










Influence of land use, occupation, and riparian zones on zooplankton diversity in Cerrado streams

Influência do uso e ocupação do solo e das zonas ripárias na diversidade do zooplâncton em riachos do Cerrado

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Abstract: Aim: The riparian zones of the Cerrado biome have decreased significantly due to human expansion, altering the ecological dynamics of ecosystems, and zooplankton can respond to these changes. Therefore, we seek to evaluate the impact of riparian zones and environmental changes on zooplankton communities in streams, considering the trophic state and integrity of riparian zones. The research seeks to determine which predictors play the most significant role in structuring these communities. The main hypothesis is that local factors have a direct influence on zooplankton communities due to nearby limnological conditions. **Methods:** We collected zooplankton samples and physicochemical variables at 20 points located in the Silvânia National Forest and surrounding areas (Goiás, Brazil). A Redundancy Analysis (RDA) was employed after selecting significant variables. A Multivariate Regression Tree (MRT) analysis was used to model relationships between species and environmental characteristics. **Results:** We found that trophic state and forest cover had no significant influence on zooplankton richness and density. Despite identifying 88 species of zooplankton, we did not observe clear relationships with environmental factors. The Multivariate Regression Tree (MRT) analysis, however, revealed distinct clusters, clarifying the factors that shape the zooplankton community. **Conclusions:** Our findings emphasize the need for further investigation into the interaction between zooplankton and their environment to offer valuable insights for ecological management and conservation efforts. Unforeseen disturbances can introduce stochastic elements into community variations, camouflaging the influence of local and spatial factors.

Keywords: metacommunities; impacts; anthropization; landscape; environmental variables.

Resumo: Objetivo: As zonas ripárias do Cerrado diminuíram significativamente devido à expansão humana, alterando a dinâmica ecológica dos ecossistemas, e o zooplâncton pode responder à essas mudanças. Desta forma, buscamos avaliar o impacto das zonas ripárias e das mudanças ambientais



nas comunidades de zooplâncton em riachos, considerando o estado trófico e integridade destas zonas. A pesquisa busca determinar quais preditores desempenham um papel mais significativo na estruturação dessas comunidades. A hipótese central é que os fatores locais têm uma influência direta nas comunidades de zooplâncton devido às condições limnológicas próximas. **Métodos:** Coletamos as amostras de zooplâncton e variáveis físico-químicas em 20 pontos localizados na Floresta Nacional de Silvânia e arredores, Goiás, Brasil. Uma Análise de Redundância (RDA) foi empregada após a seleção de variáveis significativas. A análise de Árvore de Regressão Multivariada (MRT) foi utilizada para modelar as relações entre espécies e características ambientais. **Resultados:** Descobrimos que o estado trófico e a cobertura florestal não tiveram influência significativa na riqueza e densidade do zooplâncton. Apesar de identificarmos 88 espécies de zooplâncton, não observamos relações claras com fatores ambientais. A análise da Árvore de Regressão Multivariada (MRT), no entanto, revelou agrupamentos distintos, esclarecendo os fatores que moldam a comunidade zooplancônica. **Conclusões:** Nossas descobertas destacam a necessidade de mais investigações sobre a interação entre o zooplâncton e seu ambiente, a fim de fornecer informações valiosas para a gestão ecológica e os esforços de conservação. Perturbações imprevistas podem introduzir elementos estocásticos nas variações das comunidades, mascarando a influência de fatores ambientais e espaciais locais.

Palavras-chave: metacomunidades; impactos; antropização; paisagem; variáveis ambientais.

1. Introduction

Riparian zones are interface environments that include portions of terrestrial ecosystems, such as vegetation and soil, close to aquatic ecosystems, which directly affect or are affected by each other (Gregory et al., 1991). Human activities in these environments, such as agriculture, can result in more exposed soils, causing changes in the physical, chemical, and biological relationships of this system, with consequent habitat losses and negative impacts for biota (Karr & Schlosser, 1978; Schlosser, 1991; Allan, 2004; Almendinger et al., 2014). The reduction of riparian zones can make water bodies more exposed and susceptible to silting (Ortega et al., 2014) and the use of herbicides, fertilizers, and pesticides from agricultural activities near affected riparian zones can be leached directly into watercourses (Kalavrouziotis & Drakatos, 2002; Zalidis et al., 2002; Dudgeon, 2011; Broetto et al., 2014; Aguiar Junior et al., 2015). Thus, the removal of the riparian vegetation may increase the input of pollutants to rivers and streams. Vegetation buffers the transport of nutrients to rivers and controls impacts by retaining sediments and substances that could silt up, pollute, and increase eutrophication in watercourses (Karr & Schlosser, 1978; Lowrance et al., 1997; Naiman & Decamps, 1997; Dudgeon, 2011; Aguiar Junior et al., 2015)

Riparian vegetation influences the environment on various scales, and agricultural impacts on stream ecosystems affect habitat quality and alter the availability of resources. This alteration affects the habitat structure and the structural characteristics of aquatic organism communities (Johnson, 2005; Allan & Castillo, 2007; Lorion & Kennedy, 2009). For zooplankton, the quality

of the environment is decisive, as they respond quickly to environmental changes. Their sensitivity to alterations in temperature, nutrient levels, and pollution highlights the importance of maintaining a healthy environment to support zooplankton populations and, by extension, the overall ecological balance of aquatic systems (Richardson, 2008; Jakhar, 2013; Xiong et al., 2019). Thus, variations in the environment can alter species composition and zooplankton abundance, making them important for biomonitoring and water quality analyses (Odemis & Evrendilek, 2007). Zooplankton is also used as an indicator of trophic status, which is related to the concentration of nutrients and organic matter in a water body (Harper, 1992; Nixon, 1995) that affects biological communities. For zooplankton, these changes can occur in their composition and diversity, such as increasing or decreasing the density of the community (Marcelino, 2007; Brito et al., 2011; Esteves, 2011).

The zooplankton assemblage is taxonomically diverse and has representatives from several phyla. Therefore, it has several attributes that make it an effective biological indicator of environmental conditions and environmental variation. The zooplankton composition responds to abiotic variations (e.g., pH, temperature, salinity, dissolved oxygen, turbidity, and heavy metals) due to differences in the physiological tolerances of different species (Anas et al., 2017). Biomonitoring is an appealing practice for aquatic environments that have suffered anthropic pressures (Sala et al., 2000) as it helps to understand the environment and the effects of land use and conversion near water bodies (Serrano et al., 2010). A robust bioevaluation system requires a complete understanding of the

ecological processes that structure communities. Thus, identifying the mechanisms that influence the variation of local communities is fundamental to community ecology because environmental and spatial processes operating at various scales may shape the diversity of those communities.

If the community composition is mainly predicted by environmental variables, physical-chemical parameters, disturbance regime, and productivity, the niche-related mechanisms are considered the main drivers of metacommunities and the species are organized among habitats (Heino & Mykrä, 2008; Vanormelingen et al., 2008). An alternative view shows that the structure of local communities differs mainly due to stochastic processes, determining variations in the abundance of species within the community, including dispersal limitation and ecological drift (Hubbell, 2001).

Thus, understanding the integrity of riparian zones and the dynamics of zooplankton communities is important in strategies for the assessment, monitoring, management, and conservation of rivers, streams, and springs (Naiman & Decamps, 1997), as species and populations can be threatened in different ways in the face of different types of land use and occupation scenarios (King & Baker, 2010). Thus, the objective of this

study is to evaluate the effects of the landscape, environmental characteristics, and anthropic changes on zooplankton communities. This study aims to answer the following questions: (i) does the trophic state and the integrity of riparian zones influence the attributes of the zooplankton community, such as species composition, richness, and abundance of individuals? (ii) What is the relative importance of local environmental, landscape, and spatial predictors in structuring the zooplankton community? Our hypothesis is that local environmental factors play a significant role in structuring zooplankton populations. This assumption is based on the understanding that limnological conditions in the immediate environment have a direct influence on these communities.

2. Material and Methods

2.1. Study area

We carried out the study in the microbasins of the Silvânia National Forest (FLONA) and surroundings, located in the eastern portion of the State of Goiás, in the municipality of Silvânia (Alto Paraná Basin), in Brazil, comprising a total area of 486.67 ha (Figure 1). The Silvânia municipality has

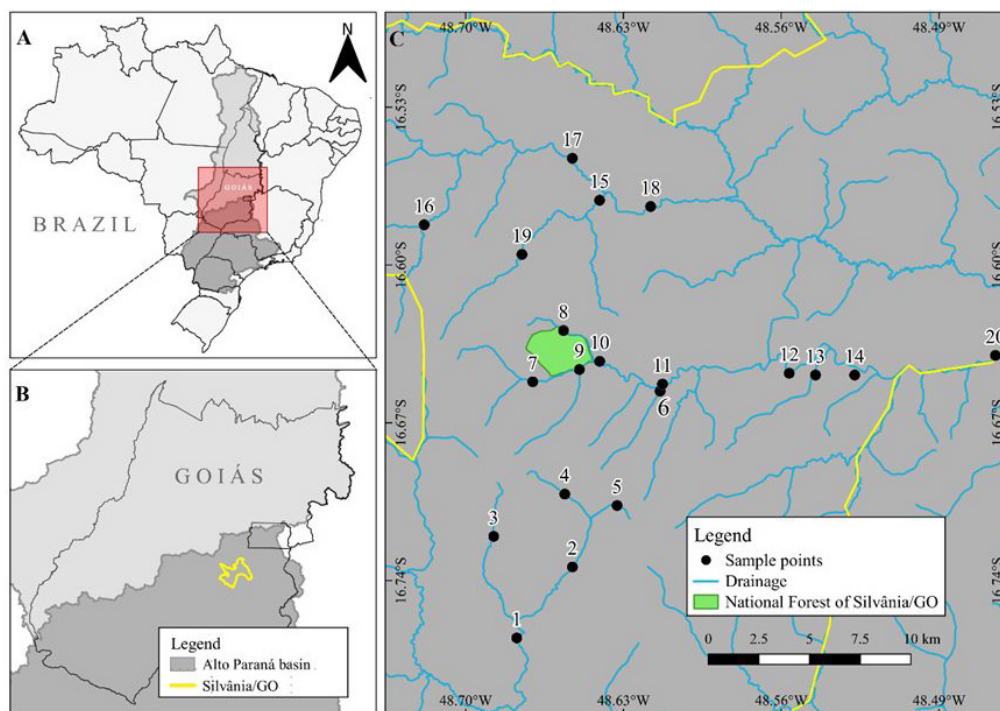


Figure 1. Location of the Silvânia National Forest and the 20 sampling sites. (A) map of Brazil, highlighting the state of Goiás; (B) detailed view of the state of Goiás, showing the Alto Paraná basin and the municipality of Silvânia/GO, outlined in yellow; (C) detailed map of the sampling points within the municipality of Silvânia, State of Goiás, Brazil.

an area of 2,345.94 km² and 19,089 inhabitants (IBGE, 2010). The climate in the region is classified as Aw (rainy tropical), with a hot and rainy summer (October–March) and a dry and cold winter (April–September) (Koeppen & Hendrichs Pérez, 1948). Also, in FLONA-Silvânia several types of vegetation that compose the Cerrado biome can be found, such as *campo sujo* (grassland), *cerrado sentido restrito* (savanna), *cerradão*, *mata seca* and *mata de galeria* (woodlands).

2.2. Data collection

We carried out field collections from the 23rd to the 27th of August and from the 1st to the 3rd of September 2017. We selected 20 sampling sites within the Rio Vermelho basin and in the surrounding microbasins of the FLONA (Figure 1). We selected the sampling sites based on their gradient of impact related to land use, ranging from highly preserved areas, with native riparian forests, to heavily impacted places, with exposed soil.

We sampled the zooplankton using a plankton net with 68µm mesh opening. We filtered 300 L of water at each sampling site. We fixed each sample in 5% formalin and concentrated it to a volume of 100 mL.

We conducted local physical and chemical measurements at the 20 sites. In all streams, we sampled the physical and chemical characteristics of the water using a multiparameter probe (Manta 2 Water Quality Sonde). Additionally, we collected water samples at each site for laboratory analysis, following the Standard Methods for the Examination of Water and Wastewater (APHA, 1926).

We measured water temperature (°C), pH, oxidation-reduction potential (mV), electrical conductivity (S.m⁻¹), depth (m), blue-green algae (cells.mL⁻¹), chlorophyll-*a* (µg.l⁻¹), rhodamine (µg.l⁻¹), oxidation reaction (HDO), oxidation-reduction reaction percentage (HDO%), turbidity (NTU), transparency, dissolved oxygen (mg.l⁻¹), biochemical oxygen demand (BOD₅ mg.l⁻¹), nitrate (mg.l⁻¹), total nitrogen (mg.l⁻¹), ammoniacal nitrogen (mg.l⁻¹), total phosphorus (mg.l⁻¹), total dissolved solids (mg.l⁻¹), total solids (Residue – mg.l⁻¹), total organic carbon (mg.l⁻¹), iron (mg.l⁻¹), total coliforms (NPM.100mL⁻¹), and *Escherichia coli* (NPM.100mL⁻¹).

The landscape variables we analyzed were percentage of natural vegetation, pasture, agriculture, forestry, and the urban area around each sampling site. The land cover evaluated in

the study corresponds to native vegetation of the Cerrado Biome, based on images obtained from the TerraClass Cerrado project (<http://www.dpi.inpe.br/tccerrado/>). To obtain the landscape data, we created buffers in the basin and quantified different types of vegetation areas (i.e., preserved areas, pasture, agriculture, and forestry).

For each sampling site, we created different buffers upstream with fixed widths of 50 and 100 m. The buffers had three different lengths (i.e., 100 m, 500 m, and basin area), up to the spring. Thus, we obtained the different metrics of vegetation cover for each sampling site. We obtained the percentage of different vegetation types in the basin using updated high-resolution images from the Landsat 8 satellite (from NASA) during the drought period of 2013, with spatial resolution of 30 meters (bands 1 to 7 and 9), 15 meters (band 8, panchromatic mode) or 100 meters (thermal bands). We obtained the spatial data from the geographical coordinates of each sampled site.

2.3. Laboratory analysis

In the laboratory, we filtered the zooplankton community using a 20 µm mesh and concentrated in 100 mL. Then, we subsampled 10 mL using a Hensen-Stempel pipette and counted the organisms in a Sedgewick-Rafter chamber using an optical microscope. Subsequently, we carried out a qualitative analysis with new subsamples until we did not find any new taxa.

2.4. Trophic State Index (TSI)

The Trophic State Index is composed of the Trophic State Index for phosphorus - TSI (PT), and the Trophic State Index for chlorophyll-*a* - TSI (CL), modified by Lamparelli (2004) and established for lotic environments according to the Equations 1 and 2:

$$TSI (CL) = 10x (6 - ((-0.7 - 0.6x(\ln CL)) / \ln 2)) - 20 \quad (1)$$

and

$$TSI (PT) = 10x (6 - ((0.42 - 0.36x(\ln PT)) / \ln 2)) - 20 \quad (2)$$

where PT is the total phosphorus concentration measured at the water surface in µg.l⁻¹ and CL is the chlorophyll-*a* concentration measured at the water surface, in µg.l⁻¹.

To categorize the rivers according to their TSI, we considered the following classification: ultraoligotrophic (TSI ≤ 47), oligotrophic (47 < TSI ≤ 52), mesotrophic (52 < TSI ≤ 59), eutrophic

($59 < \text{TSI} \leq 63$), supereutrophic ($63 < \text{TSI} \leq 67$) and hypereutrophic ($\text{TSI} > 67$). The final TSI value was the arithmetic mean of the indices for total phosphorus and chlorophyll-*a*.

2.5. Data analysis

We initially rated the sampling units into three classes based on the forest cover percentages of their Ottobasins. This classification was carried out using the k-means method (Legendre & Legendre, 2012), resulting in three categories: low (1 to 23%), medium (23 to 28%), and high (28 to 35%). To evaluate the differences in zooplankton community composition and density across various Trophic State Index and Forest Cover levels and to identify significant distinctions between treatments, we employed a Permutational Multivariate Analysis of Variance with Matrices of Distance (PERMANOVA). This analysis, implemented through the *adonis2* function in the *vegan* package, used the Bray-Curtis distance matrix for density data and the Jaccard index for presence/absent data. To mitigate the influence of rare species on the analysis, we standardized the species abundance matrix using the Hellinger method (Legendre & Gallagher, 2001). Additionally, to ensure the validity of our model, we assessed collinearity within the predictor matrix. We employed the Variance Inflation Factors (VIF) to identify and remove values exceeding ten, addressing potential multicollinearity issues. To enhance parsimony and minimize the number of explanatory variables, we subsequently applied a forward selection analysis, employing two criteria for terminating the selection process (Borcard et al., 2018).

Upon conducting the forward selection analysis, we conducted a Redundancy Analysis (RDA) when the test yielded significance. To maintain model simplicity and avoid overfitting, we established significance as the initial stopping criterion and adjusted R^2 as the secondary criterion (Blanchet et al., 2008). This approach involved incorporating only variables displaying both significance and an adjusted R^2 lower than that of the global model. The analysis was performed using the *adespatial* package (Dray et al., 2018).

To model the intricate relationships between species and environmental characteristics, we harnessed the power of Multivariate Regression Tree (MRT) analysis. Here, we clustered sampling units based on threshold values of the explanatory variables (De'ath, 2002). Our implementation of MRT analysis in the R program used the *mvp*

function from the *mvp* package, an extension of the *party* package specifically designed for constructing regression trees involving multiple response variables. Subsequently, we combined this model with an examination of indicator species (IndVal) to pinpoint the species contributing most to the explained variance within each cluster (Borcard et al., 2018).

To assess whether zooplankton species can serve as indicators of Trophic State Index levels, we conducted an analysis of indicator species using the index of indicative value (IndVal) (Legendre & Legendre, 2012). To carry out this analysis, we employed the *indval* function from the *labdsv* package. All analyses were executed using the R statistical software.

3. Results

We identified 88 zooplankton species at the sampled sites, distributed in 32 genera and 23 families. Out of all species found, 49 were testate amoebae, 18 cladocerans, 16 rotifers, and 5 copepods. The sites that showed the highest species richness values were 1, 5, and 4, respectively. On the other hand, sites 17, 18, and 20 showed the lowest zooplankton species richness. Zooplankton density ranged from 500 ind.m⁻³ (site 17) to 5,700 ind.m⁻² (site 3). In general, testate amoebae contributed to the highest density, except for site 3, where cladocerans had the highest density.

We grouped the 20 sampled sites into different trophic levels following the Trophic State Index (TSI). We also grouped them according to the percentage of Forest Coverage (FC), as low (23%), medium (28%), and high (35%). The PERMANOVA analyses showed no significant relationship between zooplankton community composition and density with the trophic state index and the percentage of forest cover (Table 1).

Regarding species density and occurrence in the streams evaluated, the environmental, landscape, and spatial variables were not important predictors of the zooplankton community (Table 2).

The MRT analysis calculated for the 20 sampled sites in the study indicated a division of six groups and explained 39.6% of the variation in the structure of the zooplankton community in the streams (Figure 2). The first and strongest separation factor was pH, this node explained 9.11% in the data variation, and the main taxa that contributed to the explanation of this cluster were *Chydorus eurynotus*, *Moina minuta*, *Diaphanosoma spinulosum*, *Alona yara*, and *Brachionus* sp. (Group 6), which are related to pH values below

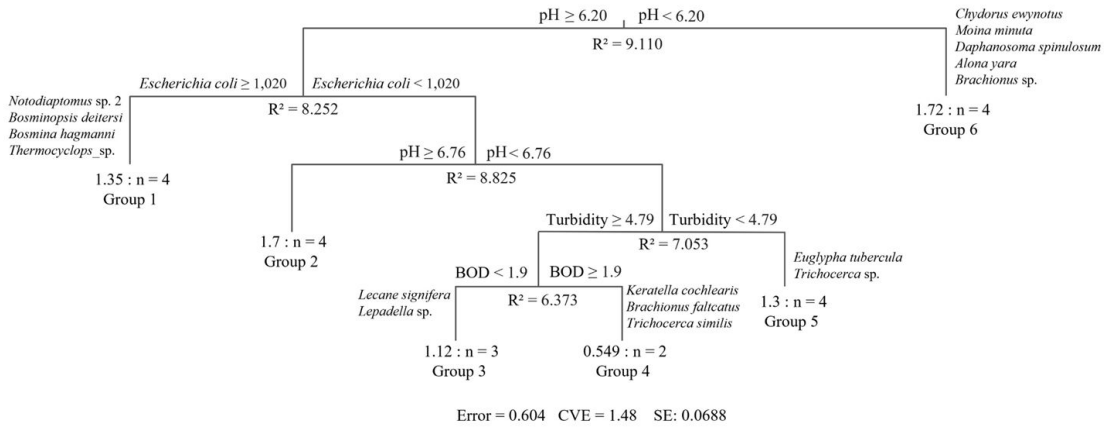


Figure 2. Multivariate regression tree analysis (MRT) depicting the interplay among zooplankton densities across the 20 sampled sites ($R^2 = 0.392$). Here, n represents the sample count, while the accompanying figures denote the sum of squared errors within individual groups. The designated labels correspond to the primary species contributing to the variance within each MRT node.

Table 1. PERMANOVA results comparing zooplankton community structure with the Trophic State Index (TSI) and Forest Cover (FC).

Numeric resolution	Factors	R^2	F	p
Presence/absence data	TSI	0.161	1.015	0.429
	FC	0.108	1.026	0.403
	TSI × FC	0.146	0.922	0.765
Density data	TSI	0.16	1.005	0.471
	FC	0.106	1.001	0.501
	TSI × FC	0.145	0.907	0.727

R^2 = proportion of variability explained by the factors; F = PERMANOVA test statistic; p = significance value.

6.20. The second node divided the communities according to the values of *Escherichia coli* and explained 8.25% of the variation in the community, in which the species *Notodiaptomus* sp.2, *Bosminopsis deitersi*, *Bosmina hagmanni*, and *Thermocyclops* sp. (Group 1) were related to values equal or greater than 1,020 NPM.100mL⁻¹. The next factor responsible for node separation was again pH, explaining 8.82% of the variation. In Group 2, with pH values greater than or equal to 6.76, the community was differentiated. When the pH was less than 6.76, turbidity became the decisive factor, explaining the subsequent division. Turbidity was responsible for the separation of the fourth node of the analysis, in which the species *Euglypha tubercula* and *Trichocerca* sp. (Group 5) were associated with turbidity values below 4.79 NTU. Finally, the fifth node of the MRT revealed a discontinuity related to the biochemical oxygen demand (BOD), explaining 6.37% of the variation of the zooplankton community, where the species *Lecane signifera* and *Lepadella* sp. (Group 3) were related to BOD lower than 1.9 mg.l⁻¹,

Table 2. Results of redundancy analysis for the zooplankton community.

Variable	R^2_{adj}	p
Environmental	0.013	0.460
Landscape	0.006	0.406
Spatial	0.003	0.405

R^2_{adj} = adjusted determination coefficient; p = significance value.

while *Keratella cochlearis*, *Brachionus falcatus*, and *Trichocerca similis* (Group 4) were related to BOD equal or greater than 1.9 mg.l⁻¹.

The Analysis of Indicator Species suggests that the copepod species *Thermocyclops* sp. (indicator value, IV = 0.6, p = 0.043) and *Notodiaptomus* sp.1 (IV = 0.69, p = 0.017) were indicative of mesotrophic streams, and the *Keratella americana* rotifer species (IV = 0.66, p = 0.04) was indicative of oligotrophic streams. The rotifer species *Lecane signifera* (IV = 0.78, p = 0.046) and the testate amoebae species *Arcella gibbosa mitriformis* (IV = 0.82,

$p = 0.35$), *Euglypha acanthophora* ($IV = 0.68$, $p = 0.032$), and *Euglypha denticulata* ($IV = 0.8$, $p = 0.042$) were indicators of eutrophic streams.

4. Discussion

Eutrophication encompasses a range of biological impacts stemming from increased nutrient and organic matter concentrations within aquatic ecosystems. Shifts in zooplankton composition and density are closely linked to the trophic status of the water (Esteves & Sendacz, 1988; Marcelino, 2007; Brito et al., 2011). However, our results did not demonstrate significant changes in zooplankton composition and density across different trophic states, as indicated by the PERMANOVA results. Nonetheless, in our investigation, we identified some species that were indicative of specific trophic states. Copepod species were indicative of mesotrophic environments, rotifer species characterized oligotrophic settings, and testate amoebae were associated with eutrophic conditions. Previous research has noted similar patterns, with eutrophic environments typically exhibiting a prevalence of cyclopoid copepods and rotifers (Nogueira, 2001; Sendacz et al., 2006; Parra et al., 2009), while cladocerans are more commonly linked to oligotrophic environments, given their role as filter feeders.

Environmental variations in riverine ecosystems are common due to the constant presence of water flow, which can act as a “washing” effect, preventing zooplankton communities from reaching equilibrium. This constant movement disrupts the settlement and development of stable communities, causing fluctuations in population densities and species composition (Reynolds, 2000; Ward et al., 2002; Thorp & Casper, 2003; Lair, 2006; Allan & Castillo, 2007). Our results, showing no significant relationship between zooplankton composition and density with the trophic state index and the percentage of forest cover, suggest that stochastic processes play a crucial role in shaping zooplankton communities in lotic environments.

The water flow, combined with the low swimming capacity of zooplanktonic organisms, likely influenced the absence of a relationship between local environmental and spatial predictors of zooplanktonic communities in these environments (Astorga et al., 2012; De Bie et al., 2012). Additionally, the effect of the landscape on communities in lotic environments can largely be associated with the scale of the study. This is due to the limitation by dispersion of organisms and local

environmental conditions, resulting in stochasticity that masks the landscape effect (Nabout et al., 2009; Heino et al., 2015).

Streams, being shallower with higher current speeds, cause greater interaction between the planktonic compartment and sediment. This interaction is reflected in our results, as the zooplankton community was mainly represented by testate amoebae. Velho et al. (2004) observed higher densities of these organisms in lotic environments, particularly during drought periods, due to increased exchange between sediment and plankton. The predominance of families such as Diffflugidae, Centropyxidae, and Arcellidae aligns with composition patterns in lotic and shallow environments (Mucio-Alves et al., 2008; Lansac-Tõha et al., 2014).

Ecosystem structure is influenced by a dynamic interplay of deterministic and stochastic processes across various spatial scales (Pickett & White, 1985). The absence of statistically significant impacts of environmental, landscape, and spatial variables on zooplankton communities suggests that stochastic processes, such as birth, mortality, dispersion, and colonization, significantly shape these communities (Hubbell, 2001; Chase, 2007). These processes are particularly influential in lotic ecosystems, characterized by hydraulic stress and dynamic flood-drought cycles (Johnson et al., 1995; Ward et al., 2002; Thorp & Casper, 2003; Dodds et al., 2004).

Different zooplankton groups showed distinct responses to environmental factors, as evidenced in the MRT results. Indicators such as pH, *E. coli*, turbidity, and biochemical oxygen demand directly reflect differences in functional traits, reproduction, and dispersion capacity (Cáceres & Soluk, 2002; Allen & Gillooly, 2006; De Bie et al., 2012). Zooplankton, particularly rotifers, are highly sensitive to acid stress (Anas, 2012). Morgan (1985) suggested that primary productivity can raise pH levels, acting as a selective filter for pH-tolerant species. However, Morgan (1986) found no significant changes in the abundance patterns of dominant taxa in response to pH changes, indicating uncertainty in the literature.

Escherichia coli serves as an indicator of water quality, reflecting the conditions of a water source and influencing zooplankton habitat conditions (Gannon & Stemberger, 1978; Savichtcheva & Okabe, 2006; Dulić et al., 2008). Elevated *E. coli* concentrations result from organic and fecal matter runoff (WHO, 2003). Rainfall and riparian vegetation significantly affect the transport

and introduction of allochthonous materials into aquatic ecosystems, leading to variations in organic matter processing, nutrient absorption, and oxygen concentrations. Elevated levels of suspended solids and algae increase biochemical oxygen demand (BOD), affecting zooplankton communities, particularly rotifers (Laws, 2000; Arauzo, 2003).

Rotifer species, known for their opportunistic nature and adaptability to dynamic environments, exhibit a marked association with elevated turbidity levels (Allan, 1976; Lair, 2006). Turbidity favored the development of rotifers while inhibiting cladocerans, as suspended particles interfere with their feeding (Kirk & Gilbert, 1990). Our results align with these observations, indicating that rotifers are well-adapted to varying turbidity levels.

The exceptional species diversity and rapid reproductive rate of rotifers provide adaptive responses to environmental conditions, making them valuable indicators for specific contexts (Gasca & Suárez, 1996; Stoch et al., 2009; Schuler et al., 2017; Strecker & Brittain, 2017). Their plasticity enhances resilience to anthropogenic pressures, allowing them to thrive in degraded environments (Keppeler et al., 2010; Kuczyńska-Kippen & Basińska, 2014; Zhai et al., 2015).

Given the highly variable nature of stream ecosystems and the exclusion of biotic interactions in this study, the substantial unexplained variability was expected. Local redistribution driven by unpredictable disturbances likely introduced stochastic variations in species composition and density, obscuring the influence of other environmental and spatial factors. This highlights the necessity of comprehensively understanding river dynamics to guide efforts in mitigating anthropogenic impacts on aquatic ecosystems.

5. Conclusion

Investigations focusing on trophic assessment and the impact of riparian vegetation in stream ecosystems play a vital role in the early detection and prediction of eutrophication and its repercussions on biota, particularly zooplankton, known for their responsiveness to environmental fluctuations. This comprehension significantly contributes to shaping strategies that ensure enhanced management practices and multiple utility of these ecosystems. Notably, Brazil, and particularly the Cerrado region, has experienced growing concerns regarding the accelerated degradation of riparian zones. This degradation is attributed to rapid population expansion over recent years, significantly disrupting

the natural processes of these ecosystems. Alterations in the physicochemical properties of water, stemming from eutrophication, impose imbalances on the biotic communities of these ecosystems, with pronounced effects on the zooplankton community, making these organisms valuable indicators of environmental disturbances.

We recommend further studies that delve into a more comprehensive evaluation of environmental and spatial components, as well as their temporal dynamics. Given that this study lacked a time-series perspective, the observed sampling period might not have fully captured conditions that could elucidate the variations in metacommunity structure. From this perspective, long-term investigations aimed at elucidating the impacts of eutrophication on zooplankton community structure have the potential to provide consolidated insights into the organization of these communities. Such studies will be instrumental in devising appropriate management strategies to safeguard the integrity of biota in these ecosystems.

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