Trophic structure and functional feeding groups of macroinvertebrates in a section of the Gallinazo tropical stream

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ABSTRACT. Aquatic macroinvertebrates play crucial roles in ecosystem processes such as grazing, decomposition, and mineralization. Classifying these organisms into functional feeding groups (FFGs) enables a more comprehensive understanding of energy and matter flow through trait-based approaches, complementing traditional taxonomic methods. The study analyzed the trophic structure and FFG variation of aquatic macroinvertebrates in a section of a tropical stream, located in the municipality of Aguachica, Colombia. Sampling was carried out during the rainy season in May and the dry season in July 2024, during which the composition and abundance of macroinvertebrate feeding groups were analyzed. Physical and chemical parameters were measured both in situ and ex situ at strategically selected stations based on accessibility and location. Macroinvertebrates were collected using Surber and D-type nets and identified to the family level. They were then assigned to functional feeding groups. Ecological indices and multivariate statistical analyses were applied to evaluate ecosystem attributes. Results revealed seasonal variations in water parameters, including lower dissolved oxygen and higher chemical oxygen demand during the dry season, suggesting potential organic pollution. Macroinvertebrate richness was higher during the dry season, with *Caenis* sp. and *Tanypodinae* sp. being dominant, while *Drepanotrema* sp. and *Physa* sp. were more abundant during the rainy season, reflecting eutrophic conditions. The P/R index indicated heterotrophic dominance, and low CPOM/FPOM ratios pointed to limited riparian cover. These findings underscore the importance of implementing conservation strategies to mitigate anthropogenic pressures and preserve the ecological integrity of freshwater ecosystems.

Keywords: neotropical streams, predators, FFG, trophic guilds, disturbance, shredders

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1. Introduction

Aquatic ecosystems are essential to the socioeconomic development of human populations, as communities rely on the ecological health and services provided by these systems (Nuñez and Fragoso-Castilla, 2019; Cabrera et al., 2021). Freshwater ecosystems, in particular, are among the most exploited globally due to their high functionality and their direct interaction with anthropogenic activities (Reid et al., 2019; Bănăduc et al., 2024). However, the ecological condition of these water bodies is increasingly affected by land-use changes driven by urban development and agricultural expansion (Forrest et al., 2015; Pascual et al., 2022). Numerous studies have documented the effects of such disturbances on the structural integrity of aquatic ecosystems, particularly in relation to changes in biological communities (Beckmann et al., 2019; Li et al., 2019; Reid et al., 2019).

The use of biological communities to assess the health of freshwater systems has gained reliability in recent decades, as these organisms integrate the cumulative effects of anthropogenic disturbances (Rizo-

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Patrón et al., 2013; Ding et al., 2017; Fierro et al., 2017). Aquatic macroinvertebrates are particularly useful bioindicators due to their varying tolerance levels to environmental stressors and their ability to respond to a wide range of physical and chemical changes in water bodies (Ertaş and Yorulmaz, 2022; Assie et al., 2025), Additionally, their cost-effective sampling methods make them ideal for long-term ecological monitoring (Agboola et al., 2020; Ko et al., 2020). Nevertheless, the taxonomic approach has limitations, especially in regions with high species diversity, as identification to the species level can be challenging and time-consuming (Juvigny-Khenafou et al., 2021). For more than 30 years, multiple studies have addressed this limitation by shifting the focus to food functional ranges of groups, as they reduce the taxonomic effort required for comparison with other methods (Cummins et al., 2005; Ndatimana et al., 2023).

Accurate determination of ecosystem attributes is a complex process that requires extensive data collection along spatial and temporal gradients (Merritt et al., 2002). It is, therefore, that the functional analysis of communities, in particular through FFGs, represents a key tool in community ecology, allowing us to understand how species mediate fundamental ecological processes such as nutrient cycling, primary productivity, and decomposition (Abdul and Rawi, 2019; Doong et al., 2021). The FFG approach requires less taxonomic effort while providing information on the functional structure of macroinvertebrate communities, thus aligning with the principles of functional ecology, which seeks to identify general patterns and mechanisms applicable to multiple ecosystems (Assie et al., 2025). Thus, the aim of this study was to analyse the trophic structure and variation of aquatic macroinvertebrate FFGs in a section of a tropical stream. The study of FFGs not only allows us to assess the ecological integrity of specific systems such as the Gallinazo stream but also contributes to the understanding of the functional responses of tropical lotic ecosystems to gradients of anthropogenic disturbance.

2. Material and methods

2.1. Study area

The present study was carried out in the municipality of Aguachica, located in the department of Cesar, Colombia, at coordinates 8.30667° latitude and -73.6153° longitude, at an altitude of 179 meters above sea level. This region has a mean annual temperature of 28 °C and an average annual rainfall of 1687.13 mm (Alcaldía de Aguachica, 2024). The study focused on a 546.63-meter-long section of the Gallinazo stream, located downstream from the nearest urban settlement, approximately 260 meters away (Fig. 1A). The area has two types of vegetation cover: weedy grasslands (27.29%) and secondary vegetation (72.71%), as well as hydrological soil groups, sandy soils (15.1%), moderately coarse-to-fine textures (56.6%), and moderately fine textures (28.3%) (Saldaña-Escorcia et al., 2022). This area was selected because it receives point source discharges of domestic wastewater, as well as diffuse

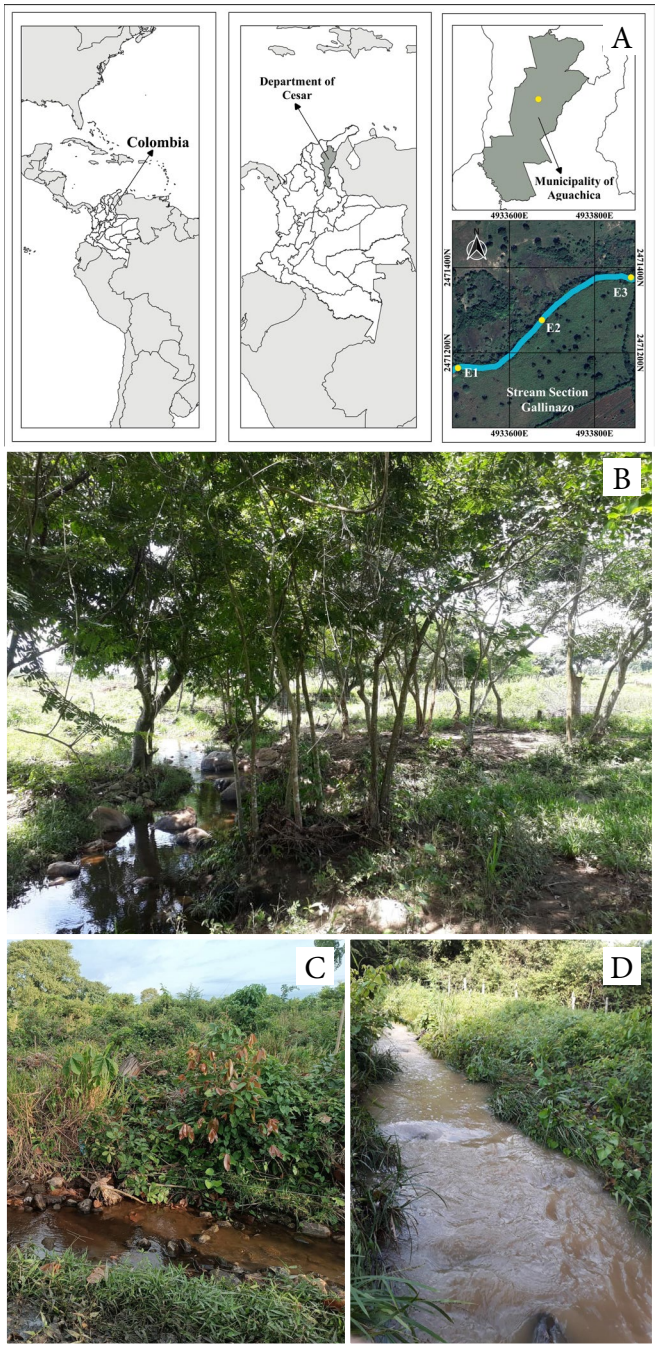

Fig.1. A. Location of the Gallinazo stream section and sampling sites. **B-D** Display a representative image of each sampled site type.

inputs from agricultural activities (Saldaña-Escorcia et al., 2024). Likewise, this section of the stream receives water inputs from a marshy wetland on the left bank, which is directly influenced by livestock farming, factors that are relevant for evaluating changes in water quality and the structure of functional trophic groups.

2.2. Sampling design

Sampling was performed during two distinct climatic periods, with one sampling campaign conducted in each: the rainy season in May and the dry season in July 2024. Three sampling stations were established along the selected stretch in order to capture spatial variability associated with the disturbance gradient. The

first station (E1, Fig. 1B) is at an altitude of 160.7 m; the second (E2, Fig. 1C) is at an altitude of 152.6 m; and the third station (E3, Fig. 1D) is at an altitude of 149.8 m. At E1, the riparian vegetation is moderately preserved, dominated by medium and large trees that provide shade to the stream section, with low human activity. E2 shows high human intervention, with the presence of livestock (cattle, horses, and buffalo) as well as corn crops (Saldaña-Escorcia et al., 2024). The riparian vegetation at this station consists mainly of shrubs, due to human-induced deforestation. At the last station, medium and low-height trees predominate, forming a low canopy over the stream section; this station has high anthropic activity due to its proximity to farm properties. The coordinates of the sampling sites, as well as some environmental and structural characteristics, are presented in Table 1.

2.3. Physical and chemical parameters

A range of physical and chemical parameters (each measured in triplicate) was assessed in situ using specialized field equipment. Temperature (°C) and dissolved oxygen (DO) levels were measured using the HI 98193 probe, while electrical conductivity (μS/cm) was determined using the HI 9835 probe. The pH was recorded using the HI 98191 field meter. For ex situ analysis, water samples were collected in 1000 mL polyethylene bottles and stored at approximately ± 4 °C until further laboratory analysis, following the guidelines of the IDEAM (2020), manual for the collection and preservation of water and sediment samples for water quality monitoring, using standard methods established for the analysis of drinking water and wastewater, according to the recommendations of APHA, AWWA and WEF (Ann and Franson, 1992). In this context, the standard method 2130 B was used to measure turbidity (NTU), the SM 4500-PE method–for the determination of phosphates (mg PO_4^{-3}/L), and the SM 4500-NO_3 B method–to quantify nitrates (mg N-NO_3^-/L). Moreover, the SM 2540 D method was applied to measure total suspended solids (mg/L), while chemical oxygen demand (COD) was determined by the SM 5220 method. Finally, the five-day biochemical oxygen demand (BOD_5) was assessed by the SM 5219 standard method.

2.4. Sampling and identification of macroinvertebrates

Macroinvertebrates were collected using a Surber sampler (500 μm mesh) for stony substrates and a D-frame net (500 μm mesh) for marginal vegetation. The D-net was used to sweep against the current for five minutes at each station, repeated ten times per site (Mena-Rivera et al., 2018; Vargas-Tierras et al., 2023). Samples were transferred to plastic trays, then to sterile, airtight bags, and preserved in 96% ethanol. In the Water Laboratory at Universidad Popular del Cesar, Aguachica campus, organisms were sorted, counted, and identified under a stereoscope. Taxonomic identification was carried out to the genus level using standard keys for Neotropical macroinvertebrates developed by Bejarano (2006), De Carvalho et al. (2005), Domínguez and Fernández (2010), Heckman (2006), Neiss et al. (2018), Passos et al. (2018), Roldán (1988) and Ronderos et al. (2018). Identification to family was deemed sufficient based on literature suggesting that family-level identification provides robust data for water quality assessments (Chará-Serna et al., 2015; Goncharov et al., 2020; Hotor and Kwaku Atsu, 2021; Mendoza-Ramírez et al., 2022), especially in regions lacking species-level taxonomic keys (Cabrera et al., 2021).

2.5. Assignment of traits according to feeding habits

Functional traits were assigned according to Ramírez and Gutiérrez-Fonseca (2014), Damanik-Ambarita et al. (2016), Wehrtmann et al. (2019), and Yang et al. (2020). Taxa were grouped into functional feeding groups following Ramírez and Gutiérrez-Fonseca (2014) and Coccia et al. (2022); these being Pr = Predators, CG = Collector-collectors, CG-Ft = Collector-filtrators, Collector-detritivores (CG-Hb), Sh = Shredders, and SC = Scrapers. Some families were assigned to multiple FFGs to reflect feeding versatility (Cabrera-García et al., 2023). Functional group assignment was not possible for four taxa (Thaumasia, Heleobia, Aropyrgus, and Chlamydotheca) due to limited ecological information.

Table 1. Environmental and structural characteristics recorded at the sampling sites.

Variable	E1	E2	E3
Coordinates (Lat, Long)	8°17′59.60″N – 73°36′19.30″O	8°17′56.10″N – 73°36′26.40″O	8°17′52.10″N – 73°36′33.50″O
Altitude (m above sea level)	160.7	152.6	149.8
Flow velocity (m/s)	0.18 ± 0.06	0.22 ± 0.01	0.10 ± 0.05
Average depth (cm)	21 ± 0.01	36 ± 0.05	51 ± 0.03
Channel width (m)	1.8 ± 0.5	2.4 ± 1.2	3.1 ± 0.3
Structural substrate (available habitat)	Little leaf litter and exposed roots	Abundant leaf litter, fragments of thin branches, and exposed roots	Scattered leaf litter and exposed roots
Presence of logs or submerged wood	Low	Moderate	Moderate

2.6. Indicators of stream ecosystem attributes

FFG-based indices were used to characterize ecosystem attributes following criteria established by Cummins et al. (2005) and Yaagoubi et al. (2023), as presented in Table 2.

2.7. Data treatment

For the analysis of the physical and chemical data, descriptive statistics were used to calculate the mean and standard deviations (SD ± mean) for each parameter and at each sampling station. Additionally, a principal component analysis (PCA) under the Bray-Curtis index was performed to identify distribution patterns and key variables influencing the results. Hierarchical clustering was performed based on Euclidean distance complemented with the Simproff test ($p < 0.05$), and differences between stations, as well as between sampling periods, were evaluated using a permuted multivariate analysis of variance (PERMANOVA) with 9999 permutations, using Euclidean distance for environmental variables; Rv4 software was used. For macroinvertebrate structure, genus richness was estimated, and graphical analyses were performed to determine the relative abundance and percentage proportion of biomass by taxon and period, taking into account the classification of functional groups.

3. Results

3.1. Physical and chemical parameters

Analysis of the water's physical and chemical parameters revealed notable seasonal variations, indicating shifts in environmental conditions between the rainy and dry seasons (Table 3). Dissolved oxygen (DO) ranged from 3.3 to 6.08 mg/L, with a mean of 5.07 ± 1.03 mg/L. The lowest value was recorded during the dry season (station E1M2), falling below the seasonal average, while all rainy season measurements exceeded this average.

Turbidity ranged from 6 to 10.5 NTU, with a mean of 8.56 ± 1.75 NTU. The lowest turbidity was observed at station E2M2 during the dry season, and the same station also recorded the minimum in the rainy season. The maximum value occurred at station E1M1. A coefficient of variation of 20.14% indicated moderate variability. A negative correlation was observed between turbidity and DO (Fig. 2), suggesting that higher turbidity can reduce sunlight penetration, impair aquatic photosynthesis, and reduce oxygen production. Turbidity may also signal the presence of organic pollutants consuming oxygen during decomposition.

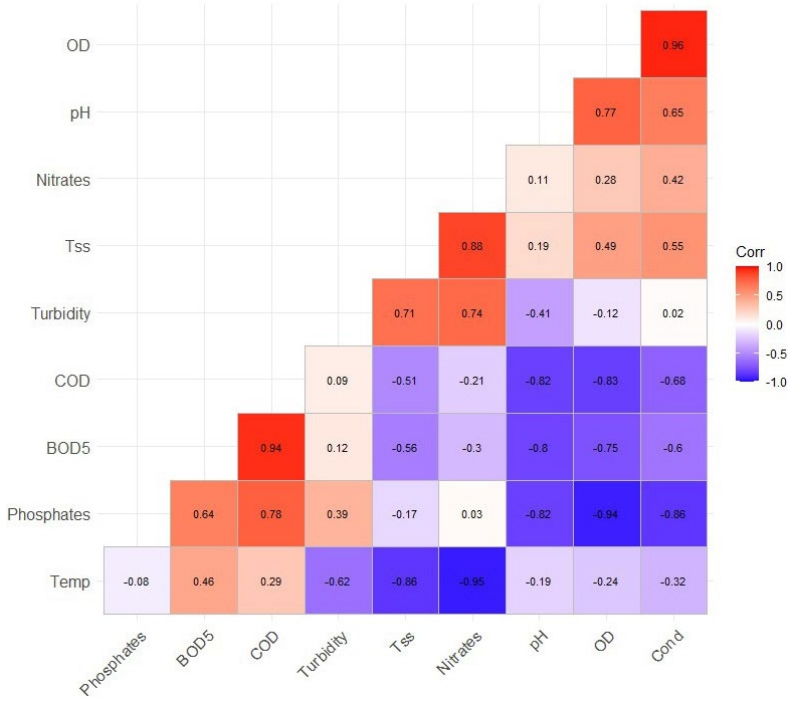

Fig.2. Correlation analysis based on chemical and physical parameters.

Table 2. Functional feeding group ratios as indicators of stream ecosystem attributes.

Attribute	Symbols	Equation	General criteria for ratio levels
Autotrophy to heterotrophy ratio	P/R	$P/R = \frac{Sc}{Sh + CG + CGHb}$	Autotrophic > 0.75
Predator to prey ratio	P/P	$P/P = \frac{Pr}{Total - Pr}$	< 0.15 indicates normal predator/prey ratio
Ratio of coarse particulate organic matter (CPOM) to fine particulate organic matter (FPOM)	Intellectual Property Management Committee (CPOM) and the Intellectual Property Management Committee (FPOM)	$CPOM/FROM = \frac{Sh}{CG + CGFt + CGHb}$	Normal association of shredders linked to riparian zone functioning > 0.25
FPOM in transport (suspended) to FPOM storage in sediment	TFPOM/BFPOM	$TFPOM/BFPOM = \frac{CGFt}{CG}$	Transport of FPOM (in suspension) enriched with (unusual) particle load > 0.50
Substrate stability	Substrate stability	$Est = \frac{Sc + CGFt}{Sh + CG}$	Abundant stable substrates > 0.50

Table 3. Chemical and physical parameters.

Station	Period	Turb	OD	T °C	pH	Cond	BOD_5	COD	TSS	Nitrates	Phosphates
E1	Wet	10.5	5.32	29	7.2	249	2.00	32	22	31.24	0.53
	Dry	9.26	3.3	29.9	7.11	126.3	2.00	37	14	21.12	0.9
E2	Wet	6.94	6.07	29.4	7.6	252	1.00	10	17	23.76	0.26
	Dry	6.00	4.95	33.5	7.24	201	2.00	31	6.0	8.36	0.42
E3	Wet	9.67	6.08	29.6	7.35	248.5	1.00	6	25	24.2	0.35
	Dry	9.04	4.75	32	7.3	195.3	2.00	24	12	17.16	0.48

Water temperature varied from 29 to 33.5 °C (mean = 30.56 ± 1.78 °C), with higher readings at E2M2 and E3M2. E1M1 recorded the lowest temperature. The coefficient of variation was low (5.82%), indicating relative temperature stability. A moderate negative correlation (-0.62) was found between temperature and turbidity, possibly due to temperature-dependent changes in solubility and particle dispersion. However, this relationship is not very strong, so other factors could influence turbidity.

The pH levels ranged from 7.11 to 7.6 (mean = 7.3 ± 0.17). Slight variation was observed, with a low coefficient of variation (2.31%). Electrical conductivity varied significantly, ranging from 126.3 to 252 μS/cm (mean = 212 ± 49.08 μS/cm), with the lowest value at E1M1 and the highest at E2M1. A moderate positive correlation between pH and conductivity suggests a link to dissolved ion concentrations, such as bicarbonates.

Chemical oxygen demand (COD) ranged from 6 to 37 mg/L (mean = 23.33 ± 12.64), with the lowest and highest values at E3M1 and E1M2, respectively. BOD_5 averaged 1.66 ± 0.52 mg/L, indicating relatively low biodegradable organic matter. COD and BOD_5 showed high variability (CV = 54.18% and 30.98%, respectively) and a strong positive correlation (0.93), reflecting a shared response to organic content in water. Both COD and BOD_5 were negatively correlated with pH (-0.82 and -0.80, respectively), indicating that acidic conditions may elevate oxygen demand due to decreased microbial activity and enhanced resistance of organic matter to degradation.

TSS ranged from 6 to 25 mg/L with an average of 16 ± 6.89 mg/L, a relatively low value, suggesting a potentially low amount of suspended particles in the water. Moreover, the coefficient of variation was 43.12%, indicating significant variability in the number of suspended solids. Similarly, nitrates ranged from 8.36 to 31.24 mg/L, with an average of 20.97 mg/L, implying a moderate concentration of nitrates; the minimum value was at E2M2, while E1M1 showed the maximum value. Additionally, the standard deviation was ±7.710 mg/L, reflecting considerable variability in nitrate levels.

A strong positive correlation (0.74) was observed between TSS and nitrates, suggesting that the presence of organic or inorganic material retains or transports nitrates in the water, which may be indicative of contamination from agricultural or industrial sources. This parameter also showed a strong negative correlation with temperature (-0.95), indicating that temperature affects certain biochemical processes that facilitate the conversion of nitrates to more complex forms or their uptake by aquatic organisms. However, the inverse relationship may also reflect seasonality or variation in the source of nitrate. Finally, phosphates averaged 0.49 mg/L, a relatively low value, indicating a low concentration of phosphates in the water. However, the CV was 45.37%, demonstrating significant variability in the number of phosphates in the water. The ratio of phosphate to nitrate was low (0.03), implying that these two compounds are not strongly correlated in the water samples. Although both are important nutrients that contribute to the eutrophication of water bodies, their behaviour in water may depend on other factors, such as pollution sources and biological interactions in the aquatic ecosystem.

The cluster analysis showed three groups, consisting of stations E1M1 and E1M2, E2M2 and E3M2, as well as E2M1 and E3M1 (Fig. 3A). In the principal component analysis, the first two principal components explain more than 87% of the variability in the data (Fig. 3B), meaning that these components capture most of the underlying structure of the system. Additionally, BOD_5 (0.3756), COD (0.3830), and phosphates (0.3372) have high positive loadings, indicating that they have a major influence on PC1 being relevant in defining the variability in this component; while DO (-0.3952) and Conductivity (-0.3763) have high negative loadings. PERMANOVA revealed no statistically significant differences between stations ($F = 1.0655$; $p = 0.4667$) or between seasons ($F = 3.6966$; $p = 0.1$).

3.2. Biological variables

According to the climatic periods (Fig. 4), the most abundant taxa during the rainy season were *Drepanotrema* sp. (55 individuals) and *Physa* sp. (33 individuals), as they are associated with environments more degraded towards eutrophic conditions. In contrast, during the dry season the most abundant taxa were *Caenis* sp. (261 individuals) and *Tanypodinae* sp. (70 individuals), as they are found in conditions with less sedimentation or greater availability of food in the form of detritus.

The presence of taxa indicative of environmental stress, such as *Tubifex sp.*, *Physa* sp. and *Pomacea* sp., indicates alterations derived from excessive sedimentation or zones rich in organic matter, suggesting eutrophication. Similarly, species such as *Acanthagrion* sp. and *Neurocordulia* sp., commonly associated with

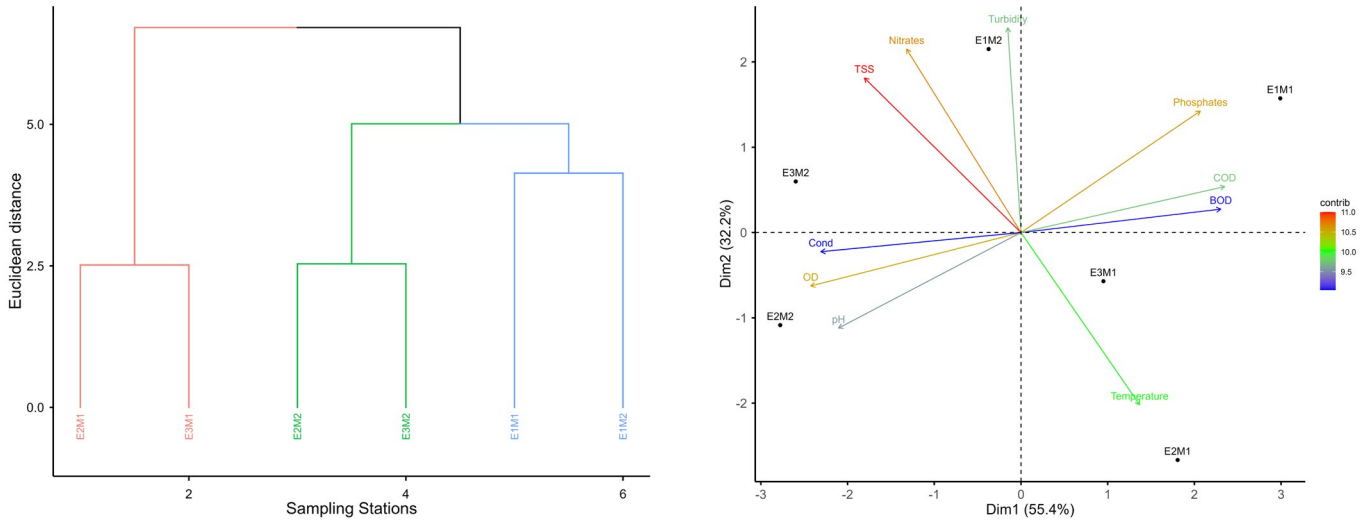

Fig.3. (A) Cluster dendrogram based on chemical and physical parameters of the sampling stations. (B) Principal component analysis (PCA) of the chemical and physical parameters of the sampling sites.

well-oxygenated environments, present a higher biomass in the blue zone, which could suggest better conditions in terms of environmental quality. In contrast, taxa such as *Chironomus* sp. or *Tubifex* sp., which usually thrive in eutrophic or low water quality conditions, have higher biomass in the red zone, which could be an indicator of degradation in certain microhabitats.

In general, among the orders recorded (Fig. 5), Ephemeroptera (297 individuals) was the most abundant, followed by Basommatophora (216 individuals) and Diptera (107 individuals), while Araneae, Trombidiformes and Lepidoptera were the least abundant. However, for the rainy season, the order Basommatophora had the highest abundance with 115 individuals, followed by Odonata with 25 individuals, while for the dry season, the order Ephemeroptera was the most abundant (283 individuals), followed by Basommatophora (101 individuals). Likewise, the orders recorded showed no significant differences in species abundance between sampling stations, except E1M1 and E1M2 ($p = 0.0001$).

The estimated composition and richness of the macroinvertebrate community in the stream section are shown in Table 4. The highest richness occurred in the dry season (46 taxa) compared to the rainy season (28 taxa). This pattern is due to several ecological factors, such as changes in habitat availability, alterations in water conditions, or variations in food resources. Aquatic insects obtained from the three stations were classified as Collector-collectors (n = 18), Collector-filtrators (n = 13), Collector-detritivores (n = 128), Predators (n = 124), Thrashers (n = 32), Scrapers, and Detritivores (n = 228). The difference in taxonomic composition between the epochs suggests that aquatic insect communities are subject to strong seasonal control, where species adapt to or tolerate changing water conditions. Moreover, a value of 0.35 is relatively low, implying that the communities of taxa in rain and drought are quite different, i.e., there is a low overlap between species from both epochs. This pattern may reflect a high specialization of species according to the seasonal conditions of the environment.

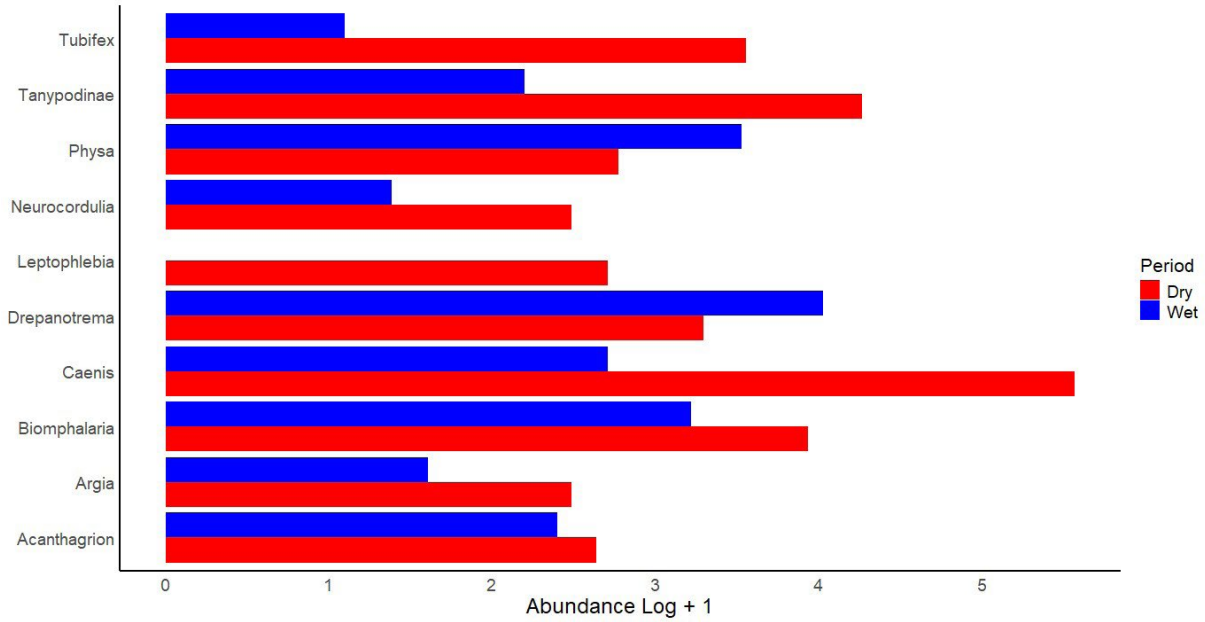

Fig.4. Abundance of taxa (Log + 1) detected in the Gallinazo stream section.

Table 4. Macroinvertebrate community structure with its functional feeding group of the Gallinazo stream section.

Family	Subfamily or genus	Functional Groups		Period	
				Wet	Dry
Dytiscidae	*Dytiscius* sp.	*Predator*	*Pr*	*0*	*1*
	Hydrovatus sp.	*Predator*	*Pr*	*1*	*1*
Scraptiidae	*Tolmetes* sp.	*Predator*	*Pr*	*1*	*0*
Elmidae	*Neocylloepus* sp.	*Collector-collectors*	*CG*	*0*	*1*
	Heterelmis sp.	*Collector-collectors*	*CG*	*1*	*1*
	Noelmis sp.	*Collector-collectors*	*CG*	*1*	*0*
Hydraenidae	*Hydraena* sp.	*Predator*	*Pr*	*0*	*1*
Chrysomelidae	*Bruchia* sp.	*Shredder-Herbivore*	*Sh-Hb*	*0*	*1*
Staphylinidae	*Scaphium* sp.	*Predator*	*Pr*	*0*	*1*
Hydrophylidae	*Derallus* sp.	*Predator*	*Pr*	*1*	*0*
	Hydrochus sp.	*Predator*	*Pr*	*1*	*0*
Staphylinidae	*Codonfomyia* sp.	*Collector-collectors*	*CG*	*0*	*1*
Ephydridae	*Ephydridae* sp.	*Collector-collectors*	*CG*	*0*	*1*
Culicidae	*Aedes* sp.	*Collector-filters*	*CF*	*0*	*1*
Chironomidae	*Tanypodinae* sp.	*Detritivore-collectors*	*CG-Hb*	*1*	*1*
	Chironomus sp.	*Detritivore-collectors*	*CG-Hb*	*0*	*1*
	Ablabesmyia sp.	*Detritivore-collectors*	*CG-Hb*	*0*	*1*
Ceratopogonidae	*Bezzia* sp.	*Predator*	*Pr*	*1*	*1*
Belostomatidae	*Belostoma sp*	*Predator*	*Pr*	*1*	*1*
Pleidae	*Neoplea* sp.	*Predator*	*Pr*	*1*	*1*
Nepidae	*Ranatra* sp.	*Predator*	*Pr*	*1*	*0*
Veliidae	*Rhagovelia* sp.	*Predator* (Perforator-carnivore)	*Pr*	*1*	*0*
Pyralidae	*Pyralidae* sp.	*Shredder-Herbivore*	*Sh-Hb*	*1*	*0*
Leptoceridae	*Nectophyche* sp.	*Shredders*	*Sh*	*0*	*1*
	Oecetis sp.	*Shredders*	*Sh*	*0*	*1*
Leptophlebiidae	*Leptophlebia* sp.	*Collector-collectors*	*CG*	*0*	*1*
Leptohyphidae	*Leptohyphes* sp.	*Collector-collectors*	*CG*	*0*	*1*
	Vacupernius sp.	*Collector-collectors*	*CG*	*0*	*1*
Caenidae	*Caenis* sp.	*Collector-collectors*	*CG*	*1*	*1*
Ephemerelloidae	*Ephemerella* sp.	*Collector-collectors*	*CG*	*0*	*1*
Gomphidae	*Phanogomphus* sp.	*Predator*	*Pr*	*0*	*1*
	Gomphidae sp.	*Predator*	*Pr*	*1*	*0*
Coenagrionidae	*Acanthagrion* sp.	*Predator*	*Pr*	*1*	*1*
	Argia sp.	*Predator*	*Pr*	*1*	*1*
Libellulidae	*Planiplax* sp.	*Predator*	*Pr*	*0*	*1*
	Celithemis sp.	*Predator*	*Pr*	*1*	*0*
	Brachymesia sp.	*Predator*	*Pr*	*0*	*1*
	Brechmorhoga sp.	*Predator*	*Pr*	*1*	*1*
Cordullidae	*Neurocordulia* sp.	*Predator*	*Pr*	*1*	*1*
Macromidae	*Macromia* sp.	*Predator*	*Pr*	*0*	*1*

Family	Subfamily or genus	Functional Groups		Period	
				Wet	Dry
Caloterygidae	*Hetaerina* sp.	*Predator*	*Pr*	*0*	*1*
Trichodactylidae	*Valdivia* sp.	*Shredders*	*Sh*	*0*	*1*
	Trichodactylus sp.	*Shredders*	*Sh*	*1*	*1*
Hydrachnidae	*Hydrachna* sp.	*Predator*	*Pr*	*0*	*1*
	Arrenuridae sp.	*Predator* (Perforator-carnivore)	*Pr*	*0*	*1*
Ancylidae	*Ferrissia* sp.	*Scrapers*	*Sc*	*0*	*1*
Physidae	*Physa* sp.	*Scrapers*	*Sc*	*1*	*1*
Planorbidae	*Biomphalaria* sp.	*Scrapers*	*Sc*	*1*	*1*
	Drepanotrema sp.	*Scrapers*	*Sc*	*1*	*1*
	Helisoma sp.	*Scrapers*	*Sc*	*1*	*1*
Ampullariidae	*Pomacea* sp.	*Scrapers*	*Sc*	*1*	*1*
Sphaeriidae	*Eupera* sp.	*Collector-filters*	*CF*	*0*	*1*
Lumbriculidae	*Lumbriculus* sp.	*Collector-detritivores*	*CG-Hb*	*0*	*1*
Tubificidae	*Tubifex* sp.	*Collector-detritivores*	*CG-Hb*	*1*	*1*
Naididae	*Stylaria* sp.	*Collector-collectors*	*CG*	*0*	*1*
	Naididae sp.	*Collector-collectors*	*CG*	*1*	*0*
Total				*28*	*46*
Jaccard Similarity Index (similarity coefficient)				*0.35*	

As shown in Table 5, ecosystem attribute indicators revealed consistent heterotrophic conditions ($P/R < 0.75$) across all stations, except E2M1 ($P/R = 0.95$). The predator/prey ratio reflected values above 0.15 (high trophic pressure), excluding E2 and E1 during M2 (indicating a normal predator/prey ratio). Similarly, low CPOM/FPOM values (< 0.25 at all stations) reflect a weak contribution of shredders, due to the loss or degradation of riparian vegetation. This coincides with visual observations that showed a reduced strip of riparian vegetation (trees, shrubs, and leaf litter), with eroded banks, sparse herbaceous cover, and no accumulated leaf litter on the shore, which reduces the available substrate. Furthermore, TFPOM/BFPOM is very low at all stations, indicating a predominance of benthic storage rather than transport of organic particles. Finally, E2M1 is the only station that showed channel stability ($0.90 > 0.50$).

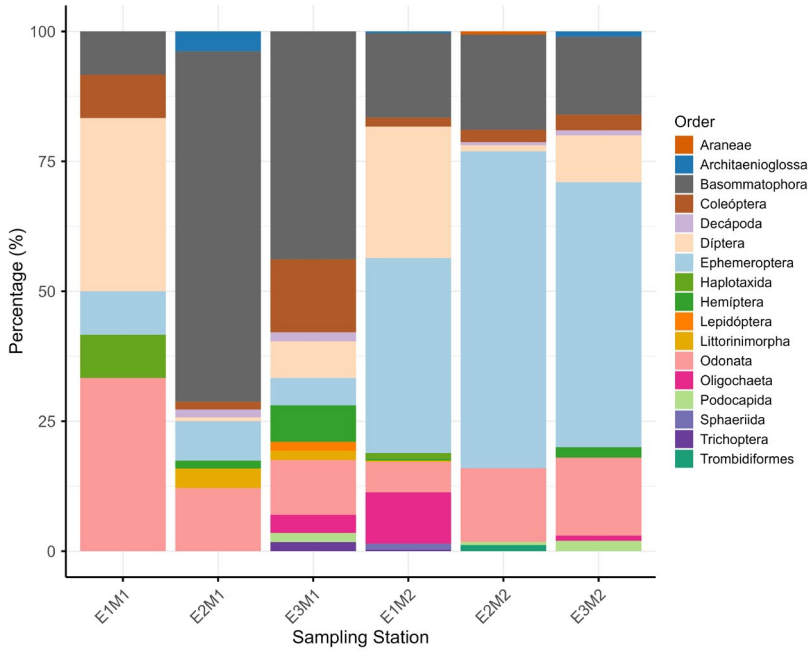

Fig.5. Percentage of aquatic macroinvertebrate orders by sampling stations in the Gallinazo stream section.

Table 5. Aquatic ecosystem attributes of the Gallinazo stream section.

Attribute	E1M1	E2M1	E3M1	E1M2	E2M2	E3M2
P/R	0.10	0.95	0.30	0.25	0.19	0.24
P/P	0.42	0.15	0.33	0.12	0.22	0.25
CPOM/FPOM	0.00	0.00	0.11	0.01	0.04	0.08
TFPOM/BFPOM	0.00	0.00	0.00	0.03	0.00	0.00
Substrate stability	0.17	0.90	0.42	0.44	0.00	0.31

4. Discussion

While some physical and chemical parameters such as turbidity, BOD_5, and COD are in acceptable ranges (Ortiz et al., 2024; Saldaña-Escorcia et al., 2024), low DO concentration may be a consequence of organic decomposition processes in combination with relatively low temperature conditions, which favour oxygen solubility but, in turn, demonstrate excessive organic input or accelerated consumption by microfauna in the water (Nuñez and Fragoso-Castilla, 2019; Kengne Fotsing et al., 2022). Likewise, high nutrient levels represent critical challenges, as these high levels can promote eutrophication processes, which in the long term could lead to algal blooms and episodes of hypoxia (Li and Dudgeon, 2008; Aguiar et al., 2017; Cortés-Guzmán et al., 2021), negatively affecting the biodiversity of the aquatic ecosystem.

Quantitative analyses of richness and abundance revealed greater diversity, more equal distribution, and less dominance in E1 and E3, while E2 showed lower relative richness. Likewise, the presence of taxonomic groups such as Basommatophora, Architaenioglossa, Coleoptera, and Diptera, which showed moderate to high diversity and an even distribution of individuals, demonstrated an ecosystem with good resilience and functionality (Zhao et al., 2017; Addo-Bediako, 2021; Cortés-Guzmán et al., 2021; Doong et al., 2021). In contrast, other taxonomic groups such as Trombidiformes, Araneae, Sphaeriida and Hemiptera showed low diversity and high dominance, reflecting stressful conditions or alterations in water quality in this section of the stream (Rizo-Patrón et al., 2013; Pallottini et al., 2017; Zaghloul et al., 2020; Cortés-Guzmán et al., 2021; Coccia et al., 2022; Fentaw et al., 2024).

The analysis of the functional groups of macroinvertebrates highlights a clear structural and functional response of the ecosystem to the change in hydrological conditions, since for the dry season characterized by a reduction in the flow velocity of the riverbed and accumulation of organic matter, there is a partial functional simplification, with a significant predominance of the Collector-detritivores (CG-Hb) and Collector-filters (CG-Ft) (Abdul and Rawi, 2019). In the rain, on the contrary, there are better oxygenation and water renewal conditions, as well as greater habitat heterogeneity; which promotes greater functional diversity, especially of sensitive groups such as scrapers, shredders and certain collectors (Motta Díaz et al., 2016).

The balance between autotrophy and heterotrophy is one of the most important attributes in the analysis of aquatic ecosystems (Cummins et al., 2005; Addo-Bediako, 2021). The P/R ratio reflected a preference for heterotrophy, excluding E2 during M1 ($P/R = 0.95$), and indicated optimal DO levels for aquatic life (6.07 mg/L) (Yaagoubi et al., 2023). Moreover, the high P/P ratio (< 0.15) found in this study showed signs of high trophic pressure in the stream section, excluding E2 and E1 during M2 with a normal predator/prey ratio. The low abundance of shredders relative to foragers observed in most research suggests a weak CPOM contribution to the system (Cummins et al., 2005; Yaagoubi et al., 2023). Because of the scarcity of leaf litter (Eyes et al., 2012; Aguiar et al., 2017), they are already non-functional riparian zones.

5. Conclusions

The present study allowed us to explore the structural and functional characteristics of aquatic macroinvertebrates and to indicate the relevance of the functional food group method for assessing the general conditions of the Gallinazo stream section at any climatic time. The data obtained and its analysis allowed us to identify signs of both physicochemical and ecological pressure, with significant spatial and temporal variability. This research, in turn, contributes key information for ecological monitoring processes, water quality assessment, and the design of conservation strategies, especially in areas where climate variability, water scarcity, lack of information, and public policies significantly affect the integrity of aquatic ecosystems.

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Conflict of Interest

The authors declare no conflicts of interest

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