

Original Article

Macrophytes' presence alters zooplankton composition and abiotic conditions in a reservoir in Northeastern Brazil

Natália dos Santos Mendes¹, Tayná de Almeida Delgado², Alan Cleber Santos da Silva³, Luddy Searom Carias de Moraes², Tatiane Mantovano^{*4}, Francieli de Fátima Bomfim⁵, Fábio Amodêo Lansac-Tôha², Sérgio Luiz Sonoda⁶

¹Postgraduate Program in Tropical Aquatic Systems, Laboratory of Shrimp Farming and Aquatic Biodiversity, Federal University of Southern Bahia, Ilhéus, Bahia, Brazil.

²Postgraduate Program in Tropical Aquatic Systems, Laboratory of Shrimp Farming and Aquatic Biodiversity, Federal University of Southern Bahia, Ilhéus, Bahia, Brazil.

³Postgraduate Program in Comparative Biology, Research Center in Limnology, Ichthyology and Aquaculture, Zooplankton Laboratory, State University of Maringá, CEP 87020-900, Maringá, PR, Brazil.

⁴State University of Northern Paraná, Department of Biological Sciences, Jacarezinho, PR, Brazil.

⁵Laboratory of Primary Producer Ecology (ECOPRO), Postgraduate Program in Ecology, Institute of Biological Sciences, Federal University of Pará, Belém, PA, Brazil.

⁶Southwest Bahia State University, Department of Biological Sciences, Limnology Laboratory, CEP 45205-490, Jequié, BA, Brazil.

Abstract: Our objective was to analyze the composition of zooplankton in areas with and without macrophytes in the Rio Preto do Criciúma Reservoir, Jequié-BA, and to associate it with different water conditions (physical and chemical parameters) and changes in zooplankton species composition. The physical-chemical parameters of water (water temperature, pH, electrical conductivity, redox potential, turbidity, dissolved oxygen and dissolved solids, water transparency, chlorophyll-a, and suspended material) and the zooplankton community were sampled at four points in a single campaign in June 2022 at the Rio Preto do Criciúma Reservoir, in the municipality of Jequié, Bahia, Brazil. Two samples were collected in the central region (without macrophytes), and one sample was collected on each of the left and right margins of the reservoir (with macrophyte banks). We observed that the presence of macrophytes on reservoir margins was associated with distinct water parameters and altered zooplankton composition. We observed five species exclusive to the limnetic region (without macrophytes) and seven exclusives to the littoral region (with macrophytes). Chlorophyll-*a* and temperature were associated with the presence of macrophytes, while dissolved oxygen, electrical conductivity, pH, and redox potential were associated with the absence of macrophytes. The Rio Preto do Criciúma Reservoir is suffering from uncontrolled anthropic activities on its margins, activities that have the potential to alter water conditions, species establishment, and biological interactions. Therefore, our study contributes to a better understanding of the relationships among macrophytes, water conditions, and zooplankton composition in reservoirs before these activities worsen and alter these relationships.

Article history:

Received 23 January 2026

Accepted 22 April 2026

Available online 25 June 2026

Keywords:

Plankton

Dam

Diversity

Aquatic ecosystems

Introduction

Artificial reservoirs are a hybrid class with characteristics intermediate between rivers and lakes (Marzolf, 1990). Such systems are built for water supply, energy generation, irrigation, navigation, and recreation (Sternberg, 2006; Soares et al., 2012). In the last decades, the increasing demand for energy, driven by economic growth in Brazil, has also significantly increased the construction of these systems (Esteves and Meirelles-Pereira, 2011; De Souza Dias et al.,

2018). River impoundment alters ecological conditions upstream and downstream of lotic systems (Yang et al., 2012; Winemiller et al., 2016), threatening biological diversity and resulting in losses of ecosystem services (Mantovano et al., 2015; Winemiller et al., 2016; Braghin et al., 2018).

When a reservoir is built, and the river becomes a lentic system, new habitats emerge, providing different niches for inhabiting species (Agostinho et al., 2008). According to Esteves and Meirelles-Pereira

*Correspondence: Tatiane Mantovano
E-mail: mantovano.t@outlook.com

(2011), there are three compartments in a lentic environment: the littoral, benthonic, and limnetic. The littoral region is directly in contact with the adjacent terrestrial ecosystem, is influenced by it, and is considered a transition zone (ecotone) (Esteves, 2011). These environments harbor various aquatic macrophyte species that form the basis of the trophic chain, provide food and refuge, influence interactions among organisms, and increase environmental productivity (Wetzel, 2007; Quirino et al., 2021; Pérez and Restrepo, 2022). The presence of macrophytes significantly influences the structure of several communities, including zooplankton, by altering species composition and biotic interactions (Braghin et al., 2018; Deosti et al., 2021; Karus et al., 2022). This is because macrophytes provide refuge for zooplankton against fish predation (Montiel-Martínez et al., 2015), as well as more organic particles, ciliates, flagellates, bacteria, and periphytic algae (Dabés and Velho, 2001), which serve as food resources for zooplankton. In addition to direct changes in community structure, macrophyte banks alter abiotic factors and indirectly influence biological groups (Moore et al., 1994; Diniz et al., 2024).

Furthermore, the construction of reservoirs and the transformation of the environment into a lentic one also favor the development of planktonic communities, such as zooplankton. This is because reduced water flow leads to a reproductive rate exceeding the carrying capacity of these organisms (Marzolf, 1990). Therefore, macrophytes and zooplankton are favored by the environmental conditions created by reservoirs. The zooplankton community mainly consists of three groups: Cladocera, Copepoda, and Rotifera. These groups exhibit high abundance and species diversity in lentic systems (Lansac-Tôha et al., 2009; Bozelli et al., 2015). Zooplankton play an important role in ecosystem dynamics and functioning, as they consume small algae, bacteria, and particles, are preyed upon by fish and macroinvertebrates, transfer energy to higher trophic levels, and serve as an energetic link (Lemke and Benke, 2009). These organisms have short life cycles and high reproductive

efficiency and, thus, are considered excellent bioindicators in aquatic environments, demonstrating short- or long-term cumulative effects of environmental changes (Ovaskainen et al., 2019; Boldrocchi et al., 2023).

The Rio Preto do Criciúma Reservoir, one of the main water supply sources for Jequié (BA), has been experiencing uncontrolled occupation of its banks by family farming and livestock activities, resulting in changes in water characteristics and biological communities, including macrophyte and zooplankton communities. Therefore, analyzing changes in the zooplankton community in the presence/absence of macrophytes in this reservoir can help better understand the ongoing anthropogenic changes in its surroundings and the possible effects on ecosystem functioning. In this context, we aimed to analyze the zooplankton composition in regions with and without macrophytes in the Rio Preto do Criciúma Reservoir in Jequié, BA. We expected that macrophytes would be associated with different water conditions (physicochemical parameters) and change zooplankton species composition.

Materials and Methods

Study area: The Rio Preto do Criciúma Reservoir, popularly known as the Cajueiro Dam, was built in 1963 to supply water to the municipality of Jequié-BA. These reservoirs release water only when the water retention capacity reaches its maximum (Oliveira et al., 2019). It is located 15 km from Jequié towards the municipality of Jitaúna, in the Atlantic Forest, within the Rio de Contas basin. Considered one of the city's main water sources, the reservoir has a capacity of 1,439 hm³. The reservoir banks support cocoa, vegetable, and banana crops, as well as some small-scale livestock activity (Oliveira, 2019). Sampling was conducted in June 2022 for two days in the spillway region of the reservoir at four different points, referred to as the right bank (MD), near the vegetable crops, with the presence of submerged aquatic macrophytes; center 1 (C1 - without macrophytes); center 2 (C2 - without macrophytes); and left bank (ME), also with submerged macrophytes

(Fig. 1).

Water physicochemical parameters: We measured water physicochemical parameters at the subsurface, middle, and bottom of each sampling site using a multiparameter probe (HORIBA U-52) for two days; water parameters included: water temperature ($^{\circ}\text{C}$), pH, electrical conductivity ($\text{mS}\cdot\text{cm}^{-1}$), redox potential (ORP - mv), turbidity (NTU), dissolved oxygen ($\text{mg}\cdot\text{L}^{-1}$), and total dissolved solids ($\text{mg}\cdot\text{L}^{-1}$). To measure water transparency, a white Secchi disk (30 cm) was used, applied at the boundary of the euphotic zone, multiplied by a factor of 2.7 (Pompêo, 1999). Chlorophyll-*a* sampling and extraction followed the method proposed by Golterman et al. (1978) and Nusch et al. (1980). Suspended material was analyzed according to Teixeira and Kutner (1962). Each environmental variable has 12 replicates in the absence of macrophytes and 12 in their presence.

Zooplankton sampling: Simultaneously with water parameters, we sampled zooplankton using a plankton net (68 μm mesh), where vertical and horizontal hauls were conducted from the bottom to the water surface for quantitative and qualitative analyses for two days, totaling eight replicates (four in the presence of macrophytes and four in the absence). The collected material was placed in properly labeled polyethylene bottles and fixed in a 4% formaldehyde solution buffered with calcium carbonate. Subsequently, the samples were analyzed in the Limnology laboratory of the State University of Southwest Bahia (UESB), using a modified Sedgewick-Rafter chamber (2.5 ml).

Species identification was performed using specialized literature (Koste, 1978; Reid, 1985; Matsumura-Tundisi 1986; Elmoor-Loureiro, 2010; Jersabeck and Leitner, 2013; Elmoor-Loureiro, 2023). For quantitative analysis, each sample was counted until 200 individuals of the most abundant species were reached. For richness determination (qualitative), the entire sample (200 ml) was analyzed.

Data analysis: To analyze changes in water conditions (physicochemical parameters) with and without macrophytes, we performed Principal Components Analysis (PCA; Pearson, 1901) on all environmental variables. Before that, we standardized

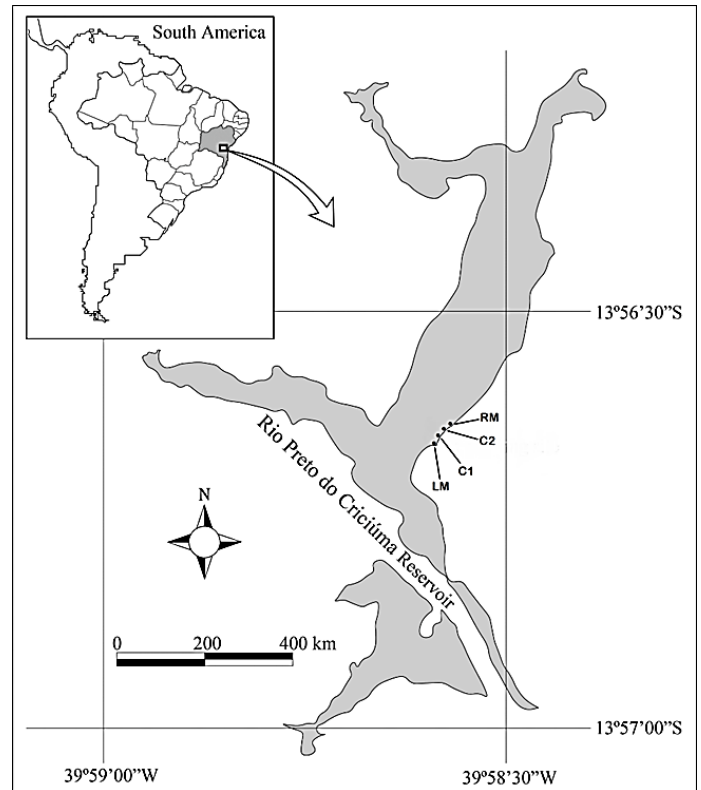


Figure 1. Map showing the sampling sites in the Rio Preto do Criciúma Reservoir, Bahia, Brazil.

the variables using the ‘decostand’ function from the “vegan” package (Oksanen et al., 2022). The significance of these relationships was tested using a permutational multivariate analysis of variance (PERMANOVA; Anderson, 2017).

To analyze changes in zooplankton composition due to the presence or absence of macrophytes, we performed a Principal Coordinates Analysis (PCoA; Gower, 1966) using the “vegan” (Oksanen et al., 2022) and “ape” (Paradis and Schliep, 2019) packages. For that, species abundance was standardized using the Hellinger method (Legendre and Gallagher, 2001) and the ‘decostand’ function from the “vegan” package. Species were transformed using the Bray-Curtis method (Bray and Curtis, 1957) to generate a distance matrix. The significance of these relationships was tested using a permutational multivariate analysis of variance (PERMANOVA; Anderson, 2017). All analyses were conducted using R software, version 4.2.3 (R Core Team, 2023). Graphs were constructed using the “ggplot2” (Wickham, 2016) and “ggfortify” (Tang et al., 2016;

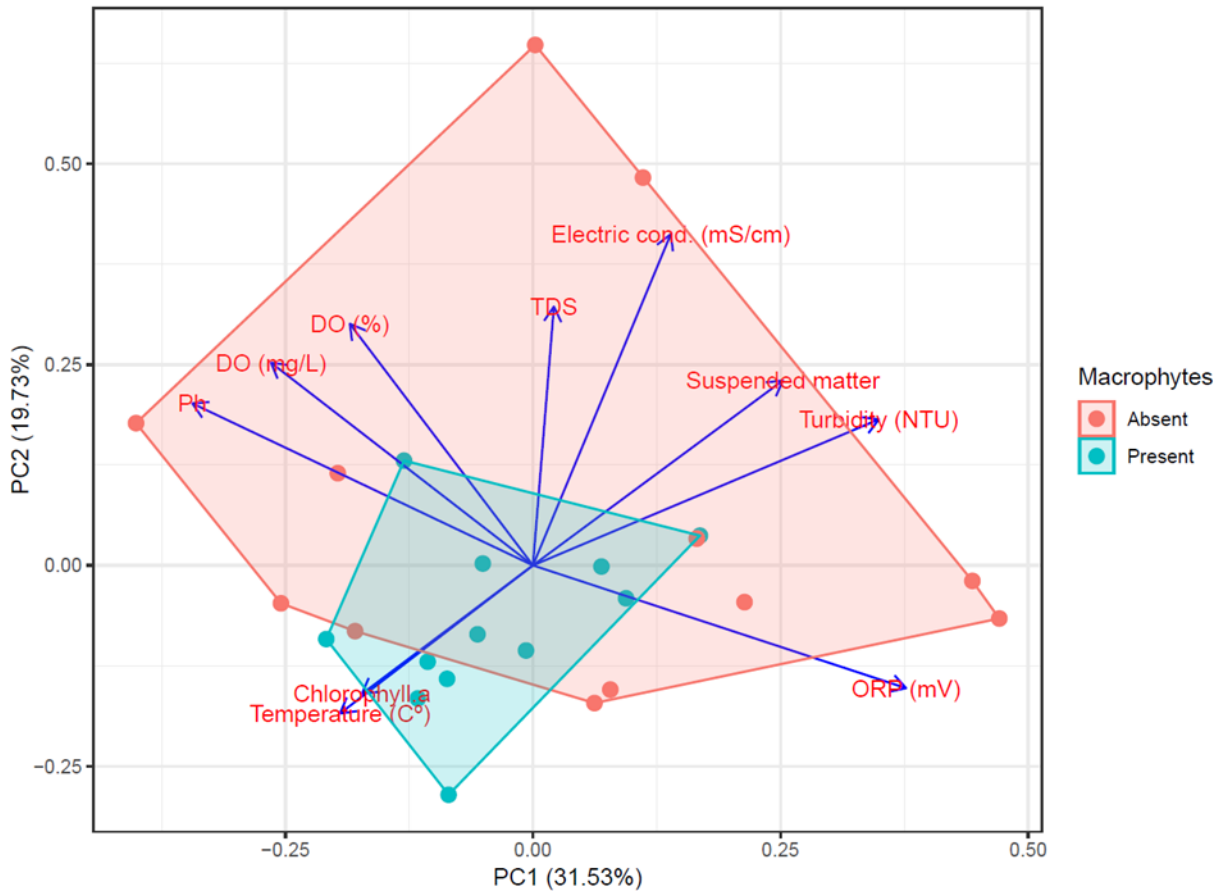


Figure 2. Principal components analysis with the environmental variables in the presence (green points) and absence (red points) of macrophytes. DO = Dissolved oxygen; TDS = Total dissolved solids; Electric cond. = Electric conductivity; ORP (mV) = Oxidation-reduction potential.

Horikoshi and Tang, 2018) packages.

Results

Environmental variables: The water physicochemical parameters differed between the presence and absence of macrophytes (PERMANOVA: $F = 2.25$, $P = 0.031$; Fig. 2), suggesting that macrophytes are associated with distinct limnological variables. Chlorophyll-*a* and temperature were related to environments with macrophytes, whereas dissolved oxygen, electric conductivity, pH, and redox potential were related to macrophyte absence (Fig. 2).

Zooplankton community: We recorded 29 species, 14 rotifers, 12 cladocerans, and three copepods. Considering the different sampling sites, the left bank (ME) exhibited the highest species richness ($n = 24$). However, C2 had the highest rotifer richness (13 species), with Brachionidae as the most representative

family. Among rotifers, the species *Brachionus falcatus* Zacharias, 1898; *Brachionus forficula* Wierzejski, 1891, *Keratella cochlearis* (Gosse, 1851), *Keratella americana* Carlin, 1943, *Lecane bulla* (Gosse, 1851), *Lecane luna* (Muller, 1776), *Hexarthra intermedia braziliensis* (Hauer, 1929), *Hexarthra mira* (Hudson, 1871), *Conochilus unicornis* (Rousselet, 1892), and Bdelloidea occurred in all samples. We recorded *B. forficula* and *H. mira* for the first time in this reservoir (Fig. 3).

Cladocerans showed the highest species richness at point ME (nine species), with Chydoridae (five species), Daphniidae (four species), and Bosminidae (two species) being the most representative families. Two species of cladocerans occurred at all points: *Bosmina tubicen* Brehm, 1953, and *Bosmina hagmanni* Stingelin, 1904. ME and MD exhibited higher copepod richness (three species) in the Cyclopoida group than at the reservoir center;

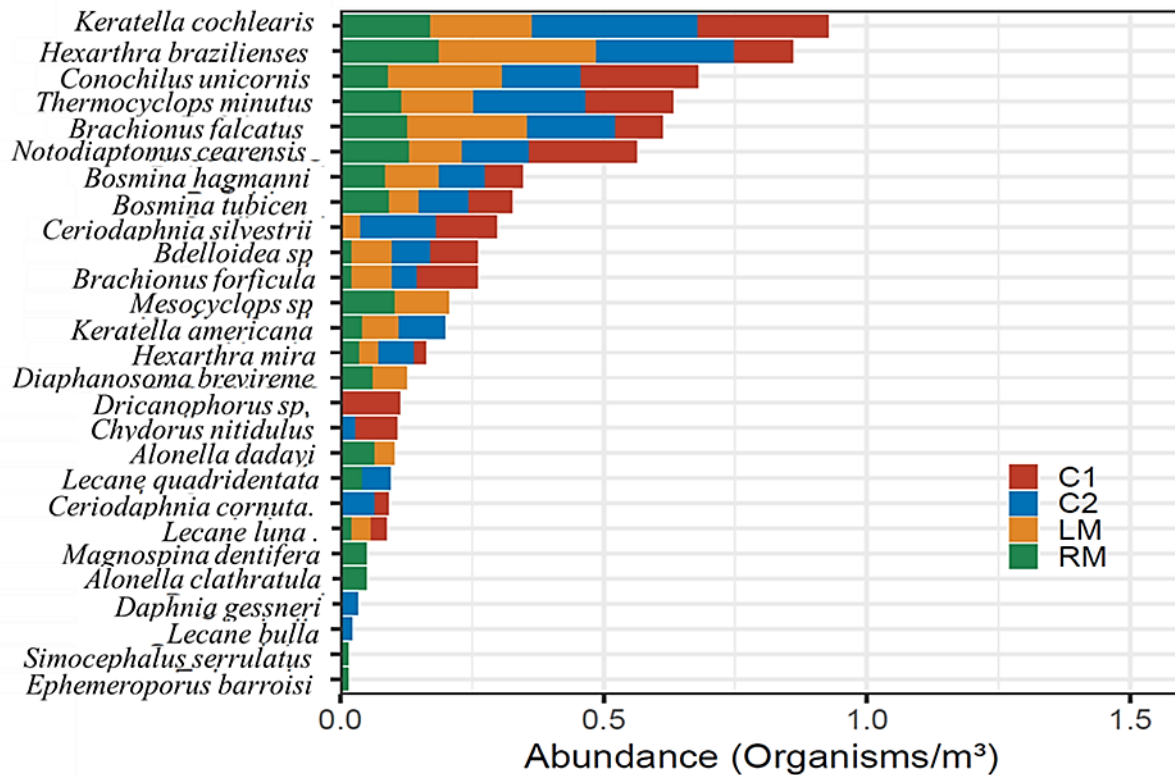


Figure 3. Abundance of individuals for each zooplankton species from the Rio Preto do Criciúma reservoir, Jequié, BA, June 2022. Red and blue represent the abundance in the center of the reservoir (C1 and C2 - without macrophytes); orange represents the abundance in the right bank (MD); green represents the abundance in the left bank (ME).

however, two species were recorded at all points: *Notodiaptomus cearensis* (Wright, 1936) and *Thermocyclops minutus* (Lowndes, 1934).

The two axes of the PCoA summarized 76.99% of changes in zooplankton composition (Fig. 4). The presence of macrophytes significantly altered zooplankton composition (PERMANOVA: $F = 2.83$, $P = 0.006$).

Discussions

We observed that macrophyte presence along the reservoir banks was associated with changes in water parameters and zooplankton composition, corroborating our hypothesis. We observed five exclusive species of the limnetic region (without macrophytes) and seven exclusives of the littoral region (with macrophytes). Chlorophyll-*a* and temperature were associated with macrophyte presence, while dissolved oxygen, electrical conductivity, pH, and redox potential were associated with macrophyte absence. Macrophytes are among the main factors structuring the zooplankton community

in aquatic environments (Meerhoff et al., 2007), mainly because they provide a diversity of microhabitats, expanding the range of niches and allowing more species to coexist (Maia-Barbosa et al., 2008).

Macrophytes have long been recognized as a structuring factor of aquatic environments, influencing the establishment and survival of several biological groups such as macroinvertebrates (Nicolet et al., 2004; Gallardo et al., 2017; Brito et al., 2020), zooplankton (Kuczynska-Kippen, 2009; Espinosa-Rodríguez et al., 2021), periphytic algae, and birds (Scheffer, 2004; Bilton et al., 2006). In our study, macrophytes altered zooplankton composition, and 7 species were exclusively associated with these plants. Braghin et al. (2016) studied floodplain lakes and observed that macrophytes were the most important factor for zooplankton diversity; they also suggested that macrophytes favor zooplankton species with specific morphological characteristics, such as feet and fingers used to attach to vegetation. Deosti et al. (2021) also observed a positive effect of macrophytes

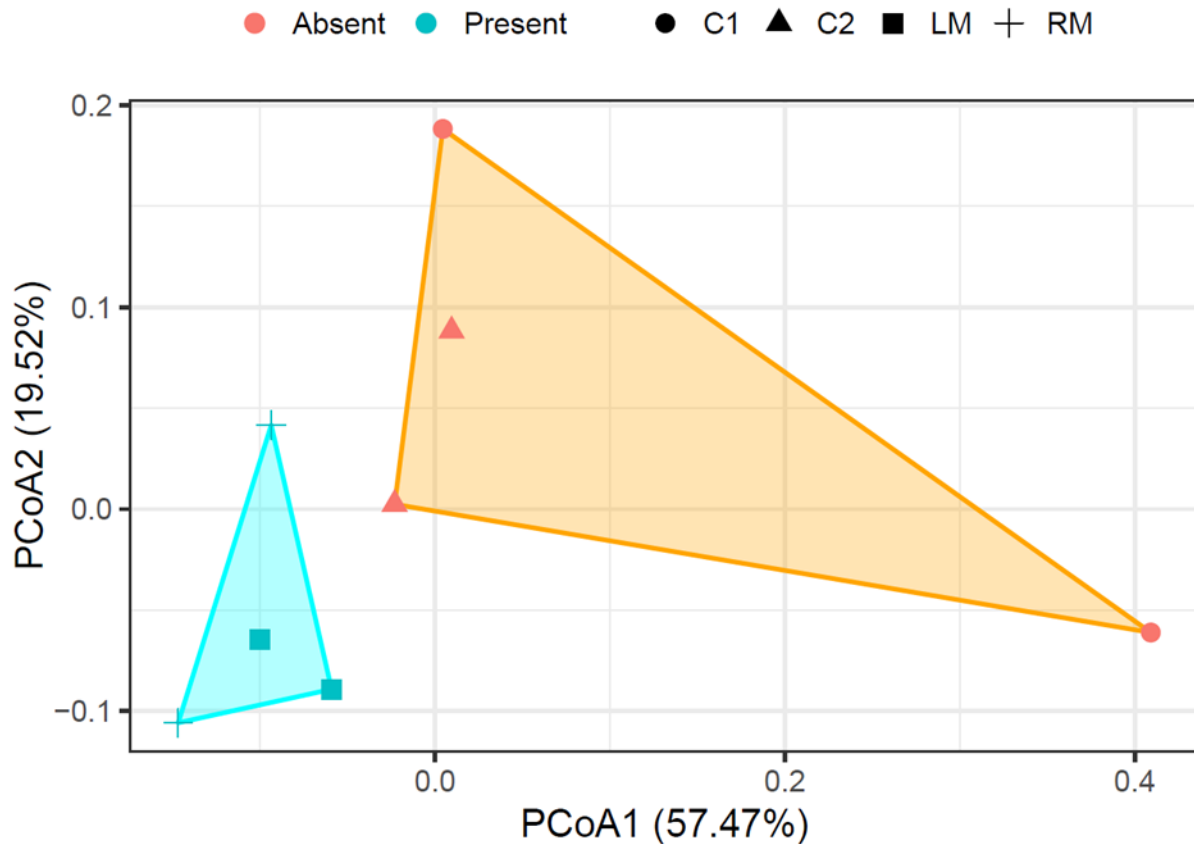


Figure 4. Zooplankton species composition in the presence (green points) and absence (orange points) of macrophytes in the Rio Preto do Criciúma reservoir, Jequié-BA. C1 and C2 are the sampling points of the center, MD are the sampling points in the right bank, and ME are the sampling points in the left bank.

richness on zooplankton taxonomic and functional richness, and taxonomic and functional beta diversity. These positive relationships are observed because macrophytes increase habitat and ecological niche availability, thereby enhancing food supply and refuge for zooplankton organisms (Viveros-Legorreta et al., 2020; Espinosa-Rodríguez et al., 2021). The different macrophyte morphological groups allow organic particles, bacteria, and periphytic algae to remain attached to their structures, thus providing food for zooplankton organisms (Dabés and Velho, 2001).

We also observed that macrophytes were associated with different water physicochemical conditions, such as high temperature and chlorophyll-*a*. The association with high temperatures might be due to these sites being shallower; thus, temperatures rise more easily. Macrophytes absorb nutrients from sediment and translocate them to the water column, positively influencing phytoplankton and periphytic algae (Carignan and Kalff, 1980), which confirms the

high chlorophyll-*a* concentrations observed in macrophyte stands. Therefore, macrophytes can modify the physicochemical and biological structure of aquatic ecosystems, influencing species composition and interactions (Deosti et al., 2021; Quirino et al., 2021).

Regarding the most common groups and species observed, rotifers are usually the most representative group for zooplankton diversity in aquatic ecosystems (Lansac-Tôha et al., 2009; Bozelli et al., 2015; Mantovano et al., 2019). A similar pattern was observed in our data, with 14 species out of 29 recorded. According to Allan (1976), rotifers are a representative group in the evolutionary history of zooplankton because they are considered opportunistic organisms. Rotifers present rapid life cycles, can survive adverse temperature and food availability conditions, and are less vulnerable to fish predation because they are smaller-bodied compared to other zooplankton groups, such as cladocerans and

copepods (Allan, 1976; Segers, 2008; Bomfim et al., 2018); all these characteristics increase their success in aquatic environments. Within the rotifer group, we observed that 10 species, most of them from the Brachionidae and Lecanidae families, occurred at all sites. Organisms in the Brachionidae family are commonly found in the littoral and limnetic regions of reservoirs, whereas Lecanidae are primarily associated with the littoral region but can also be recorded in the limnetic region (Almeida, 2006; Santos et al., 2021). In studies conducted in the same reservoir in 2019, the prevalence of the families Brachionidae and Lecanidae was also observed among rotifers (Delgado et al., 2025).

Most exclusive species of the littoral or limnetic regions were from the Cladocera group, and the richest family was Chydoridae. Chydoridae organisms are usually associated with the littoral region, contributing to higher cladoceran richness, especially in the presence of aquatic macrophytes (Fryer, 1995). This is because these organisms have appendages specialized for scraping and handling food and a highly mobile postabdomen, which favors their development near macrophytes and substrates (Santos-Wisniewski et al., 2003; Soares and Elmoor-Loureiro, 2011). *Bosmina hagmanni* and *B. tubicen* were present in all samples; these organisms are classified as planktonic and feed on a wide variety of food resources (Santos et al., 2011), which corroborates their occurrence pattern in our study. Regarding copepods, *N. cearensis* and *T. minutus* were observed in all samples; these species are commonly found in reservoirs and have been associated with oligo-mesotrophic conditions (Moura-Júnior et al., 2007; Simões et al., 2008).

Conclusion

The studied reservoir is experiencing uncontrolled anthropic activities in its banks, activities that have the potential to alter water conditions, species establishment, and biological interactions. Therefore, our study contributes to a better understanding of the relationships among macrophytes, water conditions, and zooplankton composition before these activities

worsen and alter such relationships. Macrophytes and zooplankton are important components of aquatic systems, playing several roles in ecosystem functioning, including nutrient and energy cycling (Hébert et al., 2017; Thomaz et al., 2023); thus, understanding their relationships in the reservoir is important. Also, this reservoir supplies water, and changes to these communities can affect water quality and harm the population.

Acknowledgments

The authors express sincere thanks to UESB (State University of Southwest Bahia) for the scholarship granted and for the availability of laboratory facilities. This study received support from Fapesb (Foundation for Research Support of the State of Bahia), CNPq, and UESB. Their contributions were essential to the development of this research.

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