Acta Biológica Catarinense
2023 Abr-Jun;10(2):12-21

Aquatic insects in plateau streams in Southern Brazil: a functional feeding group analysis

Insetos aquáticos em córregos de planalto no Sul do Brasil: uma análise de grupos tróficos funcionais

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ABSTRACT
Aquatic insects are bioindicators regarding the quality of streams environments. The present study aimed to analyze the community of aquatic insects in streams from the Santa Catarina Plateau, in Brazil. Insects were classified according to their functional trophic structure as gathering-collectors, filtering-collectors, shredders, swallower-predators, perforator-predators and scrapers. Autotrophy and heterotrophy indices were calculated to evaluate the ecological conditions of the sampled streams. Associations between shredders and the riparian vegetation index, filtering-collector index, riverbed stability index, and predator-prey index were performed. The sampled streams demonstrated that the insects inhabiting these environments respond to the strong seasonality observed in the study region, an area located at high altitudes (over 1,200 m a.s.l.) that suffers harsh winters with snow events. This is also reflected in the seasonal heterotrophy and autotrophy index variations noted herein, with higher autotrophy observed during spring and summer. The relationship detected between shredder insects and riparian vegetation indicates that the sampled region may be suffering from deforestation, due to the low contribution of plant matter to the stream waters. However, as many nearby areas are characterized by natural grasslands, it is possible that it is actually an inherent characteristic of the sample area.
Keywords: bioindicators; EPT; Southern Brazil; streams.

RESUMO
Insetos aquáticos são bioindicadores de qualidade ambiental de córregos. O presente estudo objetivou analisar a comunidade de insetos aquáticos em córregos do planalto de Santa Catarina, Brasil. Os insetos foram classificados de acordo com a sua estrutura trófica funcional como coletor-catador, coletor-filtrador, fragmentador, predador-engolidor, predador-perfurador e raspador. Os índices de autotrofia e heterotrofia foram calculados para avaliar as condições ecológicas dos córregos amostrados. Foram realizadas associações entre fragmentadores e índice de vegetação ripária, índice coletor-filtrador, índice de estabilidade dos substratos do leito dos córregos e índice de controle ascendente de predadores. Os córregos amostrados demonstraram que os insetos que habitam esses ambientes respondem à forte sazonalidade observada na região de estudo, uma área localizada em altitudes elevadas (1.200 m de altitude) que sofre invernos rigorosos. Isso também se reflete nas variações sazonais dos índices de autotrofia e heterotrofia aqui registradas, com maior autotrofia observada durante a primavera e o verão. A relação detectada entre os insetos fragmentadores e a vegetação ripária indica que a região amostrada pode estar sofrendo com desmatamento, em virtude da baixa contribuição de matéria vegetal para com as águas dos córregos. No entanto, como muitas áreas próximas são caracterizadas por campos naturais, é possível que seja, na realidade, uma característica inerente da área amostrada.
Palavras-chave: bioindicadores; córregos; EPT; Sul do Brasil.

Recebido em: 19 fev. 2023
Aceito em: 8 maio 2023

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INTRODUCTION

Aquatic invertebrates have been employed since the 20th century to assess the quality of streams in Europe (MERRITT *et al*., 2014). Currently, aquatic insects comprise approximately 88,500 described species, belonging to about 13 orders (STARR & WALLACE, 2021). These animals participate in several ecological cycles, such as nutrient cycling, while in reducing the size of organic particles, thus facilitating the action of bacteria and fungi (CALLISTO & ESTEVES, 1998). Furthermore, these aquatic organisms also act in the energy flow, as they serve as food for other insects, birds and fish (GONÇALVES-JÚNIOR *et al*., 2014). Their distribution in stream environments is conditioned to certain factors, such as physical and chemical habitat characteristics, as well as food resource availability and life habits (SALLES & FERREIRA-JÚNIOR, 2014).

Aquatic insects have been widely applied in the evaluation and monitoring of aquatic environments as they are widely distributed and comprise a high number of species that exhibit different responses to the varying conditions and complexities of aquatic environments and riparian vegetation, allowing for assessments concerning different environmental effects and changes affecting aquatic areas (METCALFE, 1989; ROSENBERG & RESH, 1993; SIEGLOCH *et al*., 2017).

Depending on their feeding mode, aquatic insects can be grouped into functional trophic groups, such as gathering-collectors, which feed on small organic matter particles, filtering-collectors, which filter small organic matter particles, shredders, which chew on leaves or living vascular plant tissue and may also dig wood, predators, which swallow prey whole (swallower-predators) or ingest body tissue fluids (perforator-predator), and scrapers, which are adapted to scrape hard surfaces, feeding on algae, bacteria, fungi, and organic matter (CUMMINS *et al*., 2005). This categorization is based on how each organism acquires food according to its morphology, so each functional trophic group represents a different environmental role (MERRITT *et al*., 2014).

The structure of these functional trophic groups in aquatic insects is determined by several environmental factors, such as food availability, watercourse width, water flow and oxygenation, and land use conditions in surrounding areas (FAVRETTO *et al*., 2018; MIN *et al*., 2019). Consequently, the use of these organisms and their analysis regarding functional trophic groups comprise an excellent tool for the characterization and environmental analysis of watercourses.

In this sense, the plateau region of the state of Santa Catarina, in southern Brazil, lacks studies on aquatic invertebrates, with only sporadic records concerning some species (FAVRETTO & SANTOS, 2017). This region comprises Mixed Ombrophylous Forests (*Araucaria* Forests) and natural fields, located at an altitude of over 1,200 m a.s.l., historically exploited for cattle breeding, forestry activities, and apple and tobacco planting, yet still harboring some of the largest natural environments remnants in the state (ALARCON & SILVA, 2007; LINDENMEYER, 2009; VIBRANS *et al*., 2013).

Considering the lack of knowledge concerning aquatic entomofauna in an area widely exploited for anthropic purposes and such peculiar natural environments, the present study aimed to carry out a trophic-functional characterization of aquatic insects present in streams located in a plateau area of the state of Santa Catarina, in southern Brazil.

MATERIAL AND METHODS

Three Pelotas River streams tributaries, located between the municipalities of São Joaquim and Bom Jardim da Serra, set on the Santa Catarina state plateau, in southern Brazil (c. 28°21'52.71"S, 49°48'21.31"W), were selected. These streams are located within forested areas exhibiting the predominance of Mixed Ombrophylous Forests (*Araucaria* Forests) and natural fields, mostly streams are less than 2 m wide, with rocky bottoms. The streams are located in areas between 1,100 m to 1,200 m a.s.l. with temperate climate, type Cfb (WREGE *et al*., 2012). The sampling region exhibits strong seasonality, with summers averaging 20°C and winters presenting temperatures below 0°C with frequent snow events (WREGE *et al*., 2012; VIBRANS *et al*., 2013).

Samplings were carried out between the winter of 2015 and the autumn of 2016, comprising one collection per season in each stream, by means of a collecting net, over a 5 m extension in each stream (OLIVEIRA & PES, 2014). The characterization and environmental assessment of each stream using aquatic insects were carried out according to Merritt *et al*. (2014).

Insects were classified according to their functional feeding group as gathering-collectors, filtering-collectors, shredders, swallower-predators, perforator-predators and scrapers. Autotrophy and heterotrophy indices were calculated to evaluate the ecological conditions of the sampled streams (MERRITT *et al*., 2014). Associations between shredders and the riparian vegetation index, filtering-collector index, riverbed stability index, and predator-prey index were performed according to Merritt *et al*. (2014). The index refers to the association of shredders with riparian vegetation, as they are more sensitive to alterations in this type of vegetation.

Specimens were identified using a stereoscopic microscope and dichotomous keys by Souza *et al*. (2007), Lecci & Froehlich (2007), Calor (2007), Mariano & Froehlich (2007), Pinho (2008), Segura *et al*. (2011), and Hamada *et al*. (2014). A cluster analysis was performed using the UPGMA algorithm and Bray-Curtis distance, to verify taxonomic similarities between aquatic insects among the sampling different seasons. An adapted use of the Indicator Species Analysis (IndVal) was also performed, to verify potential relationships between functional feeding groups and seasonality (DUFRENE & LEGENDRE, 1997), using the Past software, version 4.06b (HAMMER *et al*., 2001).

RESULTS

A total of 404 specimens were collected and seven orders and 18 families of aquatic insects were identified (table 1) The highest abundance was recorded in autumn (March to May) (n = 184), followed by summer (December to February) (n = 123), winter (June to August) (n = 58), and spring (September to November) (n = 39).

Table 1 – Aquatic insect taxa collected in streams of the sampling area in the plateau region of Santa Catarina, Southern Brazil. A1 – area 1, A2 – area 2, A3 – area 3, Win – Winter, Spr – Spring, Sum – Summer, Aut – Autumn, red cells – highest values, blue cell – lowest values.

Order	Family	A1	A2	A3	Win	Spr	Sum	Aut	Total
Coleoptera	Elmidae	1	5	1	2	1	1	3	7
	Psephenidae	66	22	5	2	9	51	31	93
	Dryopidae		1	1				2	2
Diptera	Simuliidae	4	3	2	1		6	2	9
	Ceratopogonidae			1		1			1
	Tipulidae	10	4	3	2	3	5	7	17
Ephemeroptera	Baetidae	47	6		4	1	12	36	53
	Leptophlebiidae	5	8	1	6	2	5	1	14
Hemiptera	Mesoveliidae		2	2				4	4
	Naucoridae	1	3		3		1		4
Odonata	Aeshnidae		1	5	2	1	2	1	6
	Calopterygidae	2	1		1			2	3
	Coenagrionidae	4	16	9	5	6	5	13	29
Plecoptera	Gripopterygidae		1		1				1
	Perlidae	10	51	10	9	14	14	34	71
Trichoptera	Hydropsychidae	51	29	4	19		19	46	84
	Polycentropodidae	2	1				2	1	3
	Philopotamidae		1	2	1	1		1	3
Total collected		203	155	46	58	39	123	184	

The applied cluster analysis demonstrated greater similarity in taxonomic composition between summer and autumn and between spring and winter (cofenetic correlation coefficient = 0.66; figure 1).

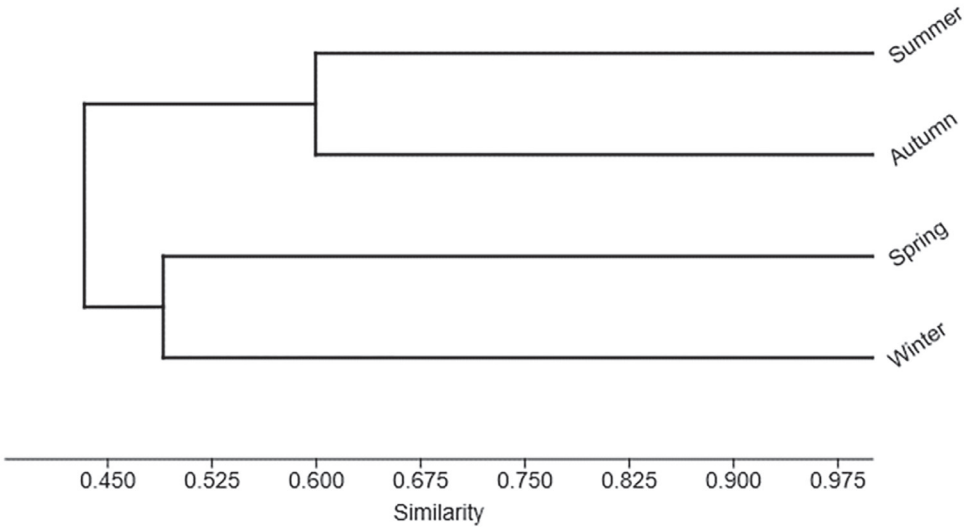

Figure 1 – Cluster analysis of similarity of taxonomic composition of aquatic insects in streams in the sampling area located in the plateau region of Santa Catarina, southern Brazil, employing the UPGMA algorithm and Bray-Curtis distance (ccc = 0.66). Source: primary.

Ephemeroptera, Plecoptera, and Trichoptera exhibited higher abundances in autumn (n = 37, 34, and 48, respectively), while Coleoptera and Diptera exhibited the highest abundance in summer (n = 52 and 11, respectively; figure 2).

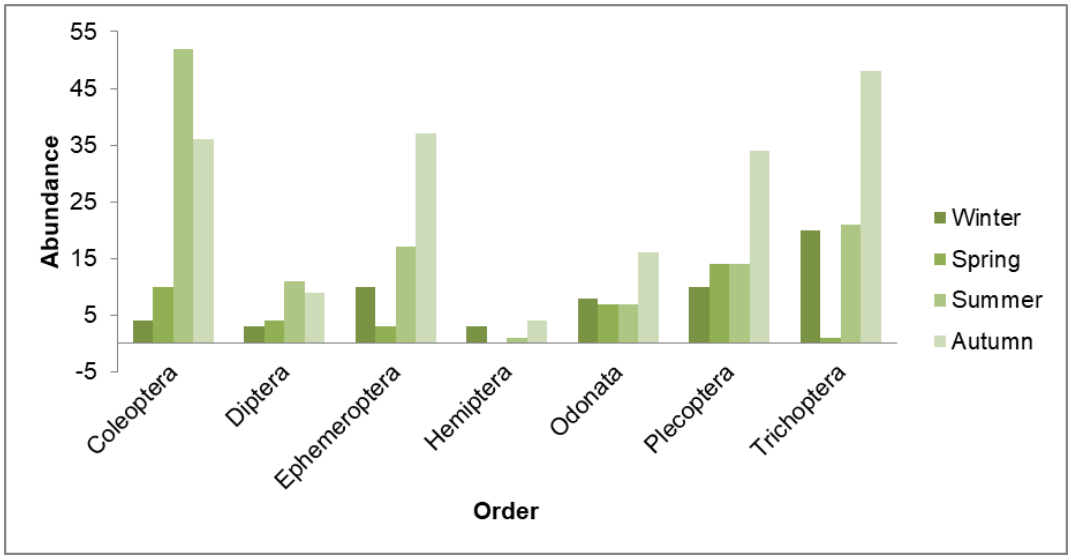

Figure 2 – Seasonal variations in abundance per aquatic insect orders in streams in the sampling area located in the plateau region of Santa Catarina, southern Brazil. Source: primary.

Regarding the calculated indices related to functional feeding groups (table 2), the investigated streams were heterotrophic during the winter and autumn (value lower than 0.75), *i.e.*, the carbon source of the aquatic insects was not based mainly on photosynthesizing organisms, but on organic matter from riparian vegetation (MERRITT *et al.*, 2014). On the other hand, streams were strongly autotrophic during spring and summer (value greater than 0.75), indicating high photosynthesizing activity in water-inhabiting organisms (MERRITT *et al.*, 2014).

Associations between shredders and the riparian vegetation index indicate a normality of this characteristic during spring (higher than 0.25), which was altered in the other sampling seasons (lower than 0.25) (MERRITT *et al*., 2014). The filtering-collector index indicated sufficient suspended organic matter loadings to support large filtering-collector populations during all seasons except spring (values greater than 0.75) (MERRITT *et al*., 2014).

Regarding the riverbed stability index, the stream substrates remained stable during all seasons (values over 0.50) (MERRITT *et al*., 2014). The predator-prey index, an adequate balance between prey and predator, was not observed for any of the sampling seasons, as the calculated value was always over 0.20, indicating the predominance of predators (MERRITT *et al*., 2014).

Table 2 – Index values related to the functional trophic structure of aquatic insects in streams of the sample area in the plateau region of Santa Catarina, southern Brazil. Win – Winter, Spr – Spring, Sum – Summer, Aut – Autumn.

Index	Win	Spr	Sum	Aut
Autotrophy and heterotrophy index	0,29	2,75	1,40	0,36
Association between shredders and riparian vegetation index	0,04	0,33	0,00	0,00
Filtering-collector index	3,50	0,50	2,08	1,28
Riverbed stability index	4,14	4,00	6,38	2,10
Predator-pray index	0,61	1,67	0,28	0,50

The application of the indicator species analysis (IndVal) at the species level revealed a strong association of scrapers to spring (IndVal = 57.06%, p = 0.04) and summer (IndVal = 62.73%, p = 0.04) (figure 3). The other functional groups did not have a statistically significant association with any season.

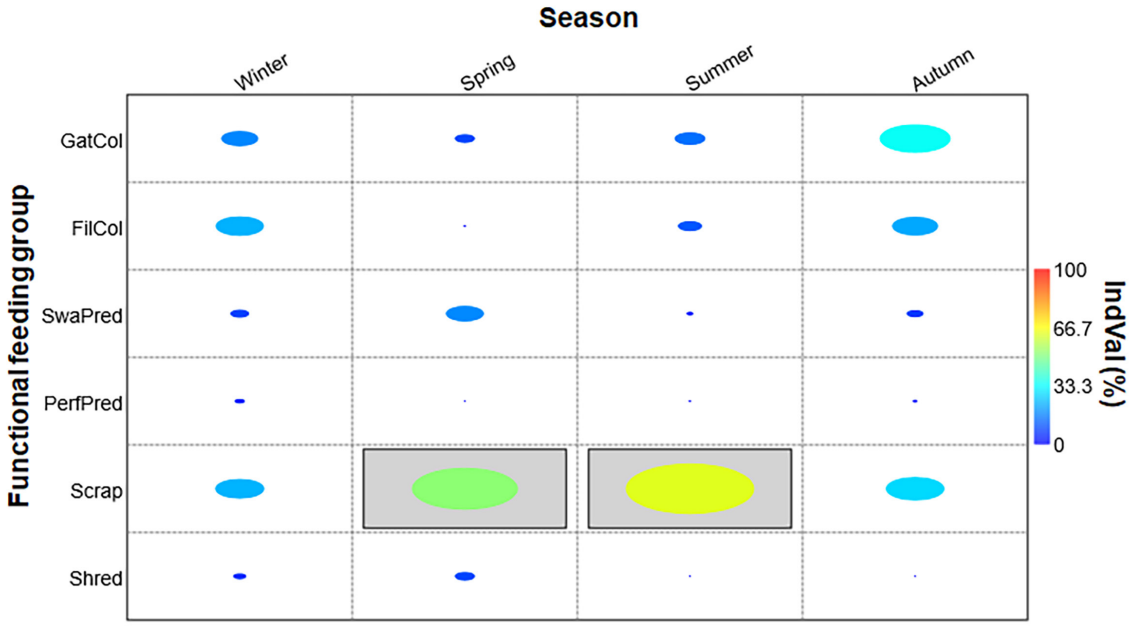

Figure 3 – Graphical representation of the results of the indicator species analysis (IndVal) at the functional feeding group level in the sampling area located in the plateau region of Santa Catarina, southern Brazil. The gray box indicates p < 0.05. GatCol: gathering-collectors; FilCol: filtering-collectors; SwaPred: swallower-predators; PerfPred: perforator-predators; Scrap: scrapers; Shred: shredders. Source: primary.

DISCUSSION

The highest abundance of aquatic invertebrates was observed in autumn,such seasonal change probably reflect variations in hydrological conditions suitable for aquatic insects (DELONZEK & KRAWCZYK, 2016; GIAM *et al*., 2017), such as different rainfall rates, which influence the amount of water present in streams, which directly affect aquatic insect abundance (BISPO *et al*., 2006; BISPO & OLIVEIRA, 2007). In the sampling region, the period with the lowest rainfall occurs in autumn, which may explain this higher abundance, considering that flood events can generate a reduction in the richness and abundance of aquatic macroinvertebrates (WREGE *et al*., 2012; THEODOROPOULOS *et al*., 2017).

Most of the sampled insects were swallower-predators, followed by scrapers and filtering-collectors. This contrasts with other forests streams in Santa Catarina, that indicate a higher abundance of filtering-collectors (FAVRETTO *et al*., 2018), or streams in higher urbanized areas with higher abundance of gathering-collector and predators (RIGOTTI *et al*., 2019). The near absence of shredders is potentially due to the presence of unpalatable plant remains, as these organisms only feed when food resources have already undergone structural and/or biochemical changes, which takes some time (CUMMINS *et al*., 1989; MORETTI, 2005; SILVA *et al*., 2009).

Streams were strongly autotrophic in the spring and summer (value greater than 0.75), indicating high photosynthesizing activity from water-inhabiting organisms (CUMMINS *et al*., 2005; MERRITT *et al*., 2014; CUMMINS, 2019). This may be due to the strong seasonality present in the sample area, with negative temperatures, reduced luminosity, frost and snow observed during the colder seasons of the year. This leads to variations in different abiotic variables which, in turn, affect in aquatic environments, altering their trophic state (KRUPEK *et al*., 2012; ADAME *et al*., 2018; JUNGER *et al*., 2019).

Associations between shredders and the riparian vegetation index indicate a normality of this characteristic during spring (higher than 0.25), which was altered in the other sampling seasons (lower than 0.25), with the absence of shredders during the summer and fall, probably due to the absence of vegetal litter input in these periods (MERRITT *et al*., 2014). Therefore, the sampled areas may not offer a vegetation cover that provides suitable plant matter inputs for this trophic group all over the year (ORUTA *et al*., 2017; CUMMINS, 2019). Another possibility is that the specific characteristics of the plateau area, such as higher current rivers and, in some areas, natural grasslands, do not favor this trophic group. However, caution is required in the interpretation of this index for a plateau region, as it has never been applied to this area and other studies in southern Brazil were conducted under different phytophysiognomic and climatic conditions (CUMMINS *et al*., 2005; SILVEIRA-MANZOTTI *et al*., 2016; FERREIRA *et al*., 2017; PEREIRA *et al*., 2017a; FAVRETTO *et al*., 2018).

The filtering-collector index indicated sufficient suspended organic matter loadings to support large filtering-collector populations during all seasons except spring (values greater than 0.75), the absence in this season is probably related to seasonal changes in land use around these streams, increasing or reducing the input of suspended organic matter in different periods of the year (MERRITT *et al*., 2014; CUMMINS, 2019). Populations belonging to this feeding group are also more abundant in streams with rocky bottoms, as those sampled in the present study (PEREIRA *et al*., 2017b).

Regarding the Riverbed stability index, the stream substrates remained stable during all seasons (values over 0.50) (MERRITT *et al*., 2014; CUMMINS, 2019). Indeed, the structures of the three sampled streams comprise rocks and large tree remains. Thus, the sampled environments provide adequate conditions for the development of filtering-collectors and scrapers. The highest Riverbed stability index was observed in the summer.

Regarding the Predator-prey index, an adequate balance between prey and predator was not observed for any of the sampling seasons (MERRITT *et al*., 2014; CUMMINS, 2019), as the calculated value was always over 0.20, indicating the predominance of predators. This may also be an indication that predator populations are polyvoltine, comprising over one generation per year (CUMMINS, 2019), which has been reported for other regions of similar phytophysiognomies at lower altitudes (FAVRETTO *et al*., 2018).

Concerning the sampled aquatic insects, shredders generally exhibit a negative relationship to deforestation, while predators are more generalist with regard to their environment (BARBOLA *et al*., 2011; ORUTA *et al*., 2017; CUMMINS, 2019). Few shredders were collected herein, while the abundance of predators was high, which could indicate that the investigated environments may be undergoing a riparian forest de-characterization process. However, it is important to note that the plateau region of Santa Catarina consists of natural grasslands interspersed with forest fragments, which may have influenced these findings (VIBRANS *et al*., 2012).

The strong recorded association of scraping insects to spring and summer is also environmentally positive, as these insects feed on algae that develop on rocks and are associated with a stable stream substrate (MERRITT *et al*., 2014). It is possible that these algae are more abundant in the study area during the warm seasons of the year, as the region is characterized by high atmospheric cloudiness during winter and autumn, possibly impairing photosynthetic algae activity, while the warm seasons of the year present higher local rainfall rates (ADAME *et al*., 2018). Furthermore, this feeding group usually exhibits reduced abundance in degraded environments suffering environmental damage (MERRITT *et al*., 2014; PEREIRA *et al*., 2020).

As indicated previously, summer and autumn exhibited the highest insect abundances, in particular, for Baetidae (Ephemeroptera), which form the largest Ephemeroptera group worldwide, found in lotic or lentic environments, mainly in the latter, as observed herein (MERRIT *et al*., 2014). The other most abundant families comprised Psephenidae (Coleoptera), Perlidae (Plecoptera) and Hydropsychidae (Trichoptera).

It is important to highlight that the three most abundant families were those that form the acronym EPT, *i.e.,* Ephemeroptera, Plecoptera and Trichoptera, known to be excellent environmental indicators (MARTINS *et al*., 2014). These groups of invertebrates are known to inhabit clear water environments presenting high amounts of dissolved oxygen (MERRIT *et al*., 2014). Thus, we can infer that the streams analyzed herein exhibit good environmental quality.

CONCLUSION

The analysis of the insects sampled in the studied streams demonstrate that they respond to the strong seasonality observed in the study region, an area located at high altitudes (over 1,200 m a.s.l.) that suffers harsh winters with snow events. This is also reflected in the seasonal heterotrophy and autotrophy index variations noted herein, with higher autotrophy observed during spring and summer. The relationship detected between shredder insects and riparian vegetation indicates that the sampled region may be suffering from deforestation, due to the low contribution of plant matter to the stream waters. However, as many nearby areas are characterized by natural grasslands, it is possible that it is actually an inherent characteristic of the sample area. In fact, the same situation has already been reported for other studies in the same state (FAVRETTO *et al*., 2018).

The relationship between predators and prey also contrasted with the expected patterns for preserved environments, based on the associations between shredders and the riparian vegetation index and predator-prey index, but reflects situations previously reported for similar vegetation types (FAVRETTO *et al*., 2018). Despite these negative results in some functional feeding group indexes, the sampled stream waters still maintain good oxygenation as indicated by the EPT insect groups, as well as the strong association of scraping insects with summer and spring and good bed stability and sediment contribution, which imply that no serious siltation and erosion is underway in the sampled areas. Considering this, our study reinforces the use of the indices proposed by Merritt *et al*. (2014) for the characterization of Neotropical streams, allowing a broad analysis of the environmental conservation status of these habitats.

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