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Scientific Article

Biodiversity, spatial, and seasonal distribution of the zooplankton community in semi-intensive fish farms in Rondônia state, Brazil

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ABSTRACT

In this study we determined the spatial and seasonal distribution (rainfall and drought) of the zooplankton community in 30 fish farms in the microregions of Vale do Jamari and Central-East of Rondônia. The experiment was organized in a completely randomized factorial scheme. The species were considered in composition, richness, frequency of occurrence, relative abundance and diversity indices (H', J and S). There were records of greater richness of Copepoda (550 to 1214), Ostracoda (360 to 989.6), Rotifera (71 to 431) and Cladocera (344 to 990). In the Jamari Valley, the most abundant species (Individuals per 100 mL) were Ostracoda (323), Copepoda (160) and Rotifera (111). In the Center-East, they were Copepoda (287), Rotifera (108) and Ostracoda (106). In the two microregions there were variations in the seasonal distribution, except for the populations of the phylum Cloadocera. The diversity indices differed, registering a greater diversity of populations of Ostracoda in the Jamari Valley and Copepoda in the Center-East and in the rainy season.

Keywords: Agroecosystem; Copepoda; Diversity indices; Ostracoda; Seasonality.

Biodiversidade, distribuição espacial e distribuição sazonal da comunidade zooplanctônica em pisciculturas semi-intensivas de Rondônia, Brasil

RESUMO

Neste estudo determinamos a distribuição espacial e sazonal (chuva e seca) da comunidade zooplanctônica em 30 pisciculturas, nas microrregiões do Vale do Jamari e Centro-Leste de Rondônia. O experimento foi organizado num esquema fatorial inteiramente casualizado. As espécies foram consideradas em composição, riqueza, frequência de ocorrência, abundância relativa e nos índices de diversidade (H', J e S). Houve registros de maior riqueza de Copepoda (550 a 1214), Ostracoda (360 a 989,6), Rotifera (71 a 431) e Cladocera (344 a 990). No Vale do Jamari, as espécies mais abundantes (Indivíduos por 100 mL) foram de Ostracoda (323), Copepoda (160) e Rotifera (111). No Centro-Leste, foram de Copepoda (287), Rotifera (108) e Ostracoda (106). Nas duas microregiões houve variações na distribuição sazonal, exceto para as populações do filo Cloadocera. Os índices de diversidade diferiram, registrando maior diversidade de populações de Ostracoda no Vale do Jamari e Copepoda no Centro-Leste e na estação da chuva.

Palavras-chave: Agroecossistema; Copepoda; Índices de diversidade; Ostracoda; Sazonalidade.

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INTRODUCTION

Rondônia state stands out as the leading producer of native fish in Brazil, with a total volume of 57.2 thousand tons in 2023 (Peixe BR, 2023). Fish farming ponds are agroecosystems with high planktonic richness; the zooplankton found in these artificial aquatic ecosystems is predominantly composed of species from the phyla Rotifera, Cladocera, Copepoda, and Ostracoda (Ibrahim et al., 2023). These aquatic invertebrates play a vital role in the food chain, facilitating the transfer of mass and energy from primary producers to higher trophic levels (Nunes et al., 2023).

Zooplankton inventories in catchment water and fishpond effluents are critical for assessing the ecological health and sustainability of aquatic systems. These inventories provide insights into biodiversity, species composition, and the responses of zooplankton communities to environmental changes, including nutrient loading and pollution (Hall & Lewandowska, 2022). Studies indicate that catchment management practices significantly influence zooplankton dynamics, affecting their roles in nutrient cycling and energy transfer within food webs (Ibrahim et al., 2023). Moreover, understanding the relationships between zooplankton assemblages and water quality parameters can inform strategies for mitigating negative impacts from effluents and improving the management of fish farming systems (Nunes et al., 2023). Thus, regular monitoring is essential for promoting sustainable aquaculture and conserving aquatic biodiversity.

Different groups of zooplankton exhibit a diversity of reproductive strategies, ranging from simple fission to sexual reproduction, and these strategies influence population size and resource availability (Helenius et al., 2015). Under suitable conditions, species of Rotifera and Cladocera often reproduce through parthenogenesis, reserving sexual reproduction for rare occasions, typically in response to unfavorable environmental conditions, resulting in the formation of resting eggs (Gilbert, 2020). On the other hand, in Copepoda species, reproduction is mainly sexual, with slower population growth compared to other zooplankton groups. Eggs are carried in the abdomen, in ovigerous sacs, and, in some genera, the production of resting eggs allows for prolonged periods of survival in sediment (Kadiene et al., 2017).

The short life cycle and rapid turnover of zooplankton result in quick responses to disturbances that impact the physical, chemical, and biological properties of water (Ibrahim et al., 2023). Among the environmental factors that exert the greatest influence on the composition and abundance of zooplankton are temperature, intra- and interspecific competition, predation, as well as food quality and availability (Picapedra et al., 2021). Plankton is affected by herbivory and nutrient recycling; ecological interactions among different trophic levels can modify the effects of nutrient additions. For instance, phosphorus excretion by zooplankton, along with phosphatase action, is one of the main mechanisms for regenerating this element in the water column (Bai et al., 2022). Changes in zooplankton community attributes are common in response to alterations caused by human activity, including variations in species diversity, evenness, dominance, population densities, as well as the exclusion of certain species and the population increase of others (Hall & Lewandowska, 2022). Given the crucial functional role of the zooplankton community in aquatic ecosystems and the impact of land use and occupation on this community, this study aimed to contribute to the understanding of zooplankton biodiversity and spatial and temporal structure (Resende et al., 2022).

Some biotic factors play a crucial role in the ecology of freshwater invertebrate fauna in environments directly linked to flow or discharge dynamics (Cantonati et al., 2020). During low-flow periods (dry season), known as the growing season, environmental conditions become more favorable for organism establishment, characterizing a hydrological scenario with reduced downstream transfer and dilution. During the dry season, when connectivity is reduced, all aquatic bodies regain their individuality, including their habitats, characteristics, and biota (Pereira et al., 2011). The effects on communities can be complex, with decreased organism recruitment and reduced physical constraints.

The Amazon region is characterized by high-flow tropical rivers and smaller water bodies, forming an extensive network of watercourses. The hydrological pulse is one of the forces regulating aquatic communities (Fassoni-Andrade et al., 2021), and, if biotic interactions are influenced by this population dynamics, the low-flow period becomes a conducive time for these interactions. For smaller tributaries, locally referred to as streams, besides interactions between abiotic and biotic elements, pressures exerted on vegetation areas and inadequate soil management have played a crucial role in ecological balance and biodiversity loss (Teramoto et al., 2022).

Modifications resulting from ongoing urbanization processes in major urban centers, along with sudden increases in water volume due to variations in precipitation regimes, are common occurrences, significantly impacting studies on invertebrate diversity in these environments (Bohus et al., 2023). Considering that the fauna of these environments is highly diversified and that studies on zooplankton ecology have increased in recent decades, few studies have been conducted in the Amazon basin, particularly in fish farm ponds in Rondônia state, to determine how human actions can modify watersheds, promoting changes in biodiversity and the aquatic ecosystem (Rico et al., 2022).

This study aimed to investigate the spatial and seasonal distribution of the zooplankton community in fish farms in the Vale do Jamari and Centro-Leste microregions in Rondônia, Brazil. By focusing on the diversity of zooplankton, which includes key groups such as Rotifera, Cladocera, Copepoda, and Ostracoda, the research sought to understand how these communities respond to environmental variations and human impacts. The findings will contribute to the knowledge of zooplankton biodiversity and its functional role in aquatic ecosystems. Conducting an inventory of zooplankton at water entry and exit points in fishponds is crucial for assessing ecosystem health and identifying potential environmental impacts. This inventory aids in monitoring biodiversity changes, evaluating nutrient cycling, and enhancing sustainable management practices, ensuring the balance of these vital aquatic ecosystems.

Given the assumptions, the aim of this study was to determine the spatial and seasonal distribution of the zooplankton community in fish farming water in the microregions of the Vale do Jamari and Centro-Leste of Rondônia state, Brazil.

MATERIAL AND METHODS

Water samples were obtained from 30 fish farms in the state of Rondônia, of which 19 fish farms are located in the Centro-Leste microregion (sampling points in yellow, Fig. 1), and 11 fish farms are located in the Vale do Jamari microregion (sampling points in green, Fig. 1). These fish farms are situated in the municipalities of Ji-Paraná, Presidente Médici, Ouro Preto do Oeste, Urupá, Mirante da Serra, Nova União, Teixeirópolis, and Vale do Paraíso (located in the Centro-Leste), and Ariquemes, Buritis, Machadinho do Oeste, Cacaulândia, Monte Negro, Cujubim, and Rio Crespo (located in the Vale do Jamari) (Fig. 1).

The fish farms were visited during the two Amazonian hydrological seasons, rainy (November to March) and dry (April to October), in the years 2022 and 2023. Laboratory

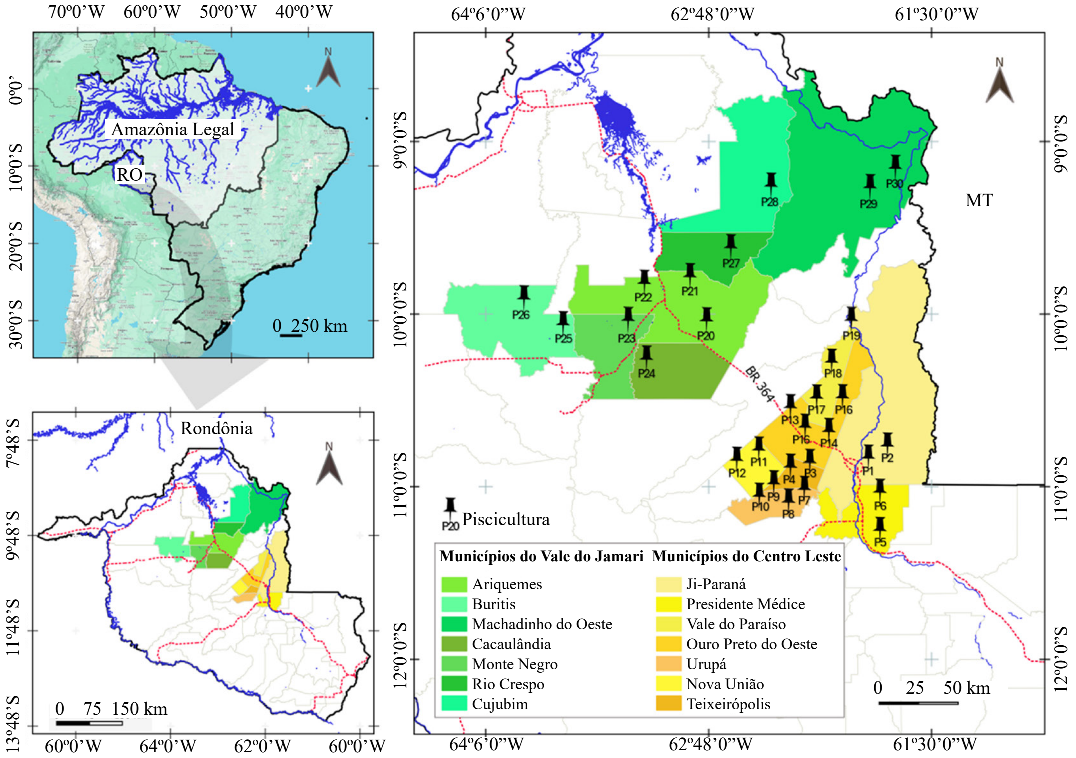


Figure 1. Location of fish farms where water samples were obtained in Rondônia state, Brazil. (each purple dot indicates five sample points from fish farms in the Centro-Leste microregion, as well as each orange point indicates five sample points from fish farms in Vale do Jamari microregion).

analyses were conducted at the Centro de Diagnóstico Animal of the Universidade Federal de Rondônia, Rolim de Moura *Campus*.

Each of the 30 fish farms was visited twice, with plankton collected in triplicate. The experimental design followed a completely randomized factorial scheme (30 fish farms × five sampling points × three repetitions), meaning 30 fish farms, three semi-intensive excavated fishponds from each sampled fish farm, one effluent from each sampled fish farm, one supply channel (or supply reservoir) from each sampled fish farm, with three replicates each. Sampling covered three points in each fish farm: water from the supply channel (water inlet), drainage pipe (water outlet, effluent), and water column in the middle of three ponds. Sampling points were selected considering the flow of water supply to the fishponds. Following the suggestion of Costa et al. (2016), the fishponds were connected in series, in which the water from the supply reservoir feeds the first pond, and so on, so that the water from one pond feeds the next. Consequently, the water contained in the last pond passed through all the previous ones. Based on this configuration, sampling was performed in alternating excavated ponds.

To obtain qualitative samples, horizontal and vertical drags were conducted on the water surface of the fishponds, supply reservoir, and effluent. Each quantitative sample was obtained using a plankton net (with a mesh size of 50 μm), and a graduated bucket was used to collect the water. Zooplankton were the focus of this study; thus, the samples were immediately stored and settled in polyethylene terephthalate bottles and kept at 7°C in cooler-type thermal boxes until they were sent to the laboratory. The settled and filtered biological material was preserved in a 6:3:1 solution, which is equivalent to 60% distilled water, 30% ethanol, and 10% formaldehyde. Then, five drops of 10% copper sulfate were added to each sample to preserve the coloration of the organisms to be observed (Pereira et al., 2011).

For qualitative-quantitative analyses, zooplankton abundance was expressed in individuals per 100 mL (Ind./100·mL^{-1}). A total of 900 water samples [(30 fish farms × five sampling points × three repetitions) × two seasons)] were examined using a micropipette (calibrated at 1 mL), with sub-samples of 2 mL taken for individual counting in a Neubauer chamber and identification under a binocular optical stereoscopic microscope, model Bioval (Sigma, United States of America), with a magnification capacity of up to 10^3 times. The microscope was equipped with a professional digital photographic camera (Canon EOS Rebel T8i EF-S 18–55 mm) attached. Subsequently, photomicrographs of the obtained images were amplified in the ViPlus software, validating morphological and behavioral identification. Taxonomic keys used for identification were from Hernández et al. (2021) and Mindat (2024).

The frequency of occurrence (Fo) of identified species was calculated based on the ratio of the number of samples in which the organism occurred to the total number of samples collected. Following the criteria of Mateucci and Colma (1982), Eq. 1 was used.

$$F = Px100/p \tag{1}$$

Where: P= the number of samples containing the species; p= the total number of samples collected.

The following classification categories were considered: ≥ 70% very common; < 70% to ≥ 40% frequent; < 40% to ≥ 10% infrequent; and < 10% sporadic. The relative abundance of different organisms was calculated taking into account the number of individuals of the species per sample analyzed in relation to the total number of individuals in the sample, expressed as a percentage. The following criteria were assigned: ≥ 70% dominant; < 70% to ≥ 40% abundant; < 40% to ≥ 10% not very abundant; and < 10% rare, according to Lobo and Leighton (1986). The specific diversity indices (H') of the analyzed species were based on Shannon (1948) and calculated using Eq. 2.

$$H' = -\Sigma pi.Log2\ pi \tag{2}$$

Where: pi= ni / N; ni= number of individuals of each species; N= total number of individuals in the sample.

The result was expressed in Ind./mL^{-1}, considering the following criteria: ≥ 3 Ind./mL^{-1} represents high diversity; < 3 to ≥ 2 Ind./mL^{-1} average diversity; < 2 to ≥ 1 Ind./mL^{-1} low diversity; and < 1 Ind./mL^{-1} very low diversity (Pereira et al., 2011). Equity (J) was calculated from the Shannon's index (H'/H max.), using the Pielou formula showed in Eq. 3.

$$J = H' / Log\ S \tag{3}$$

For this index, values between 0 and 1 were adopted, and > 0.5 indicates good distribution of individuals between species.

Statistical analysis was performed using the Minitab statistical package version 14.1. Initially, a descriptive analysis of the data was carried out, calculating means (μ), standard deviations ± SD (σ), and other relevant statistical measures for each parameter analyzed. After verifying the homogeneity and homoscedasticity of the data, analysis of variance (ANOVA) was applied to identify possible significant differences between species abundance and richness, considering spatiality and seasonality.

Post-hoc graphs were created after the ANOVA to identify which groups showed significant differences. In this study, which aimed to analyze the spatial and seasonal distribution of the zooplankton community in fish farming waters, post-hoc tests allowed comparisons between sampling points and seasons. The graphs visually present these differences, through confidence intervals or letter plots, in which groups without significant differences share the same letter. Thus, it was possible to identify variations in zooplankton composition between locations and seasons (dry and rainy), facilitating data interpretation and assisting in the sustainable management of fish farms.

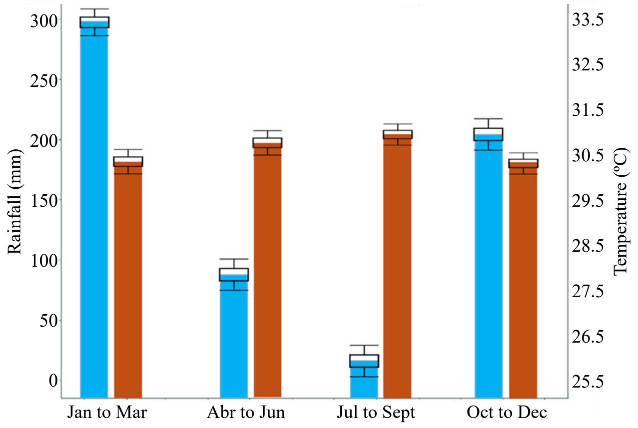
All statistical analyses were considered significant at $p < 0.05$.

RESULTS

Characteristics of fish farms and climate

Generally, fish farms adopted semi-intensive cultivation (with an average of up to 0.6 kg/m^2/year with a production cycle of 10 to 14 months), occupying an area of up to 7 hectares of water, distributed in semi-intensive excavated ponds, with an average depth of 1.60 m, for the raised tambaqui (*Colossoma macropomum*, Cuvier, 1818).

The climate of the state of Rondônia is characterized by the Köppen system as predominantly Am–rainy tropical climate. During the coldest month, the average air temperature is above 18°C (megathermal), with a well-defined dry season, moderate water deficit, and rainfall indices below 50 mm per month. Annual rainfall varies between 1,400 and 2,600 mm, while the average monthly air temperature ranges from 24 to 26°C (Fig. 2).



Source: CPTEC/INPE (2023).

Figure 2. Monthly averages of rainfall (mm) and air temperature in the interior of Rondônia, Brazil, in the different hydrological seasons (rainy and dry), in the years 2022 and 2023.

Composition, zooplankton richness, and spatial and seasonal distribution

The zooplankton composition of the species with greater richness and abundance in fishponds freshwater was represented by the groups Ciliophora (two species), Cladocera (six species), Copepoda (four species), Nematoda (one species), Protozoa (eight species), Rotifera (19 species), and Ostracoda (two species), totaling 42 taxa found during the study. Figure 3 shows some of the most frequent species per phylum, *Thermocyclops decipiens* and *Acanthocyclops* sp. (Copepoda) (Fig. 3a), *Daphnia magna* and *Daphnia ambigua* (Cladocera) (Fig. 3b), *Paraenchelys terricola* (Protozoa) (Fig. 3c), *Keratella quadrata*, *Keratella* sp. and *Brachionus* sp. (Rotifera) (Fig. 3d) and *Heterocypris* sp. and *Heterocypris punctata* (Ostracoda).

Regarding species richness, there was a predominance of the phyla Copepoda (from 550 to 1,214 records), Ostracoda (360 to 989.6 records), Rotifera (71 to 431 records), and Cladocera (344 to 990 records), showing the greatest richness, both according to spatial distribution and seasonal distribution. In both regions, there were significant variations in the seasonal distribution for all phyla (Fig. 4a).

Concerning the abundance of individuals per 100 mL, the three most abundant phyla in the Vale do Jamari microregion were Ostracoda (323 Ind./100 mL^{-1}), Copepoda (160 Ind./100 mL^{-1}) and Rotifera (111 Ind./100 mL^{-1}), while in the Centro-Leste microregion, Copepoda (287 Ind./100 mL-1), Rotifera (108 Ind./100 mL^{-1}), and Ostracoda (106 Ind./100 mL^{-1}). In both microregions, there were significant variations in seasonal distribution, except only for populations of the phylum Cloadocera (Fig. 4b).

Frequency of occurrence

A total of 42 taxas was identified, with the phyla Ostracoda and Copepoda being the most frequent in microregions and in the rainy and dry hydrological seasons. The species *T. decipiens* and *Argyrodiaptomus furcatus* (Copepoda) and *Heterocypris* sp. and *H. punctata* (Ostracoda) were very common in the two microregions and in the two hydrological seasons. There are a higher frequency of Ostracoda in fish farms in Vale do Jamari and a higher frequency of Copepoda in fish farms in the Centro-Leste of Rondônia state, while the species *D. magna* (Cladocera), *K. quadrata*, *Keratella* sp. and *Brachionus* sp. (Rotifera) were frequent in the two microregions and in the two hydrological seasons. There is a higher frequency of Rotifera in the Centro-Leste compared to the Vale do Jamari. All other species identified were infrequent or sporadic.

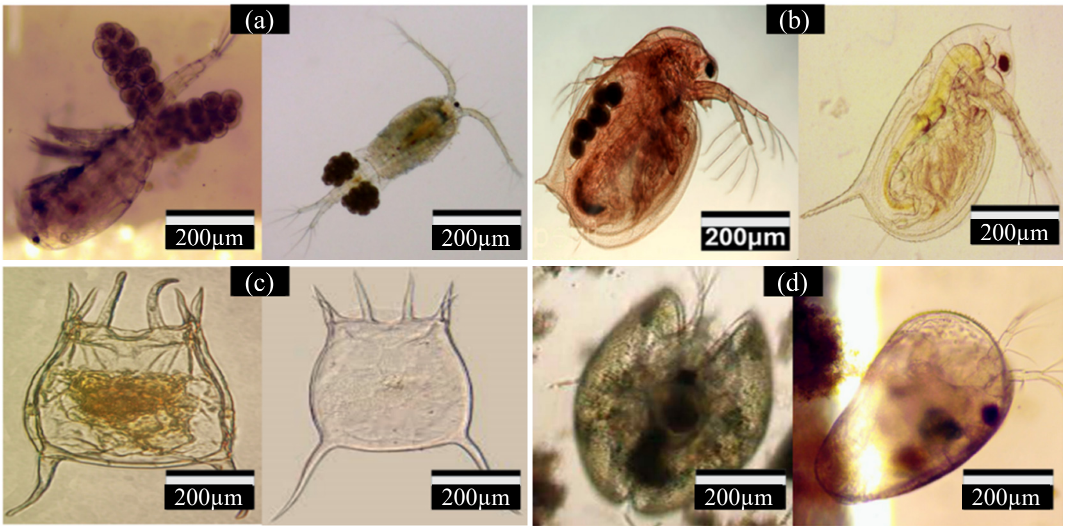


Figure 3. Photomicrographs of the most common zooplankton in the phylum: (a) *Thermocyclops decipiens* and *Acanthocyclops* sp. (Copepoda), (b) *Daphnia magna* and *Daphnia ambigua* (Cladocera), (c) *Keratella quadrata*, and *Keratella* sp. (Rotifera), and (d) *Heterocypris* sp. and *Heterocypris punctata* (Ostracoda).

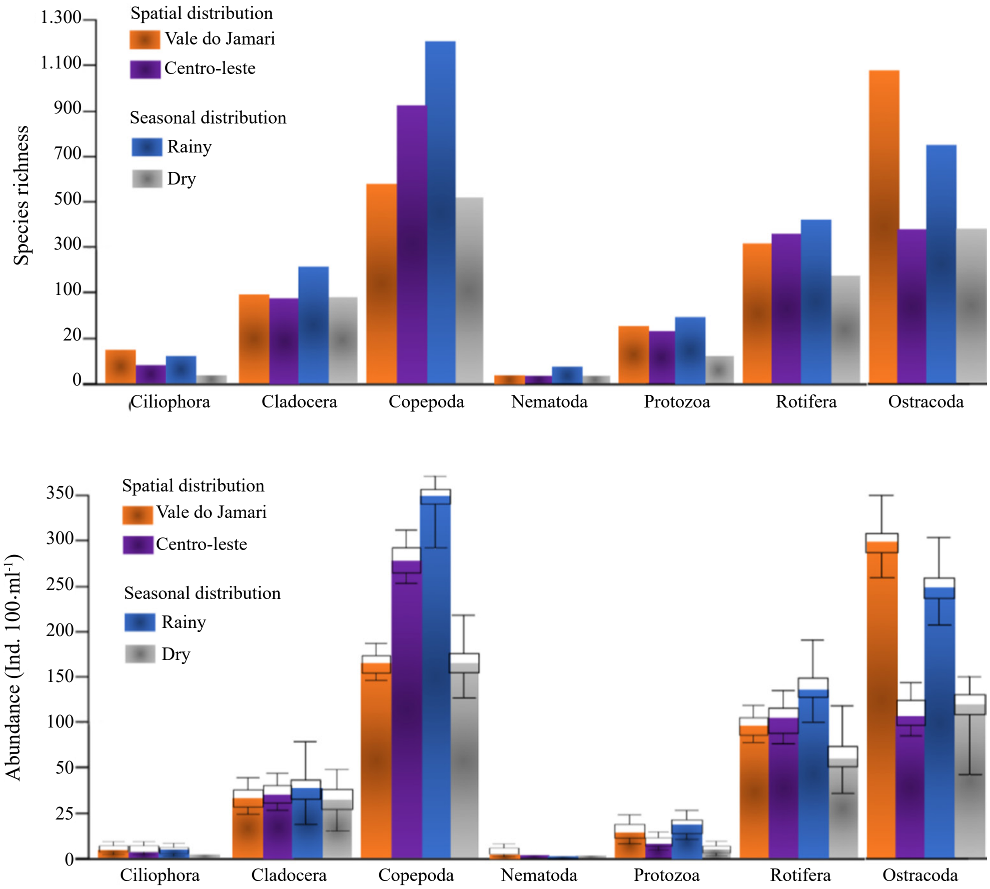


Figure 4. Graphs of post-hoc tests showing distribution variations of a) Richness and (b) abundance of zooplanktonic species in the taxonomic categories identified in fish farm water, spatial and seasonal distribution.

For the most frequent phyla, Copepoda, Ostracoda and Rotifera, the frequency of occurrence was always higher ($p < 0.05$) in the rainy season compared to the dry season (Table 1).

Relative abundance

During the study period of the 42 identified taxa, no species exhibited dominance in the microregions of Rondônia state, nor showed dominance in the hydrological seasons. Even when calculating the total per phylum, there was still no dominance; however, the highest abundances of Ostracods and Copepods can be observed. The populations of the phylum Ostracoda in the Vale do Jamari microregion showed a relative abundance of 49.370%, and Copepoda of 28.254%.

In the Centro-Leste microregion, the populations of the phylum Copepoda showed a relative abundance of 54.105%, and Ostracoda 19.042%. During the rainy season, the populations

Table 1. Average frequency of occurrence of taxa identified in fish farm water in Rondônia state, Brazil, spatial and seasonal distribution*.

Taxa	Collection points			
	Microregions		Seasonality	
	Vale do Jamari	Centro-Leste	Rainy	Dry
CILIOPHORA	10.00	6.7	9.3	1.10
Vorticella sp.	9.00	4.20	6.30	1.10
Zoothamnium sp. (Sommer, 1951)	1.00	2.50	3.0	0.00
CLADOCERA	97.30	104.38	121.17	97.28
Daphnia ambigua (Scourfield, 1947)	9.40	5.84	7.56	3.90
Daphnia magna (Straus, 1820)	40.67	44.00	52.30	46.15
Ceriodaphnia sp. (Dana, 1853)	31.23	38.47	34.76	29.05
Diaphanosoma sp. (Fischer, 1850)	8.00	7.20	8.30	6.99
Macrothrix sp. (Baird, 1843)	3.00	4.88	10.00	5.98
Moina sp. (Baird, 1843)	5.00	3.99	8.25	5.21
COPEPODA	566.27	963.94	1.213.95	527.25
Thermocyclops decipiens (Kiefer, 1929)	460.74	822.60	999.02	444.60
Acanthocyclops sp. (Kiefer, 1929)	6.09	2.24	8.11	1.99
Argyrodiaptomus sp. (Brehm, 1933)	1.09	4.33	6.42	1.99
Argyrodiaptomus furcatus (Sars G. O., 1901)	98.35	134.77	200.40	78.67
NEMATODA	4.42	3.96	6.05	3.00
Criconematidae sp. (Taylor, 1 936)	4.42	3.96	6.05	3.00
PROTOZOA	43.6	34.09	65.32	15.92
Paraenchelys terricola (Foissner, 1984)	16.12	8.92	20.25	4.24
Apospathidium terricola (Foissner, Agatha & Berger, 2002)	0.42	2.95	4.00	0.00
Spirostomum teres (Claparède & Lachmann, 1859)	0.00	0.99	2.00	0.00
Linostomella vorticella Aescht, 1999 (Ehrenberg, 1833)	1.25	0.00	1.88	0.00
Halteria grandinella (Müller, 1773) Dujardin, 1841	24.80	15.10	30.28	11.33
Sphaerophrya magna Claparède & Lachmann, 1860 (Maupas, 1881)	0.00	0.98	1.80	0.20
Paramecium bursaria (Ehrenberg, 1831) Focke, 1836	0.87	2.22	2.95	0.15
Paramecium caudatum (Ehrenberg, 1833)	0.14	2.93	2.16	0.00

Continue...

Table 1. Continuation.

Taxa	Collection points			
	Microregions		Seasonality	
	Vale do Jamari	Centro-Leste	Rainy	Dry
ROTIFERA	303.16	335.98	431.65	195.36
Keratella quadrata (Müller, 1786)	77.54	86.00	111.99	82.20
Keratella tropica (Apstein, 1907)	1.25	2.00	1.88	0.66
Keratella sp. (Bory de Saint-Vincent, 1822)	80.25	64.00	100.35	39.11
Keratella cochlearis (Gosse, 1851)	3.25	2.00	4.88	0.40
Kellicottia bostoniensis (Rousselet, 1908)	1.25	2.88	4.05	0.10
Asplanchna brightwellii (Goose, 1850)	0.14	0.96	1.86	0.00
Brachionus calyciflorus (Pallas, 1766)	0.62	0.23	0.81	0.00
Brachionus caudatus (Barrois & Dad ay, 1894)	2.25	7.00	8.88	0.37
Brachionus falcatus (Zacharias, 1898)	0.22	0.00	0.40	0.00
Brachionus havanaensis (Rousselet, 1911)	0.27	0.16	0.30	0.00
Brachionus mirus (Daday, 1905)	0.33	0.30	0.60	0.00
Brachionus sp. (Pallas, 1766)	71.02	74.00	105.85	35.26
Conochilus spp. (Ehrenberg, 1834)	42.05	73.30	50.25	25.00
Euchlanis spp. (Ehrenberg, 1830)	1.38	0.30	1.61	0.30
Filinia longiseta (Ehrenberg, 1834)	0.73	0.90	1.70	0.20
Polyarthra sp. (Ehrenberg, 1834)	1.55	0.80	3.00	0.00
Testudinella mucronata (Goose, 1866)	8.33	8.30	12.60	5.10
Testudinella patina (Hermann, 1783)	10.40	12.55	20.04	6.66
Trichocerca similis (Wierzejski, 1893)	0.33	0.30	0.60	0.00
OSTRACODA	989.6	339.26	831.43	359.72
Heterocypris sp. (Claus, 1892)	869.60	313.70	699.43	343.72
Heterocypris punctata (Keyser, 1975)	120.00	25.56	132.00	16.00
TOTAL	2.004.35	1.781.61	2.669.57	1.198.53

*≥ 70 very common, < 70 ≥ 40 common, < 40 ≥ 10 uncommon, and < 10 sporadic.

of the phylum Copepoda (45.474%) showed higher relative abundance compared to Ostracoda (31.145%). A similar result was observed in the dry season, in which the populations of Copepoda (43.991%) were more abundant compared to Ostracoda (30.013%). However, considering the simultaneous spatial and seasonal distributions of zooplankton populations in fish farm water, the Vale do Jamari microregion showed higher abundance of Ostracodas, while the Centro-Leste had higher abundance of Copepods.

Regarding the spatial distribution of relative abundance, in the Vale do Jamari, the species *Heterocypris* sp. (Ostracoda) was abundant at 43.385%, and *T. decipiens* (Copepoda) was somewhat abundant at 22.990%, with the remaining species being rare at 33.625%. In the Centro-Leste, the species *T. decipiens* (Copepoda) was abundant at 46.172%, and *Heterocypris* sp. (Ostracoda) was somewhat abundant at 17.607%, with the remaining species being rare at 36.221%.

Next, information on the seasonal distribution of relative abundance was obtained. In the rainy season, *T. decipiens* (Copepoda) was somewhat abundant at 37.423%, and *Heterocypris* sp. (Ostracoda) was also somewhat abundant at 26.200%, with the remaining species being rare at 36.377%. Meanwhile, in the dry season, *T. decipiens* (Copepoda) was somewhat abundant at 37.095%, and *Heterocypris* sp. (Ostracoda) was also somewhat abundant at 28.678%, with the remaining species being rare at 34.227%.

Table 2. Average relative abundance (%) of taxa identified in fish farm water in Rondônia state, Brazil, spatial and seasonal distribution*.

Taxa	**Collection points**			
	Microregions		**Seasonality**	
	Vale do Jamari	**Centro-Leste**	**Rainy**	**Dry**
CILIOPHORA	**0.499**	**0.376**	**0.348**	**0.092**
Vorticella sp.	0.449	0.236	0.236	0.092
Zoothamnium sp. (Sommer, 1951)	0.049	0.140	0.112	0.000
CLADOCERA	**4.854**	**5.859**	**4.539**	**8.117**
Daphnia ambigua (Scourfield, 1947)	0.469	0.328	0.283	0.325
Daphnia magna (Straus, 1820)	2.029	2.470	1.959	3.851
Ceriodaphnia sp. (Dana, 1853)	1.558	2.159	1.302	2.424
Diaphanosoma sp. (Fischer, 18 50)	0.399	0.404	0.311	0.583
Macrothrix sp. (Baird, 1843)	0.149	0.274	0.375	0.499
Moina sp. (Baird, 1843)	0.249	0.224	0.309	0.435
COPEPODA	**28.254**	**54.105**	**45.474**	**43.991**
Thermocyclops decipiens (Kiefer, 1929)	**22.990**	**46.172**	**37.423**	**37.095**
Acanthocyclops sp. (Kiefer, 1929)	0.303	0.126	0.304	0.166
Argyrodiaptomus sp. (Brehm, 1933)	0.054	0.243	0.240	0.166
Argyrodiaptomus furcatus (Sars G. O., 1901)	4.907	7.564	7.507	6.564
NEMATODA	**0.225**	**0.222**	**0.227**	**0.250**
Criconematidae sp. (Taylor, 1936)	0.225	0.222	0.227	0.250
PROTOZOA	**2.175**	**1.913**	**2.447**	**1.328**
Paraenchelys terricola (Foissner, 1984)	0.804	0.500	0.759	0.354
Apospathidium terricola (Foissner, Agatha & Berger, 2002)	0.020	0.166	0.150	0.000
Spirostomum teres (Claparède & Lachmann, 1859)	0.000	0.055	0.075	0.000
Linostomella vorticella Aescht, 1999 (Ehrenberg, 1833)	0.062	0.000	0.070	0.000
Halteria grandinella (Müller, 1773) Dujardin, 1841	**12.37**	0.847	1.134	0.945
Sphaerophrya magna Claparède & Lachmann 1860 (Maupas, 1881)	0.00	0.055	0.067	0.017
Paramecium bursaria (Ehrenberg, 1831) Focke, 1836	0.043	0.124	0.111	0.013
Paramecium caudatum (Ehrenberg, 1833)	0.007	0.164	0.081	0.000
ROTIFERA	**15.125**	**18.858**	**16.169**	**16.300**
Keratella quadrata (Müller, 1786)	3.869	4.827	4.195	6.858
Keratella tropica (Apstein, 1907)	0.062	0.112	0.070	0.055
Keratella sp. (Bory de Saint-Vincent, 1822)	4.004	3.592	3.759	3.263
Keratella cochlearis (Gosse, 1851)	0.162	0.112	0.183	0.033
Kellicottia bostoniensis (Rousselet, 1908)	0.062	0.161	0.152	0.008
Asplanchna brightwellii (Goose, 1850)	0.007	0.054	0.070	0.000
Brachionus calyciflorus (Pallas, 1766)	0.031	0.013	0.030	0.000
Brachionus caudatus (Barrois & Dad ay, 1894)	0.112	0.393	0.333	0.031
Brachionus falcatus (Zacharias, 1898)	0.011	0.000	0.015	0.000
Brachionus havanaensis (Roussele t, 1911)	0.013	0.009	0.011	0.000

Continue...

Table 2. Continuation.

Taxa	Collection points			
	Microregions		**Seasonality**	
	Vale do Jamari	**Centro-Leste**	**Rainy**	**Dry**
Brachionus mirus (Daday, 1905)	0.016	0.017	0.022	0.000
Brachionus sp. (Pallas, 1766)	3.543	4.153	3.965	2.942
Conochilus spp. (Ehrenberg, 1834)	2.098	4.114	1.882	2.086
Euchlanis spp. (Ehrenberg, 1 830)	0.069	0.017	0.060	0.025
Filinia longiseta (Ehrenberg, 1834)	0.036	0.050	0.064	0.017
Polyarthra sp. (Ehrenberg, 1834)	0.077	0.045	0.112	0.000
Testudinella mucronata (Goose, 1866)	0.416	0.466	0.472	0.426
Testudinella patina (Hermann, 1783)	0.519	0.704	0.751	0.556
Trichocerca similis (Wierzejski, 1893)	0.016	0.017	0.022	0.000
OSTRACODA	49.370	19.042	31.145	30.013
Heterocypris sp. (Claus, 1892)	43.385	17.607	26.200	28.678
Heterocypris punctata (Keyser, 1975)	5.987	1.434	4.945	1.335
TOTAL	100.000	100.000	100.000	100.00

*≥ 70 dominant, < 70 ≥ 40 abundant, < 40 ≥ 10 not very abundant, and < 10 rare.

Diversity index (H') and equitability (E')

The diversity of zooplankton in fish farm water was assessed using the Shannon-Wiener (H'), Pielou evenness (J) and species richness (S) indices, which take into account the richness and abundance of species. In the study, the diversity indices were little similar between the sampling points, with the highest diversity indices being recorded for Ostracoda populations in the Vale do Jamari and Copepoda populations in the Centro-Leste and in the rainy season (Fig. 5).

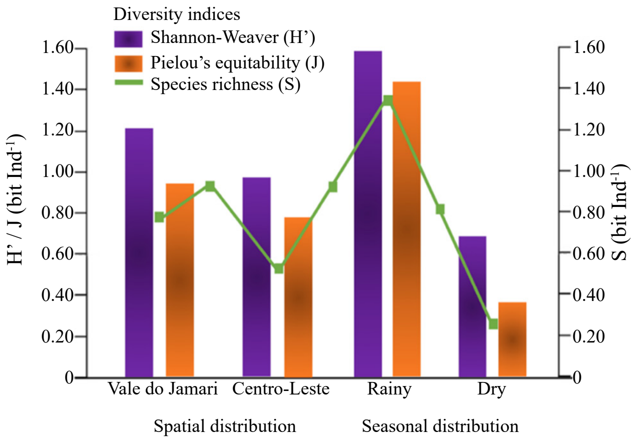


Figure 5. Shannon-Weaver diversity indices (H'), Pielou evenness (J), and species richness (S) of the zooplankton community in fish farm water in Rondônia state, Brazil, spatial and seasonal distribution.

DISCUSSION

Mentioning limitations in species identification strengthens the study's transparency and reliability. Challenges, such as morphological similarities or cryptic species, can impact data quality. This study addressed them by using taxonomic keys, software for photographic validation, and calibrated equipment like the Bioval microscope. Triplicate sampling across multiple ponds, reservoirs, and effluents minimized bias. Preservation protocols (formaldehyde and copper sulfate) ensured sample integrity for identification. Acknowledging potential errors allows readers to interpret seasonal variations cautiously and preempts criticism. It also provides valuable insights for future research, suggesting the use of molecular tools like DNA barcoding alongside traditional methods to improve precision. Such measures reinforce the study's rigor and offer guidance for improving zooplankton identification in similar agroecosystems.

Fish farms are artificial reservoir ecosystems, and changes in the environment are more evident compared to natural ecosystems, which can lead to the predominance of certain species and the decrease, or even exclusion, of others. This results in a lower variety and diversity of species although with a higher number of individuals. However, diversity is also influenced by competition and predation. The struggle for limited resources is seen as the main factor in species diversity, as when resources become scarce, only the most adapted survive, resulting in a reduction in the number of species (Santos et al., 2022).

The relationship between species diversity (quantity and evenness) and the stability of an artificial aquatic ecosystem is complicated because stable ecosystems can promote high diversity, although the opposite is not always true. Therefore, even if diversity levels are moderate to low, several reasons may be considered, especially concerning the collection period (rainy and dry seasons) and the dynamics of the watershed that supplies the fish farms. Many studies have shown that habitats in tropical regions sustain more species than in temperate regions (Xiong et al., 2020). However, there is significant uncertainty about this information in planktonic communities due to the scarcity of data from tropical regions, both in terms of taxonomic analysis of zooplanktonic groups and in the exploration of different water bodies (Setúbal & Bozelli, 2011).

The distribution of community richness of zooplankton can be examined along the spatial gradient, between the collection sites. In comparison between the analyzed seasons, a reduction in the number of organisms was observed at points closer to agricultural or urban areas, as well as an increase in populations closer to preserved areas (authors' files). The species of the phyla Copepoda, Ostracoda, Rotifera, and Cladocera (the most frequent and abundant in this study) followed this distribution pattern. This discrepancy in abundance in different fish farms can be attributed to the relative availability of food resources, characterizing a "bottom-up" effect (Dias et al., 2012).

Zooplanktonic groups residing in regions with high levels of environmental disturbance may not be found in more conserved environments, as they are unable to tolerate changes in the chemical and physical factors of eutrophicated water. Therefore, both natural environments and those without alterations in their physical integrity harbor a diverse zooplanktonic community, composed of different sets of species (Schmidt et al., 2020). This pattern can be also observed when comparing the total abundance levels of zooplankton with the structure of the water body and riparian vegetation, which are closer to a state of undisturbed environmental conservation and are located far from urban areas.

It is essential to highlight that the community of aquatic invertebrates has the unique ability to promptly respond to environmental changes, whether in terms of abundance or biodiversity (Necker et al., 2021), with the exception of species of the phylum Copepoda, which, due to their reproductive characteristics, tend to respond more slowly, as evidenced in this study by the high number of immature copepods (copepodites and nauplii) (authors' files), which contributed to more than 50% of the total density of copepod populations (Hussain et al., 2020).

For species of the phylum Copepoda, the family Diaptomidae is more prevalent in environments with higher temperatures, while the family Cyclopidae is associated with higher levels of ammonia, phosphorus concentration, and electrical conductivity (Figueiredo et al., 2014). It was noted that the distribution of species of these two families did not occur randomly. Nearby locations showed a more similar species composition, possibly due to the facilitated dispersal capacity between closer sites and the greater uniformity of environmental conditions, with total phosphorus recognized as a determining factor in the structure of the zooplanktonic community (Picapedra et al., 2021). Therefore, we found that distant locations exhibit a more diverse species composition compared to nearby ones.

For species of the phylum Cladocera, the variables acting as predictors are ammonia, electrical conductivity, transparency, flow rate, and nitrate. About 50% of the variation in Cladocera could be explained by the measured variables (Chen et al., 2010). Sididae showed positive responses to fluctuations in electrical conductivity and ammonia, a relationship previously observed by Bos et al. (1996) in lakes in Canada. Meanwhile, Chydoridae was associated with flow rate values. The strong influence of flow rate on the distribution of Chydoridae can be justified by water movement, considering that these organisms can be classified as pseudoplanktonic (Castilho-Noll et al., 2010). Macrothricidae, Ilyocryptidae, and Daphniidae showed correlation with nitrogen values, indicating higher abundance of these families in seasons with high concentrations of this compound. Regarding the quality and availability of nutrients, nitrogen can influence the composition of phytoplankton, which in turn determines the composition of zooplankton (Belfiore et al., 2002).

Variables such as turbidity, water transparency, depth, electrical conductivity, and ammonia are identified as predictors of the abundance of species of the phylum Rotifera, and the community variation corresponded to 48% concerning environmental conditions (Yin et al., 2018). Brachionidae and Keratellidae were associated with ammonia concentrations and high electrical conductivity values, while Filinidae was influenced by flow rate and Lepadellidae and Bdelloidea by transparency, turbidity, and depth. As indicated by Bos et al. (1996), ammonia concentrations tend to increase with the electrical conductivity of the system, establishing a strong relationship between these two factors. It was observed that high values of conductivity and ammonia played a determining role in species distribution, as groups correlated with variables such as water transparency, turbidity, and depth showed an opposite relationship to conductivity and ammonia, limiting the occurrence and abundance of species between seasons (Cottenie et al., 2001). Urban order seasons exhibited higher values of electrical conductivity, possibly due to the entry of organic matter resulting from inadequate effluent discharge or the absence of riparian vegetation at certain points in the watershed, allowing ions to be transported to the water body (Lemessa et al., 2023).

It was observed that the distribution of zooplankton species followed a geographic pattern, rather than a longitudinal one (in relation to the watershed to which they belong), meaning species found in water supply, effluents, and/or ponds were not present in fish farm effluents (intermediate regions). This pattern was observed consistently, suggesting that different species have distinct habitat preferences, resulting in the formation of distinct groups of coexisting species, represented by species characteristic of supply reservoirs or fishponds (Belfiore et al., 2021).

With evident variations, the spatial distribution of most species in the two microregions of Rondônia state, when considering the studied area, was similar to that found in other artificial aquatic environments in Brazil (Picapedra et al., 2021). This general pattern of spatial and seasonal zooplankton distribution was also indicated by Rosa et al. (2020), who demonstrated that environments maintaining their unchanged characteristics tend to have greater richness and diversity of aquatic invertebrates. Spatial segregation and size differences are the basic mechanisms that enable the coexistence of species and congenetic zooplankton groups. These species occupy similar ecological niches and, therefore, compete for similar resources (Hobaek et al., 2002).

The seasons showed marked differences in diversity and abundance between groups; a richness of Copepoda and Ostracoda more than ten times greater than Rotifera and Cladocera was found. The richness and abundance of Copepoda and Cladocera may be favored due to their wide range of resources associated with niche differentiation and high reproductive rates in fish farm water (Tóth et al., 2020). Cladocera are favored in these environments by their association with macrophytes, mainly feeding on algae and periphyton (Balayla & Moss, 2004). On the other hand, Copepoda have a more restricted geographic distribution due to their greater sensitivity to changes in environmental variables. However, Copepoda populations were highly abundant, possibly because larger zooplankton are more evident and vulnerable to predation, especially by fish and macroinvertebrates (Casanova & Henry, 2004).

From a total of 3 groups representative zooplankton groups in densities in continental ecosystems, Copepoda, Ostracoda, Rotifera, and Cladocera, differ in their adaptive strategies, including reproductive potential, life cycle, competitive capacity, and dispersal and resistance strategies (Rietzler et al., 2002). These differences in strategies have direct consequences on abundance fluctuations and the spatial distribution of each group and, consequently, on their potential to establish themselves in environments subject to environmental changes (Seminara et al., 2016).

CONCLUSIONS

The zooplankton community in fish farm water in Rondônia state exhibits distinctive spatial and seasonal heterogeneity. Ostracoda populations were more frequent and abundant in fish farms in the Vale do Jamari, while Copepoda populations were more frequent and abundant in fish farms in Centro-Leste of Rondônia state. Species from the phyla Copepoda and Ostracoda were more frequent and abundant in both the rainy season and the dry season, with greater diversity and abundance of zooplankton species in the rainy season.

Most studies emphasize the importance of maintaining this natural configuration to preserve the attributes of planktonic communities, such as species richness and abundance, among others. It was observed that lower organism density was correlated with lower species richness. Therefore, it is recommended that further research be conducted in lentic waters such as fishponds and effluents, as well as in the streams that supply these fish farms, given the great potential for biodiversity that has not yet been explored in these agroecosystems.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

The data will be available upon request.

AUTHORS' CONTRIBUTION

Conceptualization: Pedroti, V.P., Santos, B.L.T., Pinheiro, M.M.L.; **Methodology:** Dantas Filho, J.V., Santos, B.L.T.; **Investigation:** Pedroti, V.P., Pinheiro, M.M.L.; **Data curation:** Dantas Filho, J.V., Pinheiro, M.M.L.; **Formal Analysis:** Dantas Filho, J.V.; **Validation:** Sousa, R.G.C., Silva, F.C.; **Software:** Prado, E.J.R. ; **Visualization:** Silva, F.C., Prado, E.J.R.; **Resources:** Sousa, R.G.C., Prado, E.J.R.; **Funding acquisition:** Schons, S.V.; **Project administration:** Schons, S.V.; **Supervision:** Schons, S.V.; **Writing – original draft:** Pedroti, V.P., Santos, B.L.T.; **Writing – review & editing:** Sousa, R.G.C., Silva, F.C.; **Final approval:** Sousa, R.G.C.

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