



Distribution of functional feeding groups of aquatic and semi-aquatic insects on macrophytes in an artificial lentic system in southern Brazil

Distribuição dos grupos funcionais de alimentação de insetos aquáticos e semiaquáticos em macrófitas em sistema lântico artificial no Sul do Brasil

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Abstract: Aim: To understand the distribution of functional feeding groups (FFGs) of aquatic and semiaquatic insects associated with macrophytes in a lentic system, we tested whether the abundance of FFGs varied across sampling periods and analyzed the variation of environmental variables related to FFG composition. **Methods:** We evaluated the distribution of FFGs in four samplings conducted in March, May, July, and September of 2022, during different seasons of the year. The sampling locations were three sites in the Ponte Lake, located in the Porto Alegre Botanical Garden, southern Brazil. Relative abundances (%) were calculated for each family and for each FFG per sampling period. In this study, each seasonal sampling was considered a sample, and the three lake points were treated as subsamples. Data analysis was performed using Principal Component Analysis (PCA), Permutational Multivariate Analysis of Variance, and the Chi-square test (χ^2). **Results:** The two-axis PCA explained 90.47% of the variation. The variables that most contributed to the formation of the first axis were temperature, pH, and dissolved oxygen, with a positive relationship, while turbidity contributed most to the second axis, with a negative relationship. The χ^2 test confirmed differences in FFG abundances among the sampling periods. We collected 4.872 specimens, representing 24 families distributed across five orders. Collector-gatherers were the most abundant in the study ($N = 3.126$), with higher abundance in autumn ($N = 899$), followed by predators ($N = 1.385$), more abundant in summer ($N = 582$), and collector-filterers ($N = 359$), also more abundant in summer ($N = 158$). **Conclusions:** These findings contribute to a better understanding of how environmental factors drive the diversity of functional feeding groups in lentic systems and highlight the ecological role of macrophytes as complex mesohabitats that are essential for the structuring of aquatic insect communities.

Keywords: aquatic macroinvertebrates; aquatic plant; lake; feeding habit.

Resumo: Objetivo: Entender a distribuição dos grupos funcionais de alimentação (GFAs) de insetos



aquáticos e semiaquáticos associados a macrófitas em um sistema lântico, testamos se a abundância dos FFGs variou entre as coletas e analisamos a variação das variáveis ambientais relacionadas à composição dos FFGs. **Métodos:** Avaliamos a distribuição dos FFGs em quatro coletas nos meses de março, maio, julho e setembro de 2022, em diferentes estações do ano. Os locais de amostragem foram três sítios no Lago da Ponte, localizado no Jardim Botânico de Porto Alegre, Sul do Brasil. Foram calculadas as abundâncias relativas (%) para cada família e para cada FFGs por período. Nesse estudo, cada coleta por período sazonal foi considerada uma amostra e as subamostras os três pontos do lago. Para análise de dados utilizamos a Análise de Componentes Principais (PCA), Análise de Variância Multivariada Permutacional e o teste de Qui-Quadrado (χ^2). **Resultados:** A PCA em dois eixos explicou 90.47%, as variáveis que mais contribuíram para a formação do primeiro eixo foram temperatura, pH e oxigênio dissolvido, com relação positiva e do segundo eixo foi a turbidez, com relação negativa. Com χ^2 confirmamos a diferença nas abundâncias dos FFGs entre os períodos. Coletamos 4.872 espécimes, representando 24 famílias distribuídas em 5 ordens. Coletor-catador foi o mais abundante no estudo (N=3.126) e mais abundante no outono (N=899), seguido por predador (N=1.385) mais abundante no verão (N=582). E coletor-filtrador (N=359) mais abundante no verão (N=158). **Conclusões:** Essas descobertas contribuem para uma melhor compreensão de como os fatores ambientais impulsionam a diversidade de grupos funcionais de alimentação em sistemas lânticos e ressaltam o papel ecológico das macrófitas, como meso-habitats complexos e essenciais para estruturação das comunidades de insetos aquáticos.

Palavras-chave: macroinvertebrados aquáticos; planta aquática; lago; hábito alimentar.

1. Introduction

Aquatic ecosystems play a crucial role in maintaining biodiversity and providing ecosystem services (Allan et al., 2021). However, they are among the most impacted by anthropogenic activities, which convert natural areas into agricultural, mining, and urban landscapes (Allan et al., 2021). These activities introduce contaminant residues such as pesticides, fertilizers, and industrial chemicals (Christofolletti et al., 2015). Urbanization, in particular, alters community composition and reduces species richness in lentic environments, such as ponds and lakes, due to vegetation loss, increased water temperature, and habitat isolation (Piano et al., 2017; Prescott & Eason, 2018; Trovillion et al., 2023). Habitat-specialist aquatic insects are especially vulnerable, often facing local extinctions in degraded areas (Prescott & Eason, 2018). Moreover, species with low dispersal capacity face further limitations in urban and lentic systems, where reduced connectivity hinders colonization and recolonization after disturbances (Piano et al., 2017; Prescott & Eason, 2018).

These transformations in the physical and chemical environment of aquatic ecosystems result in altered environmental conditions, which are linked to water quality. Studies indicate that sites affected by anthropogenic impacts tend to have higher water temperatures, increased pH, vegetation loss, and greater sunlight incidence, while areas with greater environmental integrity tend to show higher native vegetation cover and higher concentrations of dissolved oxygen (Monteiro-Júnior et al., 2014; Brasil et al., 2020). Elevated temperatures

can stimulate microbial activity, alter oxygen dynamics, and accelerate the decomposition of macrophytes (Passerini et al., 2016). Furthermore, seasonal variations strongly influence temperature, precipitation, and resource availability, further shaping species abundance and composition over time (Schmitt et al., 2021).

Given these impacts, it is necessary to adopt tools that assess the ecological integrity of aquatic environments. In this regard, bioindicators such as aquatic and semi-aquatic insects have proven particularly effective due to their sensitivity to environmental changes and their key role in ecosystem functioning (Hamada et al., 2014). Because of this sensitivity, insects can respond rapidly to environmental changes and are essential to ecosystem balance, participating in nutrient cycling and energy transfer in food webs (Hamada & Ferreira-Keppler, 2012; Gullan & Cranston, 2017).

Aquatic and semi-aquatic insects are those that develop at least one life stage in aquatic or semi-aquatic environments and exhibit behavioral, morphological, and/or physiological adaptations to survive and persist in these habitats (Hamada & Ferreira-Keppler, 2012). Most specimens found in aquatic habitats are in their immature stages, while adults are terrestrial. For example, species belonging to the orders Odonata, Ephemeroptera, Plecoptera, and Trichoptera are aquatic during their immature stages (eggs and nymphs, as well as the larval stage in Trichoptera). In contrast, some Heteroptera species are aquatic (Nepomorpha) or semi-aquatic (Gerromorpha) throughout all life stages, Diptera may be aquatic during immature stages, and some

Coleoptera are aquatic throughout their entire life cycle (Hamada & Ferreira-Keppler, 2012).

To better understand the responses of these insects to environmental changes, they must be analyzed from a functional perspective, especially regarding their feeding strategies. Functional feeding group (FFG) analysis provides deeper insights into how environmental stressors influence community structure and ecosystem functioning (Lima et al., 2022), as it reflects the relative availability of necessary food resources (Cummins, 2021). FFGs are defined by behavioral and morphological traits related to how individuals obtain food. Collector-filterers capture fine particulate organic matter (FPOM) from the water column using silk nets, while collector-gatherers extract FPOM directly from sediments (Cummins et al., 2005; Brasil et al., 2014). Shredders feed on coarse particulate organic matter (CPOM), such as plant tissues, and scrapers consume periphyton (Cummins et al., 2005; Brasil et al., 2014). Predators feed on all other insect groups, and their distribution depends on the availability and abundance of prey in the environment (Brasil et al., 2014).

The composition and abundance of FFGs are linked to habitat characteristics. In lentic environments, for instance, aquatic macrophytes play a fundamental role by creating microhabitats that provide suitable physical, chemical, and biological conditions for a wide range of organisms (Thomaz et al., 2008). The insect community associated with macrophytes, known as phytophilous fauna, lives on or feeds on these plants (Peiró

& Alves, 2006). Macrophytes provide substrate for oviposition, refuge from predators, and food resources (Scheffer, 1998; Thomaz & Cunha, 2010). Despite the recognized ecological role of macrophytes in structuring macroinvertebrate communities (Brito et al., 2021; Da Silva-Araújo et al., 2023), little is known about the functional organization of aquatic and semi-aquatic insect fauna associated with *Salvinia auriculata* Aubl. (Paula-Bueno & Fonseca-Gessner, 2015).

In this context, the aim of this study was to evaluate the variation in functional feeding groups of aquatic and semi-aquatic insects associated with *S. auriculata* in an artificial lake in southern Brazil. We tested the hypothesis that the FFGs composition varies across sampling periods due to higher rates of organic matter decomposition and lower dissolved oxygen levels during warmer months. Specifically, we expected an increase in the abundance of collector-gatherers, shredders, and predators due to greater availability of organic matter and prey, and a decrease in collector-filterers and scrapers, due to high macrophyte biomass accumulation, higher turbidity, and reduced oxygenation of the water.

2. Material and Methods

2.1. Study area

Sampling was conducted in the Ponte Lake, located in the Porto Alegre Botanical Garden (30°03'06.07"S, 51°10'37.95"W), Rio Grande do Sul, Brazil (Figure 1). Previously characterized as a wetland area, Ponte Lake was created in 2003 for

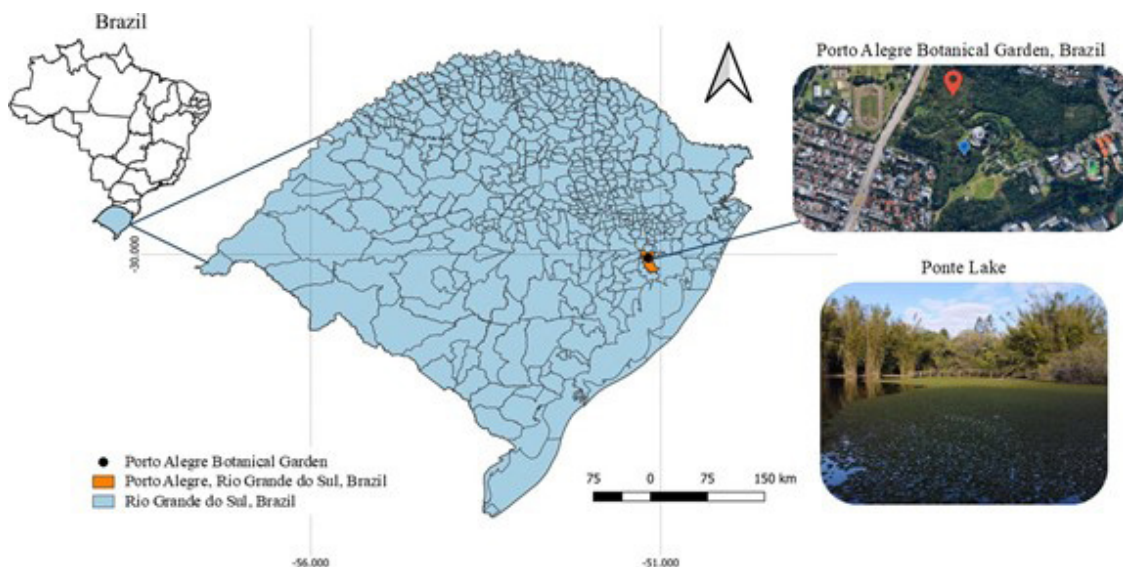


Figure 1. Sampling site located in the Porto Alegre Botanical Garden, State of Rio Grande do Sul, Brazil. Map created using QGIS version 3.36.2.

landscaping purposes and is fed by rainwater. It has a maximum depth of 1 m (Alves-da-Silva et al., 2011) and a total area of approximately 4.500 m². The lake contains a high abundance of macrophytes, with *S. auriculata* being the dominant species. Other macrophyte species occur in smaller quantities, such as duckweed (*Lemna minor* L.). The lake margins are bordered by arboreal vegetation and a pedestrian walkway. On the front margin, there is a small irrigation system, which is the only part of the lake where the water is not completely stagnant.

According to the Köppen climate classification, the region has a humid subtropical climate (Cfa), with well-distributed rainfall throughout the seasons, an average annual precipitation ranging from 1.000 to 2.000 mm, and an average annual temperature below 22°C (Alvares et al., 2013; Margulis et al., 2023). The state encompasses two biomes: the Pampa and the Atlantic Forest, with Porto Alegre belonging to the Pampa biome (IBGE, 2022). The well-defined seasonality of the region is influenced by regional atmospheric systems associated with latitude, altitude, topography, continentality, and vegetation, which together determine the climatic characteristics of the state (Sartori, 2003). Seasonal variation influences the cycle of monthly and annual average temperatures in the region, with winter temperatures ranging between 10 and 15°C (June to September), summer temperatures between 22 and 28°C, reaching up to 31°C (December to March), and intermediate values between 15 and 25°C in spring (September to December) and autumn (March to June) (INMET, 2024; Margulis et al., 2023).

2.2. Sampling and processing of macrophytes and associated insects

Four sampling events were conducted in March, May, July, and September of 2022, aiming to encompass different seasons of the year, given the well-defined seasonality in the region. Samples were collected at three marginal points of Ponte Lake (Figure 2), with an average distance of 45 meters between them. These points were selected based on marginal characteristics, such as the abundance of riparian vegetation, sunlight incidence, and the presence of an irrigation system on one margin, to represent the different habitat conditions within the lake.

Macrophytes were sampled using an entomological net with a mesh size of 0.25 mm, with two net sweeps over one meter (m) at each marginal point (Figure 2) and stored in plastic containers. The following physicochemical parameters were measured in the field using a Horiba U-50 Series Multiparameter Probe: temperature, pH, dissolved oxygen and turbidity.

In the laboratory, the samples were washed twice with running water and once with 70% ethanol using a 0.50 mm sieve (Albertoni & Palma-Silva, 2006). Insect specimens were separated and preserved in 70% ethanol and identified at the family level using specialized literature (Rafael et al., 2012; Hamada et al. 2014) in addition to the assistance of entomological experts. Macrophytes were dried in an oven at 30°C and subsequently weighed, standardizing 35 g of dry weight to ensure consistent sampling effort for the associated insects, adapted from Albertoni & Palma-Silva (2006). Plant identification was performed using the key by Miranda and Schwartzburd (2019).

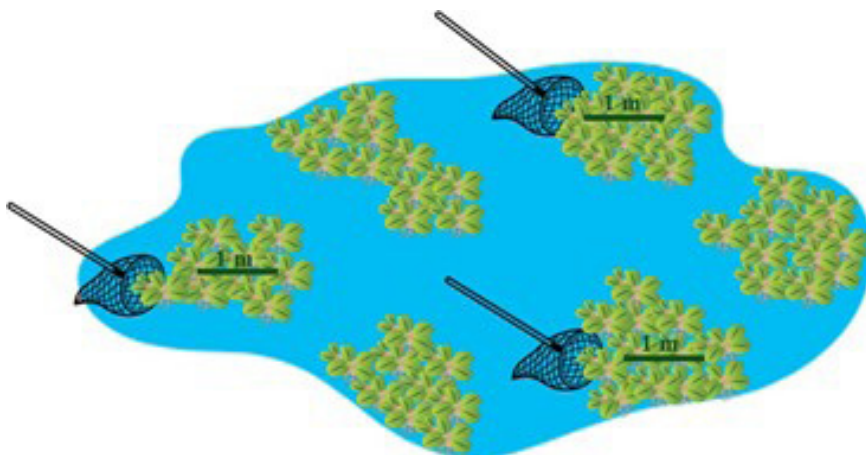


Figure 2. Visual representation of the spatial distribution of macrophyte sampling in Ponte Lake across seasonal periods. Sampling was conducted at three marginal points of the lake, with two entomological net sweeps over one meter (m) at each point.

2.3. Classification of functional feeding groups

The functional feeding groups (FFGs) were classified into collector-filterers (CF), collector-gatherers (CG), predators (P), scrapers (SC), and shredders (SH) (Table 1), using the literature (Cummins et al., 2005; Domínguez & Fernández, 2009; Oliveira & Nessimian, 2010; Hamada et al., 2014).

2.4. Data analysis

In this study, each sampling per seasonal period was considered one sample, totaling four samples. The subsamples were the three points of the lake, totaling 12 subsamples. To assess the variation of environmental variables throughout the study, ordination was performed using Principal Component Analysis (PCA) based on a correlation matrix (Legendre & Legendre, 2012). Environmental variables were standardized using z-scores to control differences in measurement scales (Legendre & Legendre, 2012). Axes were selected based on the Broken Stick model (Jackson, 1993), and variables with a loading greater than 0.7 were selected.

To evaluate the groups formed in the PCA, a Permutational Multivariate Analysis of Variance (PERMANOVA) was applied using a Euclidean

distance matrix (Anderson, 2001). Multivariate distance-based tests confuse differences in location (differences in centroids) with differences in multivariate dispersion (Anderson, 2001). Therefore, the possibility of dispersion differences was assessed through Multivariate Dispersion Analysis by Permutations (PERMDisp; Anderson, 2006). Statistical significance for both PERMANOVA and PERMDisp was evaluated by 999 permutations.

To analyze the variation in the distribution of the FFGs, a Chi-Square test (χ^2) was used for each functional group between the sampling periods, except for SC and SH, which each presented only one individual. Holm's correction was applied to control for multiple testing effects, and the assumptions that only 25% of the expected frequencies can be lower than five and that none can be lower than one was evaluated.

The analyses were performed using the statistical program R version 4.3.1 (R Development Core Team, 2023), using the Vegan package.

3. Results

The PCA on its first two axes explained 90.47% of the variation in the dataset, with 65.14% on the first axis and 25.33% on the second. Temperature,

Table 1. Functional feeding groups (FFGs) (CF = collector-filterers; CG = collector-gatherers; P = predator; SC = scraper; SH = shredder) assigned to families of aquatic and semiaquatic insects sampled in Ponte Lake, RS, Brazil, based on the cited literature.

Order	Family	FFG	References
Coleoptera	Dytiscidae	P	Cummins et al. (2005), Oliveira & Nessimian (2010)
	Gyrinidae	P	Cummins et al. (2005), Oliveira & Nessimian (2010)
	Hydrophilidae	P	Cummins et al. (2005), Oliveira & Nessimian (2010)
	Noteridae	P	Cummins et al. (2005)
	Ptylodactylidae	SH	Oliveira & Nessimian (2010)
Diptera	Scirtidae	CG	Oliveira & Nessimian (2010)
	Ceratopogonidae	P	Cummins et al. (2005)
	Chironomidae	CG	Cummins et al. (2005)
	Culicidae	CF	Cummins et al. (2005), Oliveira & Nessimian (2010)
	Psychodidae	CG	Cummins et al. (2005)
Ephemeroptera	Stratiomyidae	CG	Cummins et al. (2005), Oliveira & Nessimian (2010)
	Tabanidae	P	Cummins et al. (2005), Oliveira & Nessimian (2010)
	Tipulidae	P	Cummins et al. (2005)
	Baetidae	CG	Cummins et al. (2005)
	Belostomatidae	P	Cummins et al. (2005), Oliveira & Nessimian (2010)
Hemiptera	Corixidae	SC	Cummins et al. (2005)
	Gerridae	P	Domínguez & Fernández (2009)
	Hebridae	P	Domínguez & Fernández (2009)
	Notonectidae	P	Oliveira & Nessimian (2010)
	Naucoridae	P	Cummins et al. (2005), Oliveira & Nessimian (2010)
Odonata	Pleidae	P	Cummins et al. (2005)
	Veliidae	P	Domínguez & Fernández (2009)
	Coenagrionidae	P	Cummins et al. (2005)
	Libellulidae	P	Cummins et al. (2005)

pH, and dissolved oxygen showed a strong positive correlation with the first axis (Axis I = 0.779; 0.939; 0.926, respectively). while turbidity was negatively correlated with the second axis (Axis II = -0.827) (Table 2). A separation among subsamples was observed, with part of the samples inversely associated with the environmental variables, and the remainder showing direct associations. This pattern was statistically supported by the PERMANOVA ($F=2.859$; $p=0.023$) (Figure 3). The PERMDisp indicated that the detected differences are due to differences in location (centroid) and not in multivariate dispersion (Pseudo- $F = 0.433$, $P = 0.735$).

Significant differences were detected in the distribution of Functional Feeding Groups (FFGs) across sampling periods using the Chi-square test (CF: $\chi^2=106.73$, $df=3$, $p<0.001$; CG: $\chi^2=44.33$, $df=3$, $p<0.001$; P: $\chi^2=358.71$, $df=3$, $p<0.001$) (Table 3).

A total of 4,872 specimens were collected, representing 24 families across five orders. Chironomidae ($n= 2.753$; 56.51%) and Ceratopogonidae ($n=1.108$; 22.74%) were the most abundant families. The highest specimen count occurred in summer ($n = 1.571$ individuals, 19 families), followed by autumn ($n = 1.449$ individuals, 16 families), winter ($n = 947$ individuals, 12 families), and spring ($n = 905$ individuals, 14 families).

Predators showed the highest richness, with 16 families, followed by collector-gatherers, with five families. Each of the remaining FFGs was represented by a single family. Among collector-gatherers, Chironomidae was the most dominant in all sampling periods. And among predators, Ceratopogonidae was the most frequent family (Table 4).

Collector-gatherers represented the most abundant FFG, with 3,126 individuals (64.16%),

with its highest abundance occurring in the autumn. Predators followed with 1,385 individuals (28.43%), and collector-filterers totaled 359

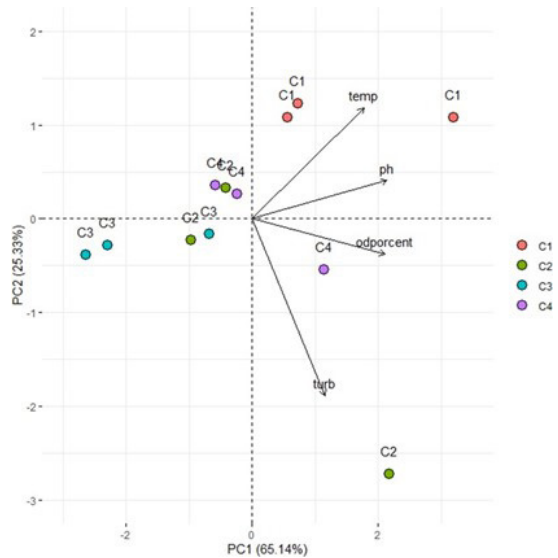


Figure 3. Ordination of environmental variables across the samples from Lago da Ponte, Porto Alegre, Rio Grande do Sul, Brazil, summarized by Principal Component Analysis (PCA). Sampling points: C1 = summer, C2 = autumn, C3 = winter, C4 = spring; Environmental variables: temp = temperature, ph = pH, odpercent = dissolved oxygen, turb = turbidity.

Table 3. Observed frequency of Functional Feeding Groups (FFGs) by sampling period and Chi-square analysis of the variation in FFG distribution across seasonal periods.

Seasonal Period	CF	CG	P
Summer	44.01	26.55	42.02
Autumn	29.80	28.76	31.91
Winter	19.22	20.79	16.46
Spring	6.96	23.90	9.60
χ^2	106.73	44.326	358.71
df	3	3	3
p	<0.001	<0.001	<0.001

CF = collector-filterers; CG = collector-gatherers; P = predators.

Table 2. Correlation of environmental variables with Principal Component Analysis (PCA) axes, along with eigenvalues, broken stick model thresholds, and the percentage of variance explained.

	Axis I	Axis II
Temperature	0.779	0.519
pH	0.939	0.179
Turbidity	0.508	-0.827
Dissolved Oxygen	0.926	-0.164
Eigen Value	2.605	1.013
Broken Stick	2.083	1.083
% of explanation	65.14	25.33

Table 4. Relative abundance of functional feeding groups (FFG) in the study.

FF G	Abundance	Relative Abundance (%)
CF	359	7.369
CG	3126	64.163
P	1385	28.428
SC	1	0.021
SH	1	0.021

CF = collector-filterers; CG = collector-gatherers; P = predators.

individuals (7.37%) with the highest abundance occurring in the summer. Scrapers and shredders were represented by only one individual each (Figure 4).

Relative abundances by sampling period are summarized in Tables 4 and 5. The summer sample showed the highest relative abundance of collector-filterers and predators, while the spring sample had the highest relative abundance of collector-gatherers.

4. Discussion

This study recorded seasonal variations in the composition of functional feeding groups (FFGs) of aquatic and semi-aquatic insects associated with *Salvinia auriculata* in a lentic environment in southern Brazil. The variables that contributed most to this variation were temperature, pH, and dissolved oxygen (DO), which were higher during summer, and turbidity, which increased in autumn.

Our expectation that higher temperatures would inversely correlate with DO availability (Brasil et al., 2020) was not confirmed, as we observed higher

DO levels during the warmer periods of summer and spring. This atypical pattern may be attributed to increased photosynthetic activity by macrophytes such as *S. auriculata*, which promotes greater oxygen production under high light and temperature conditions (Chotikarn et al., 2022). However, excessive vegetative growth leads to high biomass accumulation, altering DO concentrations, and this disturbance can result in the reduction or local exclusion of sensitive insects such as Ephemeroptera, while favoring more tolerant groups such as Chironomidae (Saulino & Trivinho-Strixino, 2017).

Furthermore, the physicochemical conditions during summer, with higher temperatures, near-neutral pH, and elevated DO, as indicated by the PCA, supported greater abundance and richness of aquatic and semi-aquatic insect families, as also reported in other lentic systems (Silva & Henry, 2013). It is worth noting that in shallow subtropical lakes, macrophytes act as environmental filters, reducing nutrient concentration and water turbidity, thereby improving water quality (Albertoni et al., 2014). However, our PCA indicated the increase in turbidity observed in autumn may negatively affect collector-filterers, as high levels of suspended sediments can clog their filtering mechanisms and compromise food quality (Ntloko et al., 2021).

The seasonal distribution of FFGs observed supports our hypothesis of temporal variation. Collector-filterers and predators were more abundant in summer, while collector-gatherers dominated in autumn. Our PCA indicated that higher water temperatures were observed in the summer. Higher temperatures can accelerate plant biomass decomposition and increase organic matter production (Bottino et al., 2013), benefiting groups such as collector-gatherers and collector-filterers. Although typically associated with lotic environments (Brasil et al., 2014; Oliveira & Nessimian, 2010), collector-filterers were well represented in this lentic system. Their presence suggests that macrophyte stands in lakes can retain sufficient suspended fine particles to meet their dietary needs.

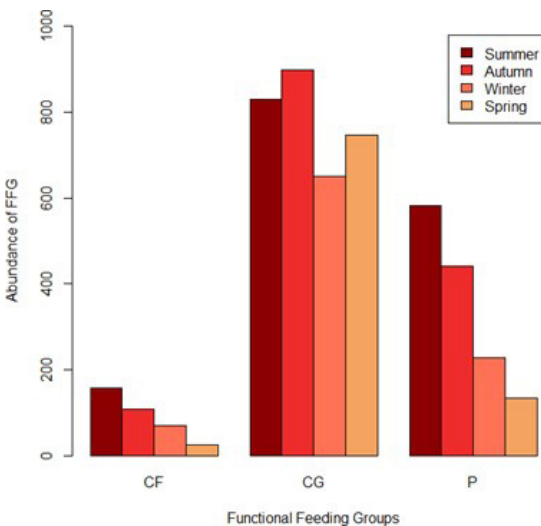


Figure 4. Absolute abundance of feeding functional groups by seasonal period. CF = collector-filterers; CG = collector-gatherers; P = predators.

Table 5. Relative abundance of functional feeding groups (FFG) by seasonal period.

Seasonal Period	Relative abundance of FFG by sampling					total
	CF	CG	P	SC	SH	
Summer	10.06	52.83	37.05	0.00	0.06	100
Autumn	7.38	62.04	30.50	0.07	0.00	100
Winter	7.29	68.64	24.08	0.00	0.00	100
Spring	2.76	82.54	14.70	0.00	0.00	100

CF = collector-filterers; CG = collector-gatherers; P = predators; SC = scrapers; SH = shredders.

Predators, which accounted for 28.43% of all specimens, were associated with the complex structure of macrophytes, especially their roots, which provide foraging areas and shelter for various invertebrates, allowing potential prey to hide and serve as food (Brito et al., 2021). Thus, predator abundance and richness are strongly related to prey density (Šálek et al. 2010; Veselý et al., 2017), as demonstrated by our results, in which summer had the highest abundance and richness of insect families.

Collector-gatherers, the most representative group (64.16%), were more abundant in autumn. We attribute this predominance to the availability of food resources due to high levels of organic particle decomposition occurring during autumn (Baker et al., 2023), as well as the ecological plasticity and generalist feeding strategy of this group (Brasil et al., 2014; Malacarne et al., 2024), which consumes various food resources used by both shredders and collector-filterers. Their predominance also indicates tolerance to environmental disturbances and anthropogenic pressures (Brasil et al., 2014; Malacarne et al., 2024).

Scrapers and shredders were poorly represented. The low number of scrapers may be associated with the low availability of periphyton - their main food source which is typically deposited on aquatic substrates, as evidenced in wetlands under anthropogenic influence (Conceição et al., 2020). Shredders were also underrepresented, possibly due to limited input of allochthonous material and litter retention, a result of restricted riparian vegetation around the lake (Oliveira & Nessimian, 2010). At the sampling site, riparian vegetation is preserved only in a small portion of the lake, as it is located in a human-altered area.

Some limitations must be acknowledged in interpreting the results. Taxonomic resolution at the family level may mask the specific ecological responses and sensitivities of genera or species to environmental variation (Tsyrlin et al., 2023; Luiza-Andrade et al., 2017). Furthermore, the sampling effort - only three subsamples per season over a single year - limits the statistical robustness for detecting interannual variability and long-term climate change effects.

We emphasize that other factors may have influenced FFG variation in this study. For example, the recurring physical management of macrophytes, conducted in an unstandardized manner to control excessive growth due to the area's recreational use, may negatively affect insect community composition by altering food, shelter,

and oviposition substrate availability (Misteli et al., 2023; Brito et al., 2021). The lack of standardization in the frequency and intensity of this management may introduce instability in the aquatic and semi-aquatic insect community structure over time (Misteli et al., 2023).

Additionally, temperature fluctuations—particularly the atypically warm winters and springs observed, which deviated from historical patterns in southern Brazil (Margulis et al., 2023)—may have influenced the results and should be considered in future studies. Long-term monitoring with annual replication and finer taxonomic resolution is necessary to more robustly and reliably elucidate temporal patterns and the effects of climate change on aquatic communities.

The results contribute to the understanding of how environmental variables influence the distribution of FFGs in lentic ecosystems. They indicate that the composition of aquatic and semi-aquatic insect functional groups associated with *S. auriculata* varies throughout the year, possibly due to changes in environmental variables. We highlight that collector-filterers and predators were more abundant in summer, while collector-gatherers dominated in autumn. The variables that most contributed to this seasonal variation were temperature, pH, and dissolved oxygen (DO) during summer, and turbidity during autumn. We observed an unusual pattern of higher DO in samples taken during warmer periods.

Furthermore, future studies should focus on lakes with varying environmental gradients and anthropogenic impacts over multiple years to assess diverse patterns and potential effects of climate change in lentic environments. These findings enhance our understanding of how environmental factors influence the diversity of functional feeding groups in lentic systems and highlight the ecological role of macrophytes as complex mesohabitats essential for structuring aquatic insect communities.

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Data Availability

The datasets were made available in the article, and the data underlying this article will be shared on request to the corresponding author.

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