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Functional feeding groups and spatial variation of aquatic insects in a hydrographic basin of Southern Brazil

Grupos tróficos funcionais e variação espacial de insetos aquáticos em uma bacia hidrográfica no sul do Brasil

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ABSTRACT

In Brazil, river basins are geographic units used for environmental and water resources management. Few studies focus on the variation of biodiversity in these units. We present the results on the spatial variation of aquatic insects in streams of the catchment area of Peixe River, southern Brazil. The insect composition was analyzed for relative abundance of families, functional trophic group and environmental assessment indices. The insects had a heterogeneous distribution among the sample areas of the basin. The most abundant families were Hydropsychidae, Philopotamidae and Leptophlebiidae, a fact that shows a good oxygenation in the waters of these streams. The most abundant functional trophic groups were collector-collector (20%) and scraper (18.92%). The indices indicate that the bed of the streams is stable, with a high presence of fine particulate organic matter, being considered heterotrophic. However, the indices also indicated a low abundance of shredders, which may be related to unsatisfactory environmental conditions in the riparian forests. Spatial variation was found in aquatic insects and the indices indicated that the main human impacts on the streams may originate from deforestation and inadequate soil use. Data obtained also contribute to reinforce the importance of watersheds as geographic units for environmental conservation.
Keywords: Hydropsychidae; Leptophlebiidae; Philopotamidae; Santa Catarina state.

RESUMO

No Brasil, bacias hidrográficas são unidades geográficas utilizadas para gestão ambiental e de recursos hídricos. Poucos estudos focam a variação da biodiversidade nessas unidades. Apresentamos os resultados sobre a variação espacial de insetos aquáticos em córregos da Bacia Hidrográfica do Rio do Peixe, sul do Brasil. A composição de insetos foi analisada quanto à abundância relativa das famílias, ao grupo trófico funcional e aos índices de avaliação ambiental. Os insetos tiveram uma distribuição heterogênea entre as áreas amostrais da bacia hidrográfica. As famílias mais abundantes foram Hydropsychidae, Philopotamidae e Leptophlebiidae, fato que demonstra uma boa oxigenação nas águas dos córregos. Os grupos tróficos funcionais mais abundantes foram coletor-catador (20%) e raspador (18,92%). Os índices indicam que o leito dos córregos é estável, com elevada presença de matéria orgânica fina particulada, tendo sido considerado heterotrófico. Entretanto os índices também evidenciaram uma baixa abundância de fragmentadores, que pode estar relacionada com condições ambientais insatisfatórias das matas ciliares. Encontrou-se variação espacial nos insetos aquáticos, e os índices mostraram que os principais impactos humanos nos córregos podem ser originários do desmatamento e do uso inadequado do solo. Os dados obtidos também contribuem para reforçar a importância das bacias hidrográficas como unidades geográficas para conservação ambiental.
Palavras-chave: Hydropsychidae; Leptophlebiidae; Philopotamidae; Santa Catarina.

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INTRODUCTION

The hydrographic basins in Brazil are geographic unities, quoted and used by the laws of environmental management of hydric resources, besides other activities related to environment in general (MMA, 2006). There is an entire policy with emphasis on these entities, for instance, the existence of committees of hydrographic basins to arbitrate water use conflicts, to approve and monitor hydric resources plans, to establish charges for the use of hydric resources and to promote debates and activities on this subject (MMA, 2006). Despite the high legal importance attributed to the hydrographic basins in Brazilian laws focused on environmental conservation, there are few studies about biodiversity and anthropic impacts that target on all or part of the extension of these geographical unities.

In the western region of the Santa Catarina state, southern Brazil, for instance, there are many studies related to insects (SILVA, 1999; SILVA & SILVESTRE, 2000; SILVA & SILVESTRE, 2004; LUTINSKI & GARCIA, 2005; GRACIANI *et al*., 2005; MARCONDES *et al*., 2006; RAVANELLO, 2007; LUTINSKI *et al*., 2008; IOP *et al*., 2009; BATTISTONI, 2012; FAVRETTO, 2012; SCHMIDT *et al*., 2012; SANTOS *et al*., 2013; FAVRETTO *et al*., 2013a; FAVRETTO *et al*., 2013b; RAIMUNDI *et al*., 2013; FAVRETTO *et al*., 2014; SANTOS *et al*., 2014; FAVRETTO & SANTOS, 2014; SILVA & SILVA, 2014; FAVRETTO *et al*., 2015; ORLANDIN *et al*. 2017). However, only Ravanello's research (2007) covers the entire extension of hydrographic basins as sampling parcels, as the other papers have focus on forest remnants, small areas or dispersal species record.

Considering the political and conservationist importance of hydrographic basins, this constitutes little information about biodiversity in these geographical unities. If these ones are really valid to the conservationist purposes, it is important to know about aquatic insects, considering that the presence or absence of a family or order and the functional feeding groups structure may be related to the biotic and abiotic characteristics of the environment (BONADA *et al*., 2006; MONTEIRO-JUNIOR *et al*., 2014; FEIO *et al*., 2015). The analysis of the community structure of aquatic insects allows to deduce if a river is under anthropic impacts and to propose measures to mitigate such impacts (GOULART & CALLISTO, 2003; COPATTI *et al*., 2010; COELHO *et al*., 2011), a fact of special importance considering that, in Brazil, the main electric energy source comes from hydroelectric plants, which have governmental incentives, but endanger the streams because of the high human impact (BRAZIL, 2002).

The trophic structure of an aquatic insect community can be classified into functional groups, for example, scrapers, predators, shredders, filtering-collectors and gathering-collectors (CUMMINS, 1973; MERRITT *et al.*, 2017). According to its functional feeding group, an insect can be characteristic of a specific environment. The collectors are frequently found in larger river areas, because more fine particulate organic matter reach these places. The distribution of the functional feeding groups is related to the availability of food, which varies along the gradient of rivers and streams (VANNOTE *et al*., 1980; MERRITT *et al*., 2014; MERRITT *et al.*, 2017). Thus, the existing functional feeding groups can be an indicator of the real functionality of hydrographic basins as valid geographical unities for environmental conservation, considering the spatial heterogeneity as a gauge of a higher biodiversity in rivers and streams of the basin and homogeneity as the opposite (BURNETT *et al*., 1998; BENTON *et al*., 2003; AZHAR *et al*., 2015).

Therefore, the knowledge of biodiversity variation in different areas of a hydrographic basin may contribute as a framework to environmental and hydric resources management programs in these geographical unities. In addition, it also helps to determine if these unities are really effective for conservationists' purposes. The aim of this study was to analyze the community of aquatic insects in streams of the Peixe river hydrographic basin, located in the state of Santa Catarina, southern Brazil, focusing in the conservation of the area.

MATERIAL AND METHODS

Study area

The aquatic insect survey was conducted in streams with 2 to 4 m wide, which belong to Peixe river hydrographic basin, in four areas distributed in the municipalities of Lacerdópolis, Ouro, Ipira and Joaçaba, in western Santa Catarina state, southern Brazil. The riparian forests of these areas are composed of little forest remnants of permanent preserved areas (protected by law), connected to larger remnants in some parts, and surrounded by agricultural areas. The main river of the basin (Peixe river) runs mainly from northeast to southwest direction.

The Peixe river hydrographic basin covers areas of pine rain forest (araucaria forest) and seasonal deciduous forest. The areas of seasonal deciduous forest occur mainly in the south of the basin following the Peixe river until its middle region. From this region to the north and moving away from Peixe river, there is the domain of pine rain forest (VIBRANS *et al*., 2012; VIBRANS *et al*., 2013). Many of these areas are nowadays de-characterized, as they suffered extensive processes of wood extraction and farming expansion, especially with the building of São Paulo – Rio Grande railway in the first decades of twentieth century (ZAGO & PAIVA, 2016). From the south to the north, there is altitudinal variation from 387m a.s.l. to 1400m a.s.l. as well as an increase of natural forest areas but also of cultivation of exotic plants as *Pinus* sp. (ZAGO & PAIVA, 2016).

Methodology

Sampling was performed submerging an entomological net into the water of streams and stirring the sediments and rocks that were up to 1 m upstream the net, thereby capturing the insects that flowed down the river.

This procedure was executed in an extension of 5 m in each stream. The sampling months were December 2013 (end of Spring) in area 1 (*c.* 27º09'13,56"S, 51º30'53,45"W) in one stream; January and March 2015 (Summer) in area 2 (*c.* 27°17'0.19"S, 51°32'41.58"W) in one stream; January 2014 and March 2015 (Summer) in area 3 (*c.* 27°21'52.04"S, 51°41'11.76"W) in three streams; and January and March 2014 (Summer) in area 4 (*c.* 27°22'49.35"S, 51°43'48.51"W) in two streams (figures 1 and 2).

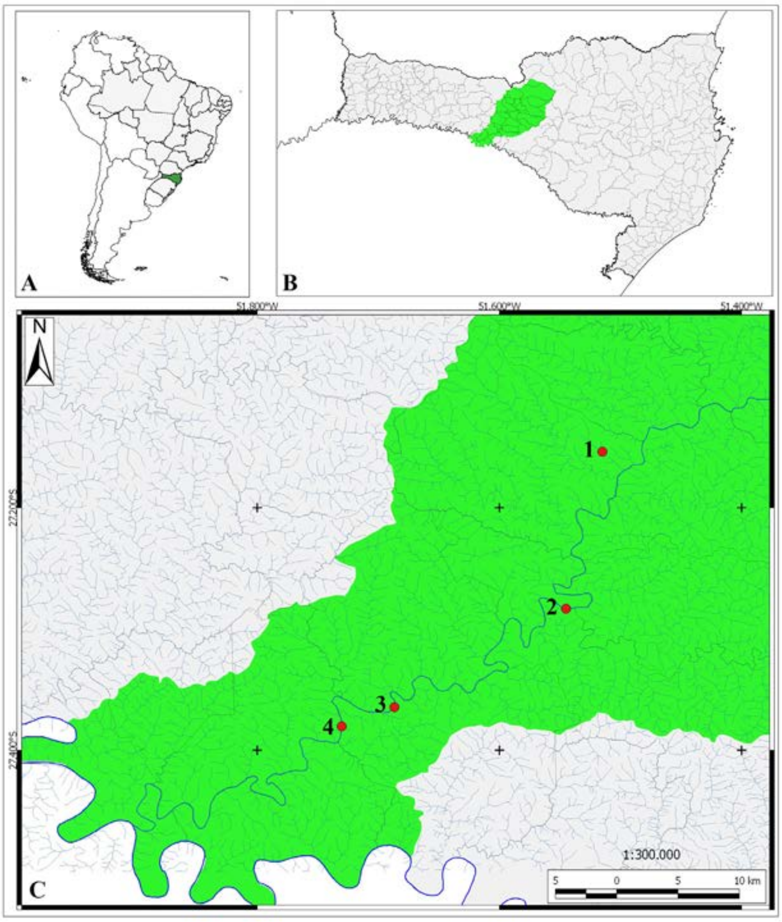

Figure 1 – Localization of the sampling areas. A) Localization of Santa Catarina state in South America. B) Localization of Peixe river hydrographic basin in Santa Catarina state. C) Localization of the sampling areas in Peixe river hydrographic basin.

Figure 2 – Photographical examples of the sampling streams.

The collected insects were identified until the lowest possible taxonomic level, with the following literature: Da-Silva *et al*. (2002), Costa *et al*. (2004), Ferreira-Júnior *et al*. (2014), Salles *et al*. (2014), Neiss & Hamada (2014), Hamada & Silva (2014), Ribeiro *et al*. (2014), Azevêdo & Hamada (2014), Ferreira-Júnior *et al*. (2014), Pes *et al*. (2014) and Pinho & Pepinelli (2014).

The categories of the functional feeding groups were based on Merritt *et al*. (2014), and are the following: gathering-collector, filtering-collector, scraper, swallower-predator, perforator-predator and shredder. To evaluate the environmental conditions of the sampling streams, some indexes were created, according to Merritt *et al*. (2014): autotrophy to heterotrophy index, connection between shredders and riparian vegetation index, filtering-collector index, riverbed stability index and predator-prey index.

Cluster analysis, using the UPGMA algorithm with Jaccard distance, was used to compare the variation of the aquatic insect community between the streams; the UPGMA algorithm with the Bray-Curtis dissimilarity was used to compare the functional feeding groups' structure between these areas. The cophenetic correlation coefficient was used to verify the result significance of the cluster. The Kruskal-Wallis test was performed to verify how significant the difference of abundance was for the families and functional feeding groups between the sampling areas. The tests were conducted through the use of Past software, version 2.16 (HAMMER *et al.*, 2001).

RESULTS

Community variation in streams

Twenty-six families of aquatic insects and 988 specimens were collected. The most abundant families in the four sampling areas were Hydropsychidae (n=256), Philopotamidae (n=212) and Leptophlebiidae (n=177) (figure 3, table 1). Among the specimens that were identified up to genus level, there were *Anacroneuria* Klapálek, 1909 (Plecoptera), present in all sampling areas, and *Kempnyia* Klapálek, 1914 (Plecoptera), present in two areas.

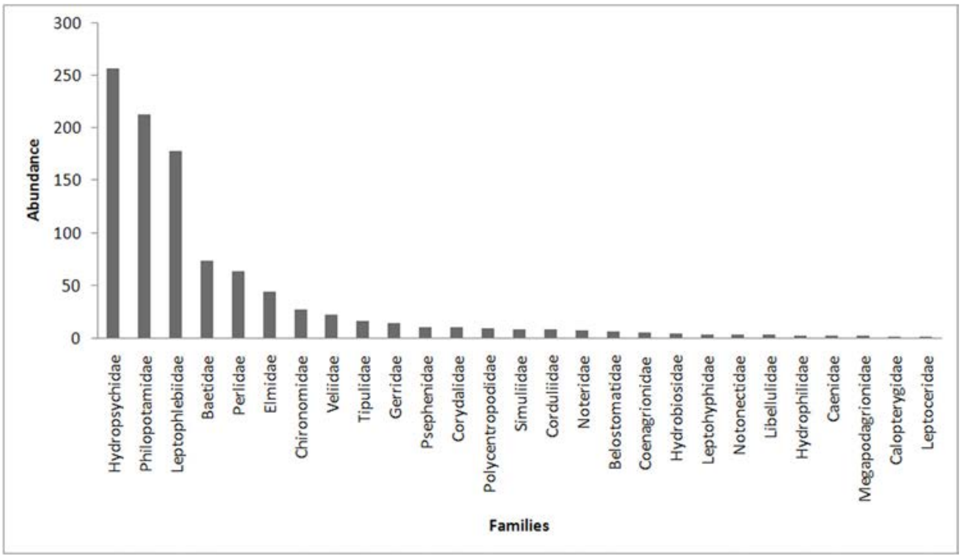

Figure 3 – Families' abundance of the aquatic insects recorded in the sampling areas of Peixe river hydrographic basin, southern Brazil.

The sampling area 3 had the highest abundance of aquatic insects (n=623) and also the highest number of families (n=19). Area 2 was the second sampling area in abundance (n=198) and the second area with more families (n=16). The difference of abundance was significant between the sampling areas (H = 9.66, p = 0.01) and the composition of aquatic insects taxa was more similar between areas 2 and 3, than among the other areas (Jaccard index = 0.545; cophenetic correlation coefficient = 0.91; figure 4).

Table 1 – List of families and genera of the aquatic insects recorded in the sampling areas, and respective abundance. FFG – functional feeding group, N Id – not identified.

Order	Family	Genus	FFG	Sampling Area			
				1	2	3	4
Coleoptera	Elmidae	N Id	Gathering-collector		6	36	2
	Hydrophilidae	N Id	Swallower-predator				2
	Noteridae	N Id	Swallower-predator			7	
	Psephenidae	N Id	Scraper		3		7
Diptera	Chironomidae	N Id	Gathering-collector		4	23	
	Simuliidae	N Id	Gathering-collector		3	5	
	Tipulidae	N Id	Swallower-predator		1	15	
Ephemeroptera	Baetidae	N Id	Gathering-collector		5	48	12

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Order	Family	Genus	FFG	Sampling Area			
				1	2	3	4
		Baetodes	Gathering-collector				5
		Camelobaetidius	Gathering-collector				2
		Cloeodes	Gathering-collector				1
	Caenidae	N Id	Gathering-collector	2			
	Leptohyphidae	N Id	Gathering-collector			2	1
		N Id	Scraper	3	30	114	28
		Massartella	Scraper			1	
		Needhamella	Scraper			1	
Hemiptera	Belostomatidae	N Id	Perforator-predator	2			4
	Gerridae	N Id	Perforator-predator	1	4	7	2
	Notonectidae	*Notonecta*	Perforator-predator	3			
	Veliidae	*Euvelia*	Perforator-predator		8	1	
		Rhagovelia	Perforator-predator	8		2	3
Odonata	Calopterygidae	N Id	Swallower-predator			1	
	Coenagrionidae	N Id	Swallower-predator	1		2	1
		Argia	Swallower-predator				1
	Corduliidae	*Lauromacromia*	Swallower-predator				1
		Navicordulia	Swallower-predator			2	5
	Libellulidae	N Id	Swallower-predator		2	1	

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Order	Family	Genus	FFG	Sampling Area			
				1	2	3	4
	Megapodagrionidae	*Heteragrion*	Swallower-predator				1
		Philogenia	Swallower-predator				1
Megaloptera	Corydalidae	N Id	Swallower-predator	1	3	6	
Plecoptera	Perlidae	*Anacroneuria*	Swallower-predator	5	18	12	15
		Kempnyia	Swallower-predator			9	4
Trichoptera	Hydrobiosidae	*Atopsyche*	Swallower-predator		4		
	Hydropsychidae	N Id	Filtering-collector	7	33	170	33
		Leptonema	Filtering-collector			1	3
		Polycentropus	Filtering-collector			9	
	Leptoceridae	N Id	Shredder		1		
	Philopotamidae	N Id	Filtering-collector		73	139	
	Polycentropodidae	N Id	Filtering-collector			9	

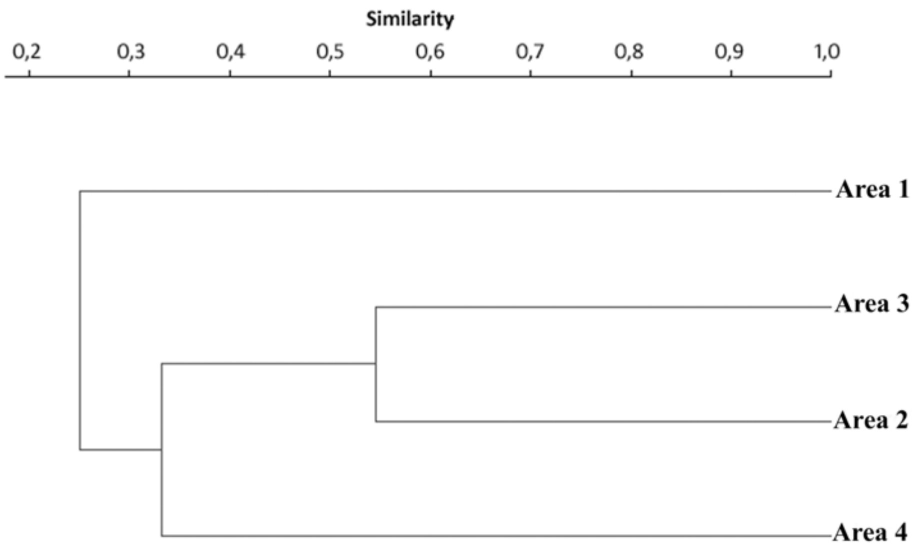

Figure 4 – Cluster analysis of the families similarity between sampling areas of Peixe river hydrographic basin, southern Brazil (coph. corr. = 0.91).

Functional feeding groups and environmental evaluation

Regarding the functional feeding groups, area 2 had the highest number of groups (n=6) as the other areas had five groups each one. The cluster analysis showed more similarity between the areas 2 and 4 (ccc=0.90; figure 5).

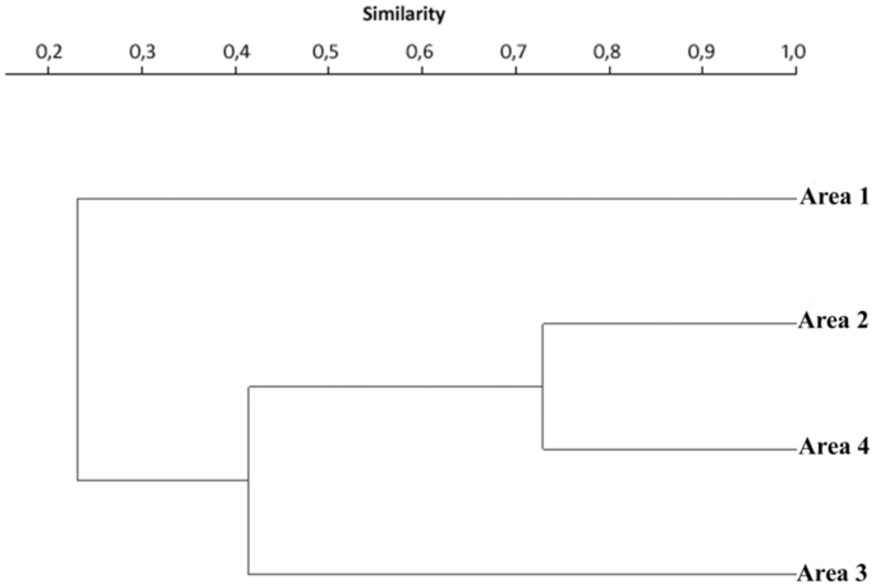

Figure 5 – Cluster analysis of the functional feeding groups similarity between sampling areas of Peixe river hydrographic basin, southern Brazil (coph. corr. = 0.90).

More than 20% of the specimens were filtering-collectors in all the sampling areas, with the highest abundance in area 3, where they represent more than 50% of the insects. Predator insects, considering swallower-predators and perforator-predators together, were also present in the areas, but their proportion varied from 10.44% in area 3 to 63.63% in area 1 (figure 6). Considering all the sampling areas, the highest insect abundance was composed by filtering-collectors (n=485), followed by scrapers (n=187) and gathering-collectors (n=149; figure 7). Despite the differences in the proportions of functional feeding groups, the differences were not significant in relation to the abundance of the groups between the areas (H = 6.42, p = 0.09).

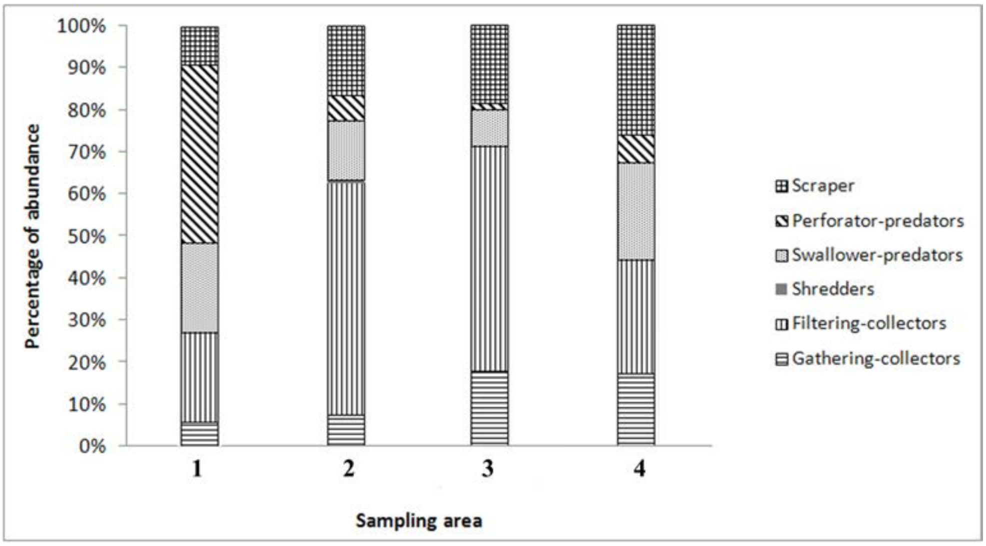

Figure 6 – Proportion of aquatic insects by functional feeding group in the sampling areas of Peixe river hydrographic basin, southern Brazil.

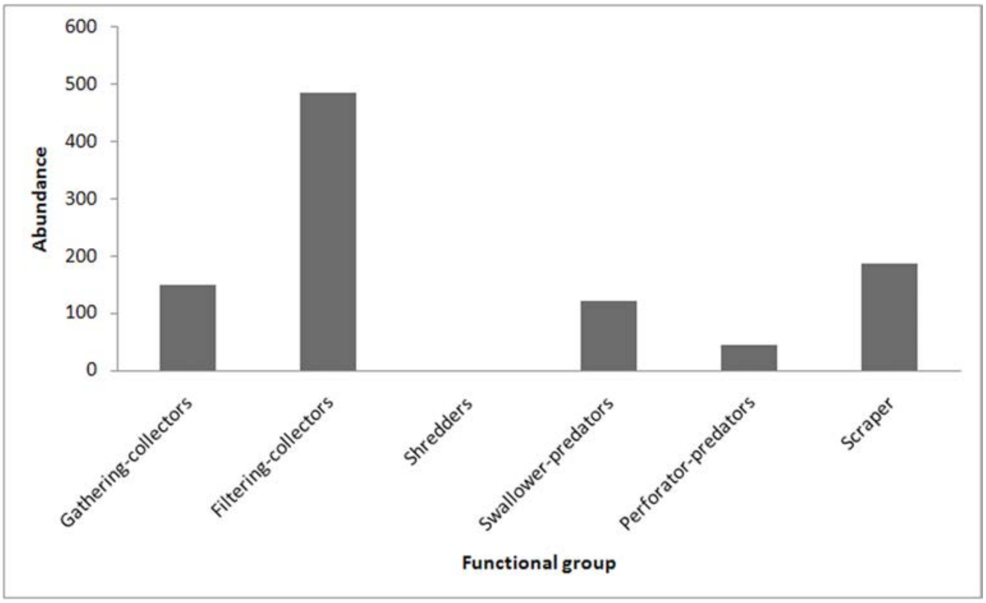

Figure 7 – Abundance of aquatic insects by functional feeding group in the sampling areas of Peixe river hydrographic basin, southern Brazil.

In relation to the indexes, the results showed that none of the streams are autotrophic as all are heterotrophic, with values lower than 0.75 (table 2). The analysis done with the data, considering it as a generalization to the hydrographic basin of the lower Peixe River, also showed a value of heterotrophy. No stream had any significant result in the index of the relation between shredders and riparian vegetation, that should be higher than 0.25 during spring and summer or higher than 0.5 during autumn and winter (MERRITT *et al*., 2014). It is possible that these results should be related to the kind of sampling, involving just insects, while some other macroinvertebrates are considered shredders too. Despite this, the almost complete absence of shredders is worrisome.

Table 2 – Ratios between the functional feeding groups in the sampling areas of Peixe river hydrographic basin, southern Brazil.

Index	Sampling area				Total
	1	2	3	4	
Autotrophy to heterotrophy index	0.33	0.26	0.26	0.59	0.27
Connection between shredders and riparian vegetation index	0	0.008	0	0	0.001
Filtering-collector index	3.50	7.27	3.06	1.57	3.26
Riverbed stability index	5.00	8.88	4.12	3.09	4.48
Predator-prey index	1.75	0.25	0.12	0.43	0.20

In all the streams, and in the general analysis, a filtering-collector index above 0.5 was found. This probably occurred because of the high abundance of fine particulate organic matter present in these areas, especially in area 2, whose index resulted 7.27. The riverbed stability index, and the general analysis, showed all streams to have a high stability. Regarding the predator-prey index, in the analysis of each stream, only area 3 had a normal value (0.12), the other streams had values above of 0.20, which is considered the normal maximum value. The general result was 0.20.

DISCUSSION

The aquatic insect composition and the functional feeding groups showed variations between the different sampling areas, even when the collection was made in the same season. This probably is related to some geospatial or phytophysiognomic variation in the sampling area of the hydrographic basin, resulting in environmental heterogeneity (BURNETT *et al.,* 1998; BENTON *et al*., 2003; SABATIER *et al*., 2014; KATAYAMA *et al*., 2014; AZHAR *et al*., 2015; ATKINSON *et al.*, 2018). When considering only aquatic insects, besides these variations of environmental heterogeneity, there is also the influence of the dispersal capabilities of each taxonomic group, with some ones being able to respond to environmental variations and others having certain stochasticity in the areas of occurrence (HEINO, 2013).

The high abundance of Ephemeroptera and Trichoptera is a positive result, as their presence is normally associated with a high level of oxygenation of the water, as these taxa have a high demand in relation to this feature. This is a sign that the evaluated streams are not receiving a too high load of organic matter (e.g. domestic wastewater) (CALLISTO *et al*., 2001; BUENO *et al*., 2003; MARTINS *et al*., 2014). Ephemeroptera may have a significant reduction of its abundance in areas where riparian forests are replaced by pastures (LORION & KENNEDY, 2009). In rivers with lower quality conditions, there is a high abundance of Oligochaeta and Chironomidae (KÖNIG *et al*., 2008). In the present study, Chironomidae specimens were collected in lower abundance if compared with orders related to a higher environmental quality (Ephemeroptera, Plecoptera and Trichoptera), which reinforces the high environmental quality of the streams sampled here (MEYER *et al*., 2005).

As previously mentioned, among the specimens identified up to genus, *Anacroneuria* (Plecoptera) was present in all streams and *Kempnyia* (Plecoptera) in half of them. Oliveira & Froehlich (1997), in the southeast of Brazil, found these genera in all sampling areas and in every month of the year, demonstrating that if the ecological requirements of these genera are met, their encounter may be common. *Camelobaetidius* (Ephemeropera) and *Polycentropus* (Trichoptera) had reduced abundance in the present study, as also recorded by Oliveira & Froehlich (1997). These two genera were found in just half of the sampled streams, showing a low distribution in the total area, a fact probably related to its environmental or dispersal requirements (HEINO, 2013).

In relation to the functional feeding groups, in all the sampled streams we had a high abundance of filtering-collectors insects, with some streams also having a high abundance of gathering-collectors and predators. Overall, collectors are frequent in streams and this can explain the data obtained in the present study (OLIVEIRA & BISPO, 2001). However, the highest richness of functional groups, in the streams of areas 2, 3, and 4, may be related to a higher availability of resources originated from the riparian area or with more vegetation variation in these areas (BUENO *et al*., 2003; AYRES-PERES *et al*., 2006).

The heterotrophic condition recorded in the streams indicates that the carbon present in these waters is originated from the decomposition of riparian vegetation that enters or falls into the streams, *i.e*., does not originate from the photosynthetic activity of autotrophic organisms (MERRITT *et al*., 2014). This is a positive aspect, because streams are usually heterotrophic, with more plant matter entering them, and less algae blooming. When this begins to occur, it indicates a change in the heterotrophic system (MALLIN *et al*., 2004; PISCART *et al*., 2009).

The high values of the filtering-collector index result from a high amount of fine particulate organic matter, generally smaller than 1 mm in diameter. The filtering-collectors filter these particles from the water column and sediments, thus the abundance of this functional group is associated to a higher abundance of this kind of organic matter (CUMMINS *et al*., 1989; CALLISTO & GRAÇA, 2013). These organic matter may be originated from the decomposition of plants, such as leaves and branches, both in the water or external to it, and later adduced to this environment, but also can be indicative of higher levels of organic matter in the water (CUMMINS, 1973; MERRITT *et al*., 2014; MERRITT *et al.*, 2017).

Although the connection between shredders and the riparian vegetation index was almost zero in the sampled streams, due to the record of only one specimen of shredders, organic matter is probably being inserted in the food chain of these streams in other ways. This absence of shredders is an indication that the riparian forests of the streams may be little preserved, especially considering that in streams as the sampled ones (2-4 m wide), the predominant functional groups generally are shredders and collectors (KARR & DUDLEY, 1981; CUMMINS *et al*., 1989; MARQUES *et al*., 1999; BARBOLA *et al*., 2011). Thus, the high abundance of filtering-collectors, rather than a result from the process of fragmentation of coarse particulate organic matter by the shredders, can be caused by organic detritus coming from the surrounding agricultural areas of these streams (CUMMINS *et al*., 2005; MERRITT *et al*., 2014; MERRITT *et al.*, 2017).

While there are negative aspects related to the indexes, the riverbed stability index reached high values in each sampled stream and in the general analysis. This indicates that these riverbeds are not suffering landslides and similar erosions, probably due to the presence of stable substrates, such as various rocks and basalt slabs, a common characteristic in the rivers of the region. Thus, despite the reduction of the riparian forests, there is still some stability in the riparian structure (CUMMINS *et al*., 2005; MERRITT *et al*., 2014).

Streams generally have a predator abundance corresponding to 10 to 20% of the total specimens (MERRITT *et al*., 2014). In this study, some streams had high values of this functional group, like the streams of areas 1 and 4. This data may result from environmental changes. Barbola *et al*. (2011) considered predators as less strict to their environment and this functional group can be found with high abundance in anthropic environments (FAVRETTO *et al*., 2014).

The streams sampled here form a heterogeneous environment that creates a geographical variation of aquatic insects inside the hydrographic basin, with a high abundance and richness of families in the streams of areas 2 and 3. Each of the sampled streams had different proportions of abundance in its structure of functional feeding groups. In addition, the insect families varied along the streams and in their local abundance. A hydrographic basin with many streams may have an important role in the maintenance of different aquatic insect species, due to the heterogeneity of abiotic and biotic characteristics that each functional group requires. We recorded the presence of some taxonomic and functional feeding groups as being related to high water oxygenation, a low amount of pollution and good stability. Other riverbed groups point to possible environmental changes, such as riparian deforestation and excessive input of organic particulate matter originated from the surrounding areas of these streams. All these findings demonstrate that deforestation and inadequate land use are the major negative anthropic impacts on the streams of the hydrographic basin. These data are important to Brazil's environmental politics with focus on the management and conservation of hydrographic basins and have shown that aquatic insects can be an important tool to increase accuracy in the application of these laws.

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