the rotifer species *Euchlanis dilatata*, *Keratella cochlearis*, *Brachionus calyciflorus*, *Filinia longiseta*, *Hexarthra intermedia* and *K. tropica*, according to RDA results.

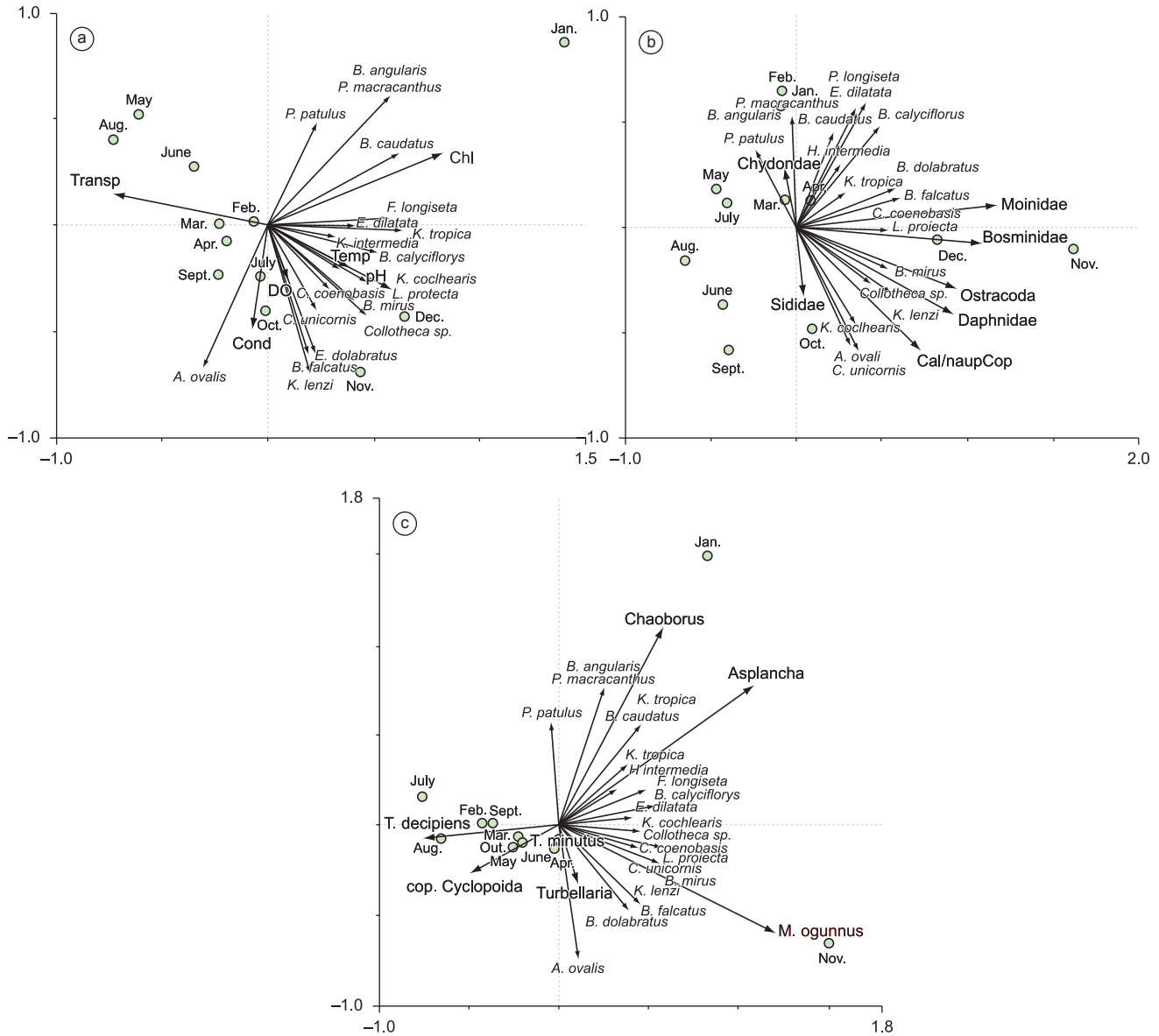


Figure 4. RDA ordination chart between: a) Rotifera density and environmental variables; b) Rotifera density and competitors; and c) Rotifera density and predators.

Predation pressure exerted by *Thermocyclops decipiens* probably determined the decrease in rotifer densities in this reservoir arm, in the dry period. The highly-developed ability of species of the suborder Cyclopoida to seize their prey among the zooplankton is already well-established (Plaßmann et al. 1997, Williamson, 1983, 1984, Matsumura-Tundisi et al. 1997, Dieguez & Gilbert 2002). Representatives from many taxa are reported to feed on rotifers. There are good quantitative data on predation on rotifers by both, predaceous Rotifera and Cyclopoida copepods (Williamson & Gilbert 1980, Stemberger & Evans 1984). Additionally, the limited information available on other predatory invertebrate taxa present in Furnas reservoir zooplankton suggests that rotifer production may contribute extensively to their diets.

Among the environmental factors, food availability as indicated by algal biomass, had an important role on rotifer abundances during the rainy period, but inter-rotifer competition was also significant in these months. On the other hand, it was probably that predation by the cyclopoid copepod *Thermocyclops decipiens* determined the structure and dynamics of the rotifer populations in the Sapucaí arm of Furnas reservoir during the dry period.

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