Acta Biológica Catarinense
2025 Jan-Mar;12(1):4-18

Aquatic macroinvertebrates as bioindicators: their importance in the health of the Jaguari River (RS)

Macroinvertebrados aquáticos como bioindicadores: sua importância na saúde do Rio Jaguari (RS)

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Recebido em: 6 ago. 2024
Aceito em: 4 fev. 2025

ABSTRACT
This study evaluated the diversity and seasonal dynamics of macroinvertebrates in the Jaguari River, in the state of Rio Grande do Sul, with collections in March and August 2021. A total of 3,667 individuals of 80 morphospecies were sampled, with emphasis on Ephemeroptera and Coleoptera. Greater abundance and diversity were observed in the summer. Data analysis showed significant differences between collection points and seasonal variations, reflecting environmental quality. The BMWP index indicated good to excellent quality in some points, while the Surface Index revealed a healthy ecosystem. The combination of methods and indices provided a comprehensive view of ecosystem health, highlighting the importance of continuous monitoring and consideration of multiple environmental factors.
Keywords: biological diversity, limnology, seasonality.

RESUMO
Este estudo avaliou a diversidade e a dinâmica sazonal dos macroinvertebrados no Rio Jaguari, no estado do Rio Grande do Sul, com coletas em março e em agosto de 2021. Foram amostrados 3.667 indivíduos de 80 morfoespécies, destacando-se Ephemeroptera e Coleoptera. Observaram-se maior abundância e diversidade no verão. A análise dos dados mostrou diferenças significativas entre os pontos de coleta e variações sazonais, refletindo a qualidade ambiental. O índice BMWP indicou boa a excelente qualidade em alguns pontos, enquanto o Surface Index revelou um ecossistema saudável. A combinação de métodos e índices forneceu uma visão abrangente da saúde do ecossistema, destacando a importância de monitoramento contínuo e a consideração de múltiplos fatores ambientais.
Palavras-chave: diversidade biológica, limnologia, sazonalidade.

INTRODUCTION

Biodiversity is one of the most important components for the maintenance of ecosystems, playing crucial roles in the regulation of ecological processes and environmental sustainability (BEGHELLI *et al.*, 2020). Within this context, aquatic macroinvertebrates have been widely used as bioindicators to assess the health of aquatic ecosystems (FERREIRA *et al.*, 2020). These organisms, which include insects, molluscs and crustaceans, respond sensitively to environmental changes,

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becoming excellent indicators of water quality and the ecological conditions of rivers and lakes (SACRAMENTO *et al.*, 2022).

The Jaguari River, located in Rio Grande do Sul state, southern Brazil, has a rich diversity of aquatic habitats and is an important water resource for the region (SANTOS *et al.*, 2020). However, like many other bodies of water, this one is subject to several anthropogenic pressures, such as pollution, changes in land use and climate change, which can significantly impact its biodiversity (BROSE & SOUTO, 2020). In this context, the analysis of the diversity and seasonal dynamics of aquatic macroinvertebrates becomes essential to understand the impacts of these pressures and to develop effective conservation and environmental management strategies (PAULA RIBEIRO *et al.*, 2020). The use of aquatic macroinvertebrates as bioindicators is a consolidated practice in aquatic ecology (PASTORE *et al.*, 2024). Several studies have demonstrated the effectiveness of these organisms in assessing water quality and detecting environmental impacts (CARARO *et al.*, 2023). Thus, macroinvertebrates are sensitive to a wide range of environmental changes, such as organic and inorganic pollution, habitat destruction and changes in water flow (HARAHAP *et al.*, 2021). This susceptibility is due to the diversity of life forms and feeding habits that these organisms present, which makes them representative of the ecological conditions of the aquatic environment (MILIŠA *et al.*, 2022).

Likewise, the richness of macroinvertebrates is directly related to water quality, with greater diversity in less impacted areas (ARIMORO *et al.*, 2021). There is a positive correlation between the presence of sensitive orders, such as Ephemeroptera and Trichoptera, and low pollution (RAPHAHLELO *et al.*, 2022). This highlights the importance of monitoring macroinvertebrates for the early detection of environmental changes and for the implementation of conservation measures (BONACINA *et al.*, 2023).

The seasonal dynamics of these organisms have also been widely studied, revealing significant variations in the composition and abundance of communities throughout the year (ERIKSEN *et al.*, 2021). Studies investigating environmental factors show that factors such as temperature, rainfall patterns, and food availability influence the temporal distribution of these organisms (KOWNACKI & SZAREK-GWIAZDA, 2022). For example, during periods of greater rainfall, the greater availability of organic debris can favor the proliferation of certain orders of macroinvertebrates, while during dry periods, the reduction of aquatic habitat can lead to a decrease in diversity and abundance (AKYILDIZ & DURAN, 2021).

In the context of the Jaguari River, previous studies indicate that this body of water has significant biodiversity, but that it is subject to environmental pressures that can compromise its ecological integrity (SCHNORR *et al.*, 2021). According to work carried out on the site, the Jaguari River region has experienced an increase in agricultural and urban activity, resulting in a greater load of nutrients and pollutants in the water (TRENTIN *et al.*, 2021). These changes have the potential to negatively impact macroinvertebrate communities, making continuous monitoring and the implementation of sustainable management practices essential (REIS *et al.*, 2022).

Therefore, the most common methodology for collecting and analyzing macroinvertebrates is also a crucial aspect for obtaining accurate and representative data (ARIAS-REAL *et al.*, 2022). The use of direct collection and taxonomic identification is widely recognized in the literature, providing efficient sampling of different aquatic mesoenvironments (LIN *et al.*, 2020). In addition, the application of advanced assessments, correlating the existence of certain organisms in relation to environmental contamination, allows a detailed estimate of this wealth, contributing to the understanding of ecological dynamics and environmental impacts (FEIO *et al.*, 2023).

Therefore, it is possible to highlight the importance of aquatic macroinvertebrates as indicators of environmental quality and the need for continuous studies to monitor ecological changes in water bodies (WILSON *et al.*, 2021). Therefore, the integration of robust sampling and analysis methods, combined with knowledge of the specific environmental pressures of each region, is fundamental for the conservation and effective management of water resources (OROZCO-GONZÁLEZ & OCASIO-TORRES, 2023).

In this context, this study aimed to investigate the richness and seasonal dynamics of aquatic macroinvertebrates in the Jaguari River stretch, providing valuable information on the ecological health of the aquatic environment. The relevance of this study lies in the contribution to the understanding of the ecological dynamics of aquatic macroinvertebrates and in the use of these organisms as environmental monitoring tools (POWELL *et al.*, 2023). Macroinvertebrates are widely recognized for their sensitivity to environmental changes, which makes them effective indicators for the appraisal of water quality and ecological conditions of rivers (SALMASO *et al.*, 2021). Therefore, the results of this study not only provide information on the biodiversity of the Jaguari River, but also highlight the importance of monitoring macroinvertebrates for the management and conservation of water resources.

MATERIAL AND METHODS

The methodology of this study was carefully designed to ensure the representativeness and accuracy of the data found on the richness and seasonal dynamics of aquatic macroinvertebrates in the Jaguari River. Collections were carried out in two distinct seasonal periods, March and August 2021, to capture the temporal variations of macroinvertebrate communities.

Nine sampling points were selected along the studied stretch of the Jaguari River, covering a variety of aquatic mesoenvironments, including rapids, pools and areas with submerged vegetation. These points were chosen based on criteria such as accessibility, representativeness of the different aquatic habitats and the absence of visible direct impacts (table 1, figures 1 and 2).

Table 1 – Geographic coordinates for sampling points for macroinvertebrates, in the Jaguari River.

Location	Coordinates UTM 22 J		Physiognomy
Point 1	770118.00 m E	6782534.00 m S	Wide Rapids
Point 2	768374.00 m E	6780583.00 m S	Rapids with Rocks
Point 3	769744.00 m E	6780152.00 m S	Backwater/Big well
Point 4	765989.00 m E	6778607.00 m S	Wide Rapids
Point 5	763975.00 m E	6779502.00 m S	Wide Rapids
Point 6	763153.00 m E	6776656.00 m S	Backwater/Big well
Point 7	763245.00 m E	6774335.00 m S	Rapids with Rocks
Point 8	761997.00 m E	6775128.00 m S	Backwater/Big well
Point 9	759624.00 m E	6773317.00 m S	Rapids with Rocks

Source: Prepared by the author.

Figure 1 – Distribution of sampling points from upstream to downstream, within the Jaguari River. Source: Primary.

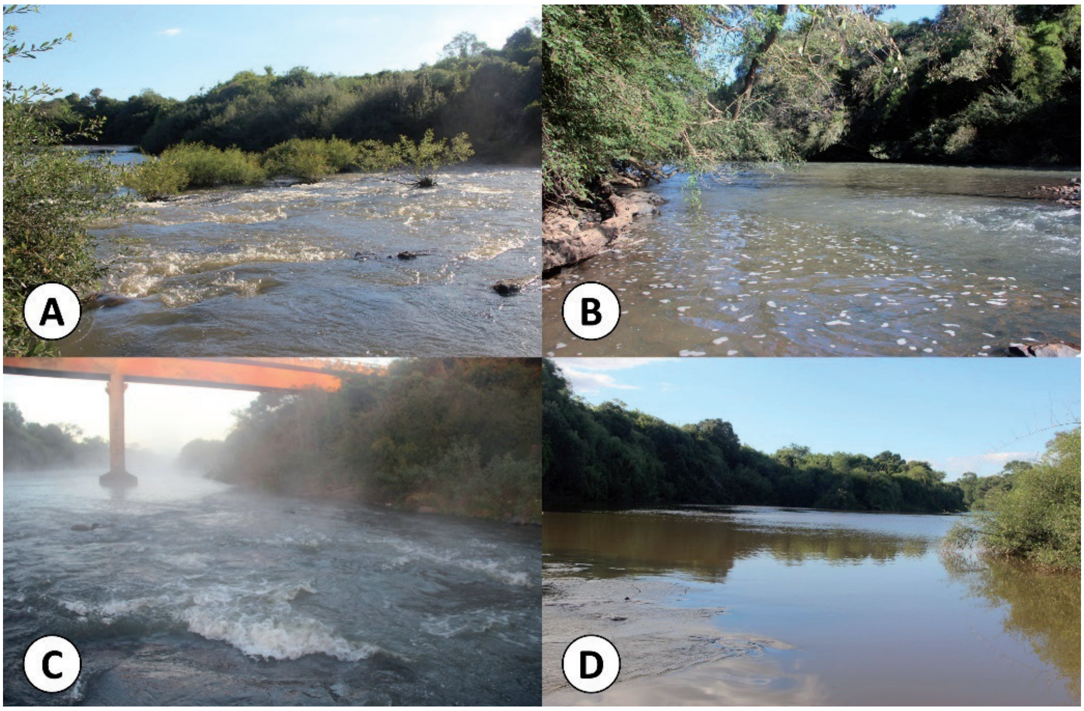

Figure 2 – Illustrated representation of the physiognomy and riparian coverage of the studied area: A) the most upstream point, point 1, with rapids with exposed rocks; B) the middle region with backwater environments, point 4; C) the high-flowing area, like a wide rapid without exposed rocks, point 5; and D) the region of large wells further downstream in the studied area, point 9. Source: Primary.

Surber collector and hand nets were used to collect macroinvertebrates. The Surber collector, with a sampling area of 0.09 m² and a 250 µm mesh, was used in places with running water, such as rapids, allowing the capture of benthic organisms. Hand nets were used in areas with calmer waters, such as puddles and regions with submerged vegetation, providing effective sampling of the macroinvertebrates present in these habitats (figure 3).

Figure 3 – Collection methods used in this study: A) surber type collector; and B) hand nets, applied manually. Source: Primary.

Each sampling point was subjected to three replicates, totaling 54 samples for each seasonal period. The macroinvertebrates collected were fixed in 70% alcohol and later sorted and identified in the laboratory, using taxonomic identification keys specific to the benthic fauna of the region.

To analyze the data, richness and diversity indices were calculated, such as the Shannon-Wiener index (*H'*) and the Pielou index (*J'*), which provide a detailed view of the structure of the macroinvertebrate communities. In addition, analyses of variance (Anova) were performed to verify significant differences between the seasonal periods and the different sampling points.

The data were also subjected to the Biological Monitoring Working Party (BMWP) index to assess environmental quality by assigning scores to invertebrate families based on their tolerance to organic pollutants, where more sensitive families receive higher scores and more tolerant families receive lower scores (table 2). The total score for a location is calculated by adding the values assigned to each family, reflecting the overall environmental condition, with higher scores indicating better conditions (OCHIENG *et al.*, 2020).

In this way, the data were processed by the following equation (NWC, 1981), which is used to calculate the total score ∑ *Si* for each collection point:

$$S_i = \sum_{j=1} \frac{n_{ij} \mathrm{x} V_j}{n_i}$$

Table 2 – Macroinvertebrates with their respective scores according to BMWP (Biological Monitoring Work Party Score System) as well as variations and innovation proposals in the original table recommended by Rimcheska & Vidinova (2020).

Families	Score
Sophonuridae, Heptageniidae, Leptophlebiidae, Potamanthidae, Ephemeridae, Ephemerellidae, Taeniopterydae, Leuctridae, Capniidae, Periododae, Perlidae, Chloroperlidae, Aphelocheridae, Phryganeidae, Molannidae, Beraeidae, Odontoceridae, Leptoceridae, Goeridae	10
Leptodostomatidae, Brachycentridae, Sericostomatidae, Athericidae, Blephariceridae, Euthyplociidae, Chilinidae, Aeglidae, Colepterygidae,	9
Astacidae, Lestidae, Gomphidae, Cordulegastridae, Aeshnidae, Corduliidae, Libellulidae, Psychomyiidae, Philopotamidae, Glossosomatidae, Helotrephidae, Leptophlebiidae	8
Ephemerellidae, Prosopistomatidae, Nemouridae, Grypopterygidae, Rhyacophilidae, Policentropodidae, Limnephelidae, Ecnomidae, Hydrobiosidae, Pyralidae, Psephenidae, Leptohyphidae	7
Neridae, Viviparidae, Ancylidae, Thiaridae, Hydroptilidae, Unionidae, Mycetopodidae, Hyriidae, Corophilidae, Gammaridae, Hyalellidae, Atydae, Palaemonidae, Trichodactylidae, Platycnemididae, Coenagrionidae	6
Oligoneuridae, Polymirtacydae, Dryopidae, Elmidae, (Elminthidae), Helophoridae, Hydrochidae, Hydraenidae, Clambidae, Hydropsichidae, Tipulidae, Simuliidae, Planarridae, Dendrocoelidae, Dugessidae, Ampullariidae	5
Baetidae, Caenidae, Haliplidae, Curculionidae, Chrysomelidae, Tabanidae, Stratyomyidae, Empididae, Dolichopodidae, Dixidae, Ceratopogonidae, Anthopmyidae, Limoniidae, Psychodidae, Schimyzidae, Rhagionidae, Syalidae, Corydalidae, Piscicolidae, Hydracarina, Staphylinidae, Hydrachnidae	4
Mesovelidae, Hydrometridae, Gerridae, Nepidae, Naucoridae, Limnocoridae, Pleidae, Notonectidae, Corixidae, Veliidae, Helodidae, Gyrinidae, Valvatidae, Hydrobiidae, Lymnaeidae, Physidae, Planorbidae, Byrhinellidae, Sphaeridae, Glossiphonidae, Hidudidae, Erphobdeliidae, Asellidae, Ostracoda, Belostomidae	3
Chironomidae, Culidae, Ephydridae, Thaumaleidae, Cyrenidae	2
Oligochaeta (all classes), Syrphidae	1

Source: Adapted from Ertas *et al*. (2021).

Thus, the use of the BMWP index provided a practical assessment of water quality, providing quick and essential information on water resources (ERTAS *et al.*, 2021). The water quality classification is presented in Table 3, categorizing the values obtained by the BMWP index into water quality classification ranges (EL SAYED *et al.*, 2020).

Table 3 – BMWP (Biological Monitoring Working Party) water quality index, related to the Class established by Conama.

Class (Conama)	Quality	BMWP Value
I	Excellent	>150
II	Good	149-100
III	Satisfactory	99-60
IV	Bad	59-20
V	Terrible	<19

Source: Adapted from Conama 357 (ICMBio, 2005).

RESULTS AND DISCUSSION

A total of 3667 individuals of benthic macrofauna were sampled, classified into 7 classes, 17 orders, 44 families and 80 morphospecies. The orders with the greatest representation were Ephemeroptera (26.35%), followed by Coleoptera (22.50%), comprising more than 50% of the sampled organisms, cumulatively for both seasons (figure 4).

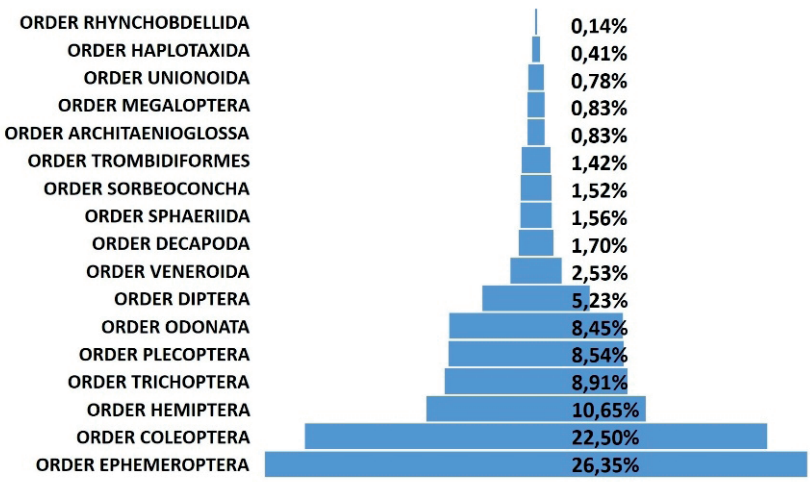

Figure 4 – Distribution of relative abundance by taxonomic order. Source: Primary.

Regarding sampling efficiency and the cumulative number of species over the number of samples, we can infer that there was sampling efficiency. Thus, the stabilization and decrease in the standard deviation after accounting for approximately five data sets indicates that most species have already been sampled. Likewise, the narrowing of the standard deviation variation shows the precision of this estimate. In the same way, the most conservative estimate, such as Jackknife, also stabilizes after six samples. This highlights the sufficiency of the sampling to capture the majority of species in the study area, as well as that additional collections would have little effectiveness in discovering new species (figure 5).

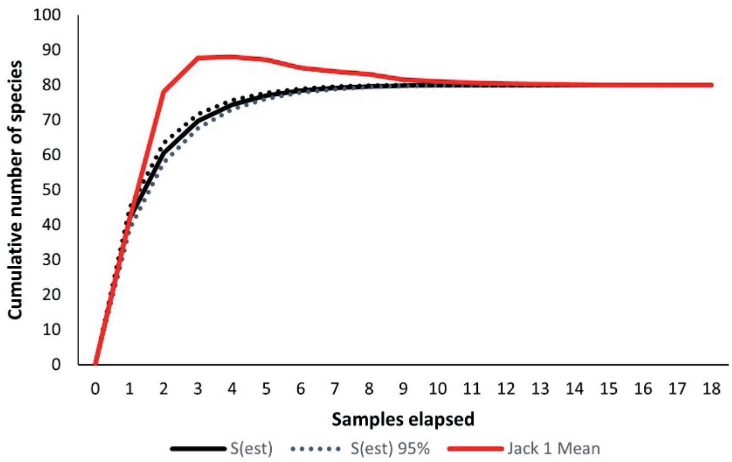

Figure 5 – Rarefaction curve, where S(est) represents the observed richness, and the first-order Jackknife estimator indicates the expected richness. The dashed black line represents the confidence interval (95%) of the observed richness. Source: Primary.

The results also show a significant difference between the climatic seasons such as summer (March 2021) and winter (August 2021). In March, 2,178 organisms representing 80 species were collected, of which 5 were exclusive to this season. In August, the number of organisms decreased to 1,489, with 76 species identified, 2 of which were exclusive to this period. This variation can be attributed to seasonal factors, such as changes in water temperature, river flow and food availability, which affect the abundance and diversity of macroinvertebrates. The presence of species exclusive to both seasons highlights the importance of monitoring different periods for a complete assessment of biodiversity.

The trophic structure of the macroinvertebrate community, considering both sampling seasons, shows the functional dominance of scrapers (39%) and predators (34%), followed by scavengers (15%), filter feeders (7%), collectors (4%) and shredders (2%). The high representation of scrapers suggests a substrate largely colonized by biofilm and periphyton, indicating environmental conditions favorable to primary production. However, this abundance can be modulated by factors such as water quality, which influences nutrient availability, and seasonality, which can alter algal biomass and the provision of suitable microhabitats for these organisms.

Therefore, the significant presence of predators suggests a top-down trophic control, in which predatory pressure can regulate herbivore and detritivore populations, shaping the dynamics of the community (PASCHOAL & COUTO, 2021). On the other hand, the high availability of primary resources and the abundance of scrapers indicate a potential bottom-up effect, driving trophic structuring by providing energy support to higher levels (SILVA CAMARGO *et al.*, 2022). The interaction between these groups can be influenced by anthropogenic disturbances, such as excessive input of organic matter and contaminants, which can favor opportunistic groups and alter the functional balance of the community.

Thus, studies in similar lotic ecosystems indicate that the predominance of scrapers may be associated with low turbidity and greater substrate stability, favoring biofilm colonization, while the expressive presence of predators may indicate a structurally heterogeneous environment, offering refuges and foraging opportunities (SOARES *et al.*, 2022). Comparisons with other river basins reveal that environmental changes, such as riparian deforestation and urbanization, tend to reduce functional diversity, affecting the representation of dominant trophic groups (SANTOS LIMA & PAMPLIN, 2023). Thus, the integrated analysis of the trophic distribution of macroinvertebrates reinforces the need to consider multiple environmental factors to understand the ecological dynamics that sustain the biodiversity of these aquatic systems.

The presence of scavengers and filter feeders suggests active processes of decomposition and dynamics of particulate matter. Although in smaller proportions, collectors and fragmenters contribute to the health and complexity of the ecosystem, reflecting a functional diversity that points to good environmental quality (figure 6).

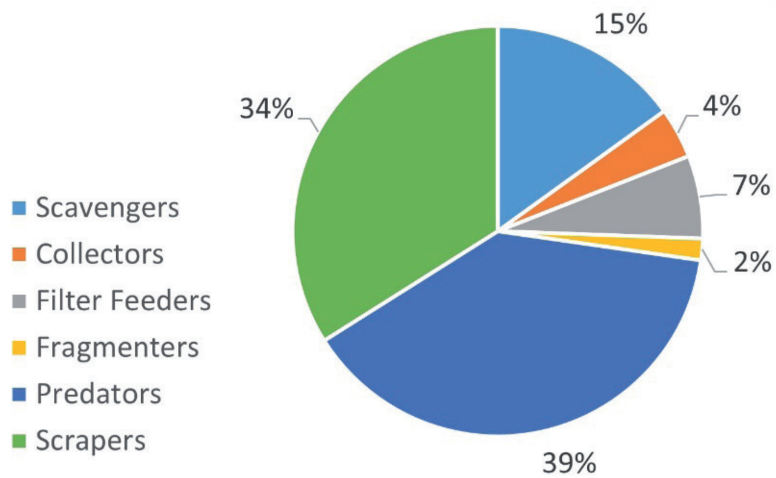

Figure 6 – Percentage of individuals of the benthic macroinvertebrate fauna by trophic category. Source: Primary.

On the other hand, the aquatic fauna found reflected the local environmental heterogeneity and is in line with that expected for headwater rivers, such as the Jaguari. The One-Way Anova analysis allowed us to identify significant differences between the collection points, with low data dispersion, indicating homogeneity and consistency in the collected data.

When analyzing the quality of the data, it was observed that the residuals of the means present significant dispersion in relation to the normality line, which suggests the presence of atypical values or a non-normal distribution of the data. To confirm this assumption, normality tests were applied, such as the Shapiro-Wilk test (as it is the most widespread and relevant test). The analysis of the standard errors revealed variations between the sample points, with emphasis on point P7, which presented the highest mean and greatest variability. This greater variability may be associated with greater uncertainty in the estimate of the mean, reflecting possible external influences or specific characteristics of this sample point.

It is important to emphasize that an important variable that can influence the representativeness of these data considering the assessment of normality is water quality. This parameter can explain the variations observed in the different sampling points and provide a more complete understanding of the environmental conditions that affect the distribution and abundance of the macroinvertebrates in the Jaguari River (figure 7).

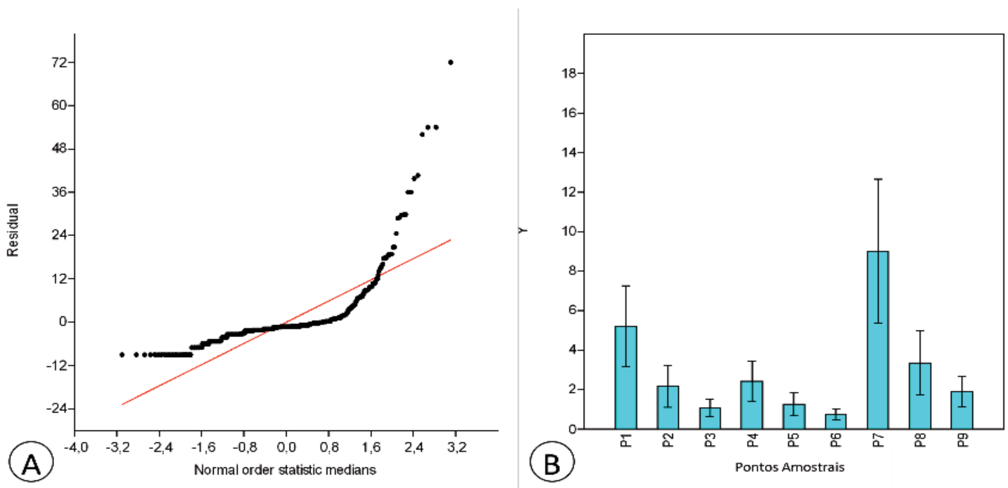

Figure 7 – Result of: A) residual accumulation of the application of One Way Anova; and B) standard deviation derived from the accumulated raw data. Source: Primary.

However, the Surface Index also allowed for the assessment of the ecosystem health in a three-dimensional way, showing that the locations with the highest number of taxa also had the greatest adherence of values for the aquatic community. The application of ecological indices highlighted points 1, 4 and 7 as presenting the highest number of taxa and high diversity indices, suggesting better environmental quality in these locations.

This is possibly related to the distribution or abundance of macroinvertebrates at different sampling points. The different intensities or concentrations of organisms indicate a guarantee of representativeness of these data and it is relevant to consider the influence of additional environmental variables, such as the composition of the riverbed substrate, the speed of the current, the presence of riparian vegetation and the quality of the water, which can significantly affect the distribution of macroinvertebrates and provide a more robust and comprehensive analysis (figure 8).

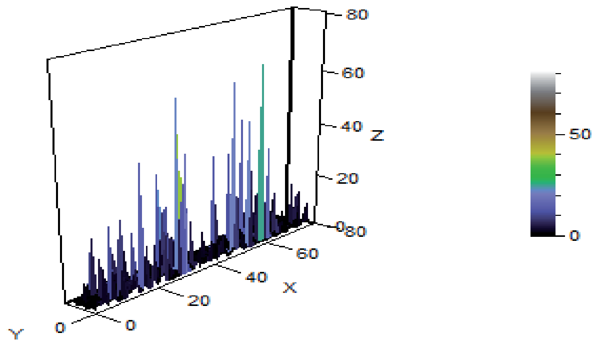

Figure 8 – Cumulative distribution seen by the Surface index of the quantities of organisms per point along the studied section. Source: Primary.

On the other hand, the comparison between the sampling points using the Shannon similarity index showed that they have similar biological and structural compositions, possibly due to shared environmental factors. This Shannon similarity index revealed that the same points 1, 4 and 7 differ significantly from the others in terms of biological diversity.

However, the BMWP index attributed values that diverged from this analysis (that is based on the sensitivity of macroinvertebrates to environmental disturbances). Thus, according to BMWP index, points 1, 3 and 7 stood out with the highest values, indicating good to excellent environmental quality. This parametric divergence is due to the taxa composition found in points 1 and 7, with organisms belonging to more sensitive groups than those found in the other sampled locations (table 4).

Table 4 – BMWP indices for each sampling point cumulatively for both climatic seasons, also indicating the Conama Class, Shannon index and local richness: Excel. (Excellent), Satis. (Satisfactory) and Good.

Points	1	2	3	4	5	6	7	8	9
BMWP	163,97	83,32	99,50	111,99	85,6	139,59	135,6	68,3	81,95
Quality	**Excel.**	**Satis.**	**Satis.**	**Good**	**Satis.**	**Good**	**Godd**	**Satis.**	**Satis.**
Class	I	III	III	II	III	II	II	III	III
Shannon	3,351	3,212	3,325	3,505	3,549	3,571	3,32	3,196	3,388
Wealth	57	43	34	53	50	37	56	41	40

Source: Primary.

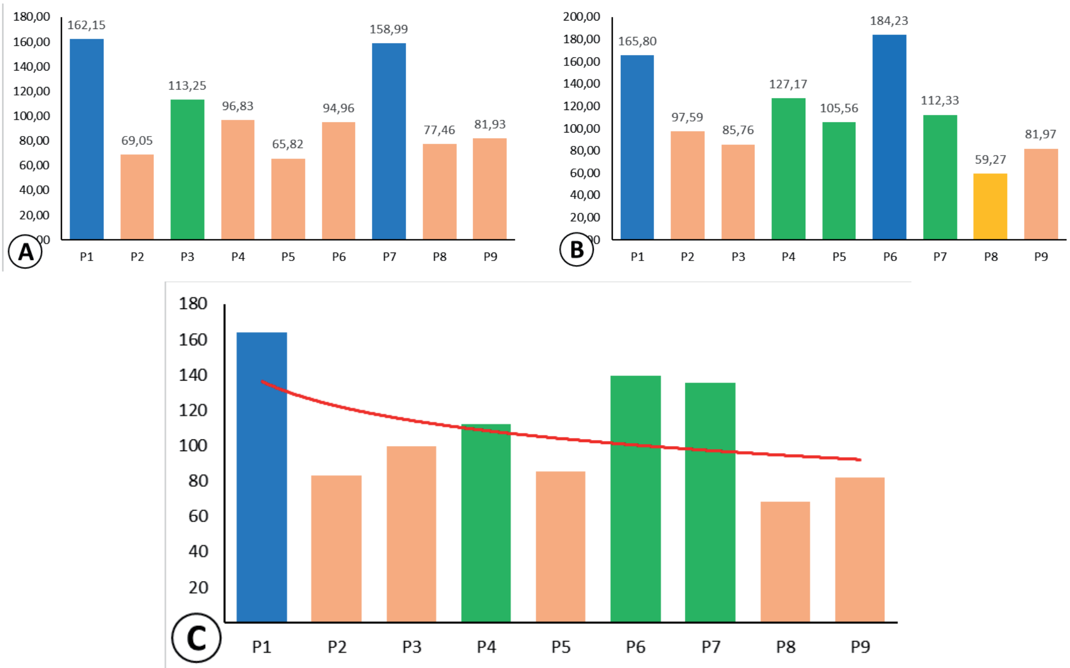

Figure 9 – Distribution of the BMWP index by sample point, where we can see the values for A) the hot and rainy season, in March 2021, and for B) the cold and dry season, in August 2021, as well as, in red, the logarithmic trend line for these values, C) cumulatively for both seasons. Source: Primary.

The results of this study revealed a rich taxonomic diversity of macroinvertebrates, highlighting the predominance of the orders Ephemeroptera and Coleoptera. The significant variation in the composition of the communities throughout the seasons was quite relevant, corroborating the hypothesis that macroinvertebrate communities are influenced by seasonal variations and environmental conditions (BUFFAGNI, 2021). The observation of fluctuations in the diversity and richness of species at different points along the river reinforces the importance of local characteristics in the structure of aquatic communities (ZHANG *et al.*, 2020).

In this way, it was possible to reveal considerable biodiversity, with the sampling of 3667 individuals belonging to 80 morphospecies, of which more than 50% are restricted to two orders, which are known to be predators. This is important, as it is an indication that there are many preys and an environment with high biological and habitat diversity (CALABRESE *et al.*, 2020).

On the other hand, the seasonal variation observed between summer and winter reflects an ecological dynamic expected in many aquatic environments (HAMID *et al.*, 2021), where the greater abundance and diversity of macroinvertebrates during the summer can be attributed to more favorable conditions, such as higher temperatures and greater food availability (CORTÉS-GUZMÁN *et al.*, 2021). And the presence of species exclusive to each season reinforces the importance of monitoring throughout the year for a complete understanding of biodiversity and seasonal variations (SALMASO *et al.*, 2021).

From a trophic point of view, the predominance of scrapers and predators suggests a well-balanced and healthy ecosystem, with a complex and adequate trophic structure (OCHIENG *et al.*, 2020). Therefore, the presence of scavengers and filter feeders is also significant, as it indicates that there are active decomposition processes and a dynamic of particulate matter, important elements for maintaining ecosystem health (POWELL *et al.*, 2023).

From a statistical analytical perspective, the data observed using the ANOVAM test revealed significant differences between collection points, with a variation in the residuals that suggests possible atypical values or a non-normal distribution of the data (WILSON *et al.*, 2021). However, this is to be expected, since water quality is a preponderant factor that can explain the observed variations (RIMCHESKA & VIDINOVA, 2020). This is crucial, as it highlights the need to consider additional environmental variables for a more accurate interpretation of the distribution and abundance of macroinvertebrates (OROZCO-GONZÁLEZ & OCASIO-TORRES, 2023).

The use of alternative indices, such as the Surface Index, to assess ecosystem health in a three-dimensional way, provided valuable insights, indicating that locations with a greater number of taxa also presented better environmental quality (MUNFARIDA & MUNIR, 2023). In contrast, the application of more common ecological indices, such as the BMWP, revealed some divergences in this context, as this index considers the importance of a given taxonomic entity in the location and its sensitivities, and not just the richness or abundance of organisms in a generalized way (TAGHINEJHAD *et al*., 2023). These divergences can be attributed to differences in the sensitivity of macroinvertebrate groups to environmental disturbances. An important point to consider when interpreting the results is that the BMWP is more assertive, as it considers not only the presence, but also the tolerance or vulnerability of organisms (SILVA SANTOS *et al*., 2023). Furthermore, the index considers the complete picture of individual research on all identified organisms or groups present (AKINDELE *et al*., 2023).

Therefore, comparing with previous studies, it is possible to verify that such results are in line with preceding observations on the diversity and abundance of benthic macrofauna (SCHIAVONE *et al*., 2012). Earlier studies also highlight the influence of seasonal variations and the importance of a detailed analysis of ecological indices to assess environmental quality (CASTRO VASCONCELOS, 2014). However, these findings provide new information on fauna composition and variation between different sampling points, contributing to a deeper understanding of the local ecosystem of the Jaguari River (COPATTI *et al*., 2010).

In summary, this study provided a comprehensive and detailed view of the local benthic macrofauna, revealing significant patterns of diversity and abundance, as well as seasonal and qualitative variations (FEIO *et al*., 2023). This reinforces the importance of continuous monitoring and consideration of multiple environmental variables for a complete assessment of the health of aquatic ecosystems (POWELL *et al*., 2023), where the combination of methods and indices used in the study provides a robust analysis, which may be valuable for conservation future efforts and environmental management services in the region.

CONCLUSION

This study highlighted the rich biodiversity of benthic macrofauna in the Jaguari River, revealing discrete seasonal variation, with small changes in abundance and taxon composition. The analysis also emphasized the environmental complexity of the region, with the presence of different habitat scales (macro, meso, and micro) that support the inherent services provided by macroinvertebrates. The variability observed between sampling points and the discrepancies between ecological indices suggest that the assessment of the biotic and abiotic qualities depends on multiple factors, and that a combination of methodologies is essential for a more comprehensive understanding of the natural community. The differences in the sensitivity of macroinvertebrate groups, indicated by the indices, call attention to the importance of considering heterogeneity and local environmental dynamics. Future studies should integrate diverse methodological approaches in order to more accurately capture the nuances of the ecological health of the Jaguari River.

ACKNOWLEDGMENTS

The first author would like to thank all who, in some way, contributed to the completion of this study, especially the partners who made it possible to carry out and obtain the field data and, in particular, Capes, for promoting and facilitating studies and bibliographic resources.

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