Influence of landscape on assemblages of Chironomidae in Neotropical streams

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Abstract – Landscape is important in determining the composition of aquatic assemblage, and benthic invertebrates, particularly Chironomidae, are often used as bioindicators of environmental quality because their occurrence and distribution are influenced by different land uses. The objective of this study was to evaluate the influence of different land uses, considering three landscape scales (drainage basins, riparian buffer and streams), on chironomid assemblage. We sampled streams located in an agricultural matrix by collecting chironomid larvae and water samples and performed a landscape analysis using Geographical Information System techniques. The drainage basins had a high percentage of agricultural land use; in all of the drainage basins studied, 79% of the riparian buffer was not in accordance with Brazilian law. *Cricotopus* proved to be a good indicator of the agricultural conditions, whereas *Thienemanniella* and *Rheotanytarsus* proved to be indicators of exposed soil. *Lopescladius* was more sensitive to disturbance and was positively correlated with the presence of riparian vegetation. Although the variables at the local scale (stream) were responsible for a major change in the assemblage, the landscape attributes at large scales (drainage basin and riparian buffer) generated significant effects on Chironomidae fauna. Our results suggest the importance of the conservation of two larger landscape scales to support the equilibrium and maintenance of aquatic assemblage.

Key words: Biomonitoring / drainage basin / environmental quality / riparian buffer

Introduction

Streams are complex networks that are hierarchically organized at large spatial scales (Allan, 2004). Streams reflect the characteristics of their drainage basins, from which they receive large amounts of organic and inorganic matter, forming the basis of the chemical composition of water and the biogeochemical cycles (Barrella *et al.*, 2000). Thus, rivers and streams are natural collectors of landscape and reflect land use in their drainage basins because water features are derived from the environments from which they originate, are stored or percolate (Tundisi and Tundisi, 2008; von Schilleler *et al.*, 2008; Sandin, 2009).

In most lotic environments, the physical and chemical parameters and biological diversity have been altered by anthropogenic inputs, particularly urbanization (Roy *et al.*, 2003; Meyer *et al.*, 2005; Smith and Lamp, 2008; Washburn and Sanger, 2011) and agriculture (Bacey and Spurlock, 2007; Maloney *et al.*, 2008; Hepp and Santos, 2009; Stewart, 2011). Agriculture is an essential activity for the production of food, but its consequences include the draining of wetlands, intensive use of agrochemicals and removal of riparian vegetation (Niyogi *et al.*, 2007; Roque *et al.*, 2009; Hepp *et al.,* 2010).

Land-use dynamics, as associated with the intensification of agricultural activities and with the conversion of natural landscapes into changing agricultural landscapes, mainly agricultural matrices, has been considered the main form of human environmental impact. The appropriation of space for farm use without adequate planning and zoning has caused a number of problems on both local and regional levels (Matson *et al.,* 1997). In long-occupied areas, land use and topography are the principal factors in the fragmentation of native vegetation (Hawbaker *et al.,* 2006), and the landscape matrix of most of the areas of intense human activity consist of agriculture or pasture. A matrix can be defined as the longest connected element of the landscape, and it plays a dominant role in its operation; in contrast, a fragment can be considered as a non-linear area with a certain degree of isolation and without direct connectivity (Forman and Godron, 1986).

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The riparian vegetation plays an important role in aquatic ecosystems by providing allochthonous organic matter used as an energy source in the aquatic food chain (Vannote *et al.,* 1980; Barrella *et al.,* 2000). By serving as a barrier to the input of material from the environment, this plant component is also important for the maintenance of water quality (Moulton and Souza, 2006; Stewart, 2011).

Several studies have highlighted the importance of riparian vegetation for maintaining the equilibrium of aquatic assemblage. In a study to observe the effectiveness of riparian vegetation in retaining sediment, Sparovek *et al.* (2002) found that a 52-m strip would retain up to 54% of the sediment from the area surrounding the water body, greatly contributing to the maintenance of water quality. Pinder (1995) argued that the presence of riparian vegetation in an aquatic ecosystem results in a significant increase in the area available for colonization by invertebrates and other aquatic organisms. Corbi and Trivinho-Strixino (2008) compared the diversity of Chironomidae in preserved regions with areas of sugar-cane plantations and pasture in Brazil and found that the removal of riparian vegetation results in significant loss of wildlife diversity. Studying the land uses in a watershed, Hepp and Santos (2009) found that sites with urban and agricultural practices caused a decrease in the number of families of Ephemeroptera, Plecoptera and Trichoptera and an increase in the density of *Chironomus* (Chironomidae). Hepp *et al.* (2010) observed a difference in the structure and composition of benthic macroinvertebrate fauna in streams in urban and agricultural areas, concluding that sites with riparian vegetation had a higher richness and lower density of pollution-tolerant organisms than sites without riparian vegetation. Washburn and Sanger (2011) reported that the benthic community varies according to stream order and also according to different land uses, such as forested or urban areas. A study by Stewart (2011) in Australia indicated that the removal of riparian vegetation leads to changes in several environmental parameters, including temperature and nutrients, resulting in the loss of sensitive species.

The Chironomidae family comprises bioindicator organisms that are often used to assess water quality (Rosin and Takeda, 2007). This family is a key component of the aquatic food web, converting organic matter into food that is then available to other consumers, and is linked to the decomposition cycle of organic matter (Hepp *et al.*, 2008). In general, chironomids respond efficiently to changes in aquatic ecosystems, and their occurrence and distribution are related to the biogeochemical aspects and heterogeneity of habitats (Rosin and Takeda, 2007; Campbell *et al.*, 2009). Chironomid assemblage have proven to be structured by landscape-level factors, such as specific land uses (Lampert and Allan, 1999; Silver *et al.*, 2004; Kleine and Trivinho-Strixino, 2005; Hepp and Santos, 2009; Roque *et al.*, 2010; Hepp *et al.*, 2010).

Changes in land use in watersheds are considered to be dominant stressors for aquatic ecosystems (Vondracek *et al.,* 2005), and the use of tools based on the georeferencing approach (Geographic Information System, GIS) has positively impacted the monitoring of water resources (Burns, 2005). The economy of southern Brazil (Neotropical region) is concentrated on farming, with large areas used for agricultural activities. Furthermore, the areas of native vegetation, including riparian vegetation, are being increasingly fragmented (Decian *et al.*, 2009; Hepp and Restello, 2010; Hepp *et al.*, 2010). By considering three landscape scales (drainage basin, riparian buffer and streams), this study aimed to evaluate the influence of different land uses on chironomid assemblage. We hypothesized that the effects generated at the local scale (streams) are strong but that the large-scale landscapes (riparian buffer and drainage basin) will generate negative effects on Chironomidae. Furthermore, we hypothesized that chironomid assemblage will be negatively influenced by low percentages of vegetation in the drainage area. We suggest that riparian vegetation alone is not sufficient to ensure water quality in severely degraded landscapes. Furthermore, we expect that the Chironomidae assemblage more closely reflects variations of the physical–chemical water variables. However, changes in the landscape will also influence the composition of bioindicator organisms.

Material and methods

Study area

This study was conducted in southern Brazil, between 49°30′ and 54°W and 26°30′ and 28°30′S, in the central/northern portion of the Uruguay River Basin (Fig. 1). The selected 18 second-order streams are contained in an area with significant agricultural occupation. According to Decian *et al.* (2009), approximately 77% of the area is used for anthropogenic activities, and 23% is covered by native vegetation. The region has altitudes ranging from 400 to 800 m. The climate is classified as Köppen Cfb subtropical temperate, with regular rainfall and well-defined seasons: an annual mean precipitation of 1912 mm and a mean annual temperature of 17.6 °C (Bernardi and Budke, 2010). The edaphic and geological formation consists of basalt, and the soil is classified as "EC" (dystrophic Oxisol type) (Hepp *et al.,* 2010). The vegetation is characterized by a mixture of subtropical forest in the Upper Uruguay Basin, along the valleys of the Uruguay River and its tributaries, and *Araucaria* forest (Budke *et al.*, 2010).

Landscape analysis and environmental variables

Landscape analysis was conducted based on the geographical coordinates of each sampling site. These points were used to calculate the area of the drainage basin of each of the streams by following the cartographic parameters for the selection of contour points and watersheds. We used the software MapInfo 8.5 and Idrisi 32. The base map used for the study had a scale of 1:35 000
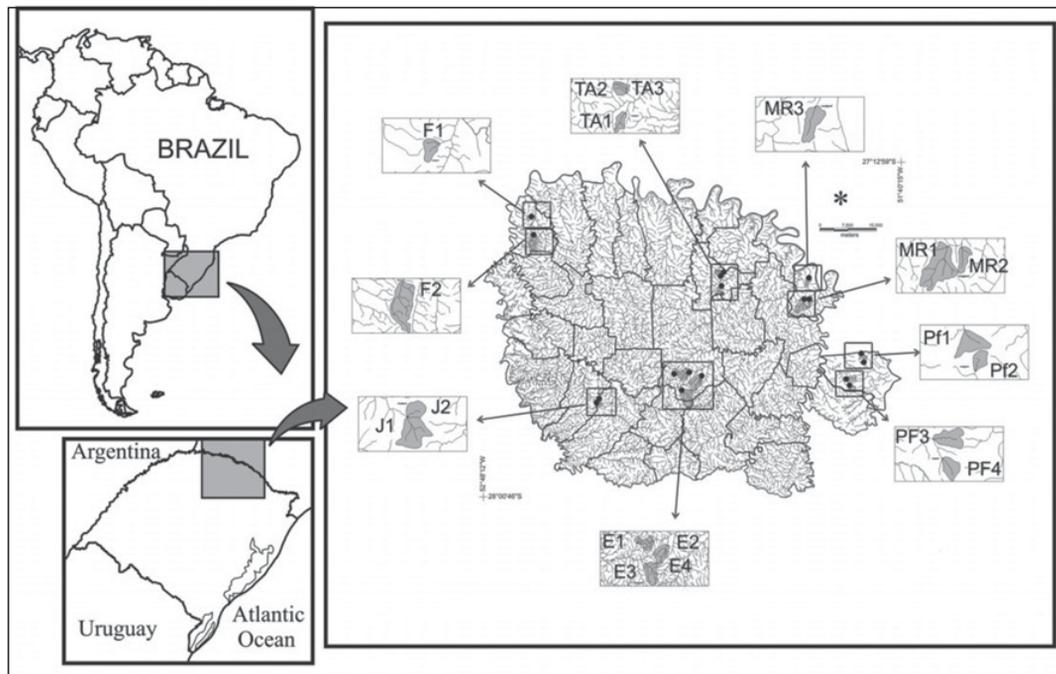
Fig. 1. Location of the sampling sites in the drainage basins studied in southern Brazil.

and was composed of layers and articulated image sensors of Landsat ETM + 7, with a 15-m spatial resolution, spectral bands 3, 4 and 5 and Panchromatic sensitivity. First, we prepared the Numerical Terrain Model, with altitudes of spatialization of 1 m, which were able to demarcate the areas of the drainage basins using the Triangle Irregular Network method. The classification of land use followed the method of Maximum Likelihood Supervised Classification (maxlike) in IDRISI GIS 32 based on the sampling units obtained in the field using GPS, with prior knowledge of the area. The classes used were as follows: agriculture deployed, exposed soil, pasture and woody vegetation. Based on the Spatial Letter of Brazilian Environmental Law and the Charter of Environmental Conflict, a second landscape scale was defined, referred to as a riparian buffer, 30 m in width, along both banks of the streams.

At each sampling site, the water temperature, dissolved oxygen, electric conductivity and turbidity variables were analysed using a multiparameter analyser (HORIBA®). Water samples were collected for analysis of the total organic carbon content (TOC) using a SHIMADZU TOC Analyzer®, and the nitrite, sulphate and chloride ions were measured using an Ionic-Exchange HPLC®.

Sampling and identification of Chironomidae

The sampling of chironomid larvae was conducted in the summer of 2010 by using a Surber collector (three sub-samplings; mesh = 250 μm; area = 0.1 m^2) on a rocky substrate. The collections were performed only in the summer because it is a station with greater stability of lotic systems. Moreover, studies in the region show that there is variability in the distribution of aquatic invertebrates during different seasons (Hepp and Santos, 2009; Hepp *et al.*, 2010). Thus, by standardizing the substrate used for the collections, we eliminated the possible effects of this environmental component, allowing us to evaluate the real effects caused by the landscape. Furthermore, this stony substrate constitutes the most abundant and common substrate in all the streams of the study area. For identification, the chironomid larvae were cleared by immersion in a solution of 10% KOH for 24 h. The cleared larvae were mounted in Hoyer's solution on glass slides (Trivinho-Strixino and Strixino, 1995) and were examined by using an optical microscope at 1000 × magnification. The larvae were identified to the genus level using the keys and articles by Trivinho-Strixino and Strixino (1995) and Epler (2001).

Data analysis

Four matrices were organized for data analysis: (i) a biological matrix consisting of the genera and abundance of Chironomidae, (ii) a landscape matrix with the attributes of the drainage basin of each stream, (iii) a riparian buffer matrix and (iv) streams (physical-chemical variables). The biological matrix was transformed into $\log(x + 1)$ to ensure homoscedasticity of the data. To evaluate the dependence of the matrices on the drainage basin and riparian buffer, a Mantel test was applied using the landscape attributes of agriculture, exposed soil,

Table 1. Total area (ha) and percentage of landscape attributes quantified in the drainage basins and riparian buffer of the streams studied in southern Brazil.

Streams	Drainage basin						Riparian buffer			
	Drainage area (ha)	Declivity (%)	Agriculture (%)	Exposed soil (%)	Pasture (%)	Vegetation (%)	Agriculture (%)	Exposed soil (%)	Pasture (%)	Vegetation (%)
PF1	330.2	34.8	27.1	18.6	0.0	48.2	22.6	14.8	0.0	58.5
PF2	220.3	30.2	20.0	23.8	0.0	32.2	28.9	33.0	0.0	24.2
PF3	81.5	24.5	24.7	49.0	0.0	21.6	25.8	57.9	0.0	16.2
PF4	177.6	20.2	44.5	37.2	0.0	10.8	21.3	69.3	0.0	6.1
F1	720.5	12.4	10.1	46.2	23.6	15.2	27.4	40.4	13.7	18.5
F2	132.7	16.4	20.4	14.1	47.5	17.9	29.2	17.6	22.8	30.4
TA1	108.8	32.5	5.8	41.7	25.9	26.6	17.0	10.4	0.1	72.5
TA2	353.1	30.2	13.0	36.0	26.9	24.1	28.8	24.2	9.6	37.5
TA3	322.5	29.5	24.2	20.0	31.7	24.0	33.7	16.7	0.0	49.5
J1	80.3	10.8	22.5	25.2	44.9	7.4	48.2	37.0	7.2	7.6
J2	217.9	12.3	37.1	39.9	21.5	1.6	26.8	51.6	21.6	0.0
ERE1	668.3	16.5	40.4	17.8	30.8	10.9	32.8	10.4	42.5	14.4
ERE2	1073.2	14.6	33.5	29.9	30.3	6.2	28.6	20.9	39.0	11.5
ERE3	199.4	12.2	19.7	24.5	39.5	16.3	38.3	35.7	5.3	20.7
ERE4	1284.8	16.9	27.8	36.0	28.4	7.8	29.3	31.6	24.4	14.8
MR1	191.2	30.6	5.9	32.8	40.2	21.1	62.1	18.7	1.7	17.5
MR2	847.2	26.8	3.1	24.3	55.5	17.0	60.8	14.0	5.7	19.6
MR3	270.1	26.7	0.8	31.3	45.3	22.6	72.8	7.6	0.0	19.6

pasture and vegetation in the riparian zone. This test was performed using a matrix of Bray–Curtis dissimilarity correlated with the Pearson correlation coefficient based on 999 permutations.

To assess the variability of chironomid assemblage at the landscape scale, we employed three partial canonical correlation analysis (pCCA; Legendre and Legendre, 2003) using the (i) drainage basin area, (ii) riparian buffer and (iii) streams as explanatory variable matrices. We used the spatial matrix as the geographic coordinate of each collection site. The analysis determined the percentage of explanation provided by the environmental variables (physical–chemical variables and landscape attributes) quantified in the drainage basin, riparian buffer and stream water variables. The variation percentage of each component was obtained from the canonical coefficients generated from the pCCA employed between the biological matrix in relation to the explanatory matrix (drainage basin, riparian buffer and stream) and spatial matrix (Legendre and Legendre, 2003; Melo *et al.*, 2011).

To evaluate the response of the organisms to the variables at larger scales, the main attributes of the landscape (drainage basin and riparian buffer) were analysed separately with a principal components analysis (PCA) to synthesize the information generated by the landscape attributes quantified using a smaller number of principal components. The scores for the first principal component (explaining more than 75% of the variation) that were used as the explanatory variable in the linear regression analysis of response variables were the richness and abundance of chironomid genera that were the most representative of the community. Analyses were conducted using the package "vegan" (Oksanen *et al.*, 2010) of the R software (R Development Core Team, 2010).

Results

Land-use characterization and environmental variables

The main land uses in the drainage basins were exposed soil (30%), pasture (30%), agriculture (22%) and woody vegetation (18%), totalling more than 80% of the area with anthropogenic land use (Table 1). The drainage basins with steeper slopes had a comparatively higher percentage of vegetation ($r = 0.82$, $P = 0.001$). However, 79% of the riparian buffer had very low percentage of native vegetation, which is incompatible with Brazilian law. In the riparian buffer, agriculture and exposed soil comprised the largest percentage of area (Table 1). Although the land used for the riparian buffer is immediately adjacent to the streams, the drainage basins have an intrinsic relationship with the water bodies. The Mantel test between the matrices of the drainage basin and permanent preservation area revealed a dependence between these landscape scales ($r = 0.80$, $P = 0.001$).

Although the water quality was similar in the studied streams (Table 2), the observed changes were reflected in the landscape in the riparian buffer. The water temperature of the streams averaged $22.30 \pm 1.98\,^{\circ}\mathrm{C}$, was well oxygenated ($8.0 \pm 1.0$ mg L^{-1}), slightly basic pH (8.20 ± 0.45), had a mean electrical conductivity of 0.10 ± 0.03 mS cm^{-1} and a turbidity of 1.80 ± 1.91 NTU.

Composition of Chironomidae

We collected 4222 chironomid larvae in 18 streams. The larvae were identified in 28 genera of three subfamilies (Table 3). Members of Orthocladiinae were the most

Table 2. Physical–chemical variables (mean, standard deviance [SD], maximum and minimum) of the streams studied in southern Brazil.

Streams	Water temperature (°C)	Dissolved oxygen (mg.L^{-1})	pH	Conductivity (mS.cm^{-1})	Turbidity (NTU)	COT (mg.L^{-1})	Chloride (mg.L^{-1})	Nitrite (mg.L^{-1})	Sulphate (mg.L^{-1})
PF1	21.50	8.73	8.55	0.11	3.3	27.44	2.66	4.47	0.89
PF2	22.10	9.21	8.31	0.07	0.8	37.55	2.87	6.11	0.82
PF3	22.50	7.24	8.33	0.07	6.4	19.31	1.83	1.52	0.49
PF4	24.60	8.27	9.12	0.09	0.6	34.77	3.64	3.35	0.83
F1	21.70	7.95	7.7	0.03	1.1	335.3	1.29	1.24	0.25
F2	21.10	8.01	7.13	0.01	0	19.46	0.69	1.19	0.13
TA1	21.40	9.31	8.33	0.11	1.7	24.73	3.71	5.43	1.58
TA2	24.30	6.57	8.33	0.12	0.5	63.39	3.27	5.76	1.08
TA3	22.30	5.45	8.03	0.10	3.4	30.16	2.81	3.73	1.22
J1	22.00	7.08	7.72	0.03	0	6.73	1.13	2.32	0.17
J2	23.26	6.81	7.87	0.04	4.6	16.36	1.01	2.98	0.27
ERE1	24.30	8	8.77	0.08	0	14.59	1.86	2.47	0.26
ERE2	27.80	8.45	8.76	0.11	3.4	17.78	2.52	3.84	0.00
ERE3	20.31	7.91	8.37	0.05	1.2	9.63	1.45	1.52	0.25
ERE4	20.80	8.83	8.37	0.08	4.1	40.41	2.31	2.99	0.38
MR1	19.90	8.61	8.24	0.08	0.4	59.19	2.27	1.02	0.72
MR2	19.90	8.7	8.15	0.09	0.8	92.5	1.67	2.27	0.25
MR3	21.30	8.09	8.16	0.09	0.1	77.79	2.20	1.16	0.76
Mean	22.28	7.96	8.24	0.07	1.80	51.51	2.18	2.96	0.57
SD	1.98	1.00	0.45	0.03	1.91	74.76	0.89	1.65	0.44
Maximum	27.80	9.31	9.12	0.12	6.40	335.30	3.71	6.11	1.58
Minimum	19.90	5.45	7.13	0.01	0.00	6.73	0.69	1.02	0.00

numerous (2062 individuals, 48.8% of the total), followed by Chironominae (1425, 33.8%) and Tanypodinae (735, 17.4%). *Cricotopus* Vander Wulp, 1874 was the most abundant genus (1653, 39.2% of the total), followed by *Rheotanytarsus* Thienemann and Bause in Bause, 1913 (985, 23.3%) and *Thienemanniella* Kieffer, 1911 (548, 13%). These three genera comprised more than 75% of the entire fauna of Chironomidae collected in the streams.

Influence of landscape on chironomid assemblages

The pCCA showed that the environmental component at the three studied scales had the largest variation in Chironomidae assemblage composition (Fig. 2). At the small scale (stream), the environmental variables were responsible for 48.1% of the variation of the assemblage, whereas the landscape attributes at the two large scales (drainage basin and riparian buffer) explained approximately 25% of the assemblage variation. The spatial component (geographic coordinates) and the shared component (environment + space) were similar at all three of the scales (Fig. 2). At the small scale, the electrical conductivity and sulphate and nitrite ions were the variables responsible for assemblage variation. At the large scales (drainage basin and riparian buffer), agriculture and exposed soil were the main attributes responsible for assemblage variation (Fig. 3).

The first two principal components calculated from the PCA to synthesize the information generated by the characteristics of the drainage basin explained 91.3%; this high percentage resulted in PC1 representing a gradient of agriculture and exposed soil to all the drainage areas studied. PC1 influenced the abundance of Chironomidae ($F_{1,16} = 4.83$, $P = 0.04$) and the abundance of *Cricotopus* ($F_{1,16} = 4.36$, $P = 0.05$). The PCA calculated using information from the riparian buffer with the first two components explained 85.3%. PC1 influenced the abundance of Chironomidae ($F_{1,16} = 4.79$, $P = 0.05$) and *Thienemanniella* ($F_{1,16} = 4.34$, $P = 0.05$).

The landscape influence features in the drainage basin were dependent on the high percentage of agricultural land use and exposed soil at this landscape scale. This was reflected in the effect of the percentage of agriculture on the total abundance of Chironomidae ($F_{1,16} = 6.53$, $P = 0.02$) and *Cricotopus* ($F_{1,16} = 8.93$, $P = 0.008$) and of the percentage of exposed soil on the abundance of Chironomidae ($F_{1,16} = 5:48$, $P = 0.03$) and *Rheotanytarsus* ($F_{1,16} = 4.01$, $P = 0.05$) and *Thienemanniella* ($F_{1,16} = 7.38$, $P = 0.01$). These results demonstrated the influence of the removal of native vegetation on the genera *Cricotopus*, *Rheotanytarsus* and *Thienemanniella*. In contrast, *Lopescladius* was positively correlated with the percentage of vegetation in the drainage basins ($F_{1,16} = 6.24$, $P = 0.02$) and riparian buffer ($F_{1,16} = 5.22$, $P = 0.03$), and was sensitive to the disturbances caused by agricultural activities.

Discussion

The greatest variation in the community was generated by the variables obtained at the smallest scale studied (streams). In a way, this is expected because local variables

Table 3. Subfamilies and genera of Chironomidae (Insecta, Diptera) in streams of southern Brazil.

Genus	PF1	PF2	PF3	PF4	F1	F2	TA1	TA2	TA3	J1	J2	ERE1	ERE2	ERE3	ERE4	MR1	MR2	MR3	Total
Chironomidae																			
Beardius Reiss e Sublette, 1985	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cryptochironomus Kieffer, 1918	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Endochironomus Grodhaus, 1987	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Paralauterborniella Lenz, 1941	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Paratendipes Kieffer, 1911	3	0	1	0	0	0	0	1	1	0	0	0	6	0	0	1	0	30	43
Phaenopsectra Kieffer, 1921	0	0	2	0	0	0	0	21	0	0	0	0	0	0	0	0	0	1	24
Polypedilum Kieffer, 1912	7	19	2	15	17	2	14	62	12	2	0	6	164	0	7	2	1	4	336
Pseudochironomus Malloch, 1915	0	0	0	1	4	24	0	0	0	0	0	0	0	0	0	0	0	0	29
Rheotanytarsus Thienemann and Bause in Bause, 1913	2	16	10	119	494	113	0	3	1	19	9	11	155	15	13	1	0	4	985
Stenochironomus Kieffer, 1919	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Tanytarsus Van der Wulp, 1874	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Orthocladiinae																			
Corynoneura Winnertz, 1846	2	24	8	18	10	0	2	4	0	25	7	5	0	0	2	1	0	1	109
Cricotopus van der Wulp, 1874	2	2	7	257	3	30	0	4	0	5	61	1	1212	0	54	0	14	1	1653
Cricotopus/Orthocladius*	0	0	0	50	0	1	0	4	0	1	1	0	0	0	0	0	4	0	61
Lopescladius Oliveira, 1967	19	25	0	0	28	0	1	2	40	2	0	1	1	1	6	4	10	7	147
Metriocnemus van der Wulp, 1874	0	0	3	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	5
Nanocladius Kieffer, 1912	0	0	0	0	6	0	1	1	2	0	0	8	0	0	0	0	0	2	20
Parametriocnemus Goetghebuer, 1932	2	0	5	2	2	1	2	4	0	0	1	0	0	0	0	0	10	2	31
Psectrocladius Holmgren, 1869	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Rheocricotopus Thienemann e Harnisch	0	9	0	0	0	1	0	1	0	0	0	1	22	0	0	1	0	0	35
Thienemanniella Kieffer, 1911	1	2	3	14	141	7	1	42	0	45	111	5	135	0	36	5	0	0	548
Tanypodinae																			
Ablabesmya Johannsen, 1905	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labrundinia Fittkau, 1962	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Larsia Fittkau, 1962	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Nilotanypus Kieffer, 1923	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	3	6
Pentaneura Philippi, 1865	3	2	41	1	32	13	6	3	7	3	3	5	39	2	1	1	0	0	162
Thienemannimyia Fittkau, 1957	0	0	0	0	0	0	0	2	0	0	0	0	4	0	1	0	0	0	7

*Genus not determined, identified as *Cricotopus/Orthocladius* due to similarity between the two taxa (Epler, 2001).
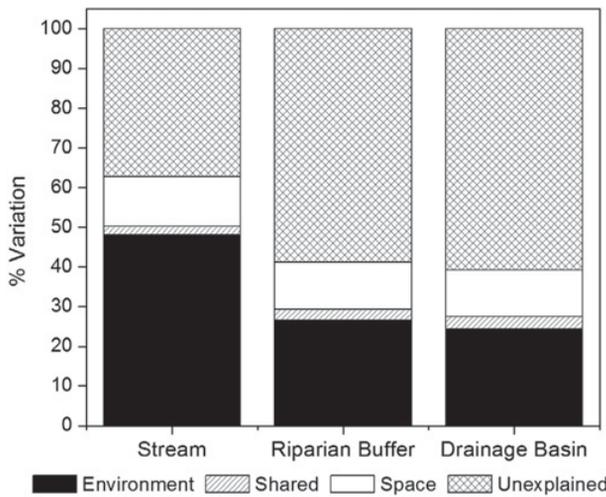
Fig. 2. Per cent of the total variance attributable to the environment, shared component (environment + space), space and unexplained components at stream (physical–chemical variables), riparian buffer and drainage basin scales.

have the greatest effect on the variation of community variables at large scales (Hepp *et al.*, 2012). The results of Lencioni *et al.* (2012) corroborate the results of the present study; furthermore, the distribution of Chironomidae is greatly influenced by environmental variables at a local scale, which are, in turn, influenced by variables at large scales (Lencioni *et al.*, 2012).

Agriculture contributes to diffuse pollution in aquatic environments, partly due to the changes caused by the removal of riparian vegetation (Kyriakeas and Watzin, 2006). This high percentage of default of a permanent preservation area is mainly a function of the slope: regions with gentler slopes have a higher percentage of agricultural land because such areas are easier to farm. The dependence between the characteristics of the drainage basin and the riparian buffer shows that both landscape scales are important and can be used as indicators of the effects of land use.

Recently, studies conducted in the region assessed the effects of changes in land use on aquatic invertebrate fauna. The results of these studies showed that the point sources of pollution (*e.g.,* urbanization) cause major changes in the abundance, richness and assemblage composition of benthic macroinvertebrates (Hepp *et al.*, 2010). However, when evaluating the effects of non-point sources (*e.g.,* agriculture and exposed soil), the effects are most evident with regard to changes in the composition of communities, which was observed in the present study when considering the composition of chironomid fauna (Hepp and Santos, 2009; Hepp and Restello, 2010).

The family Chironomidae proved to be an efficient bioindicator group for the effects of the landscape near streams because the land uses studied on different scales affected the distribution of this family. According to Sandin (2009), the benthic macroinvertebrate assemblage, including Chironomidae, is structured by environmental factors acting at different spatial scales, and the riparian
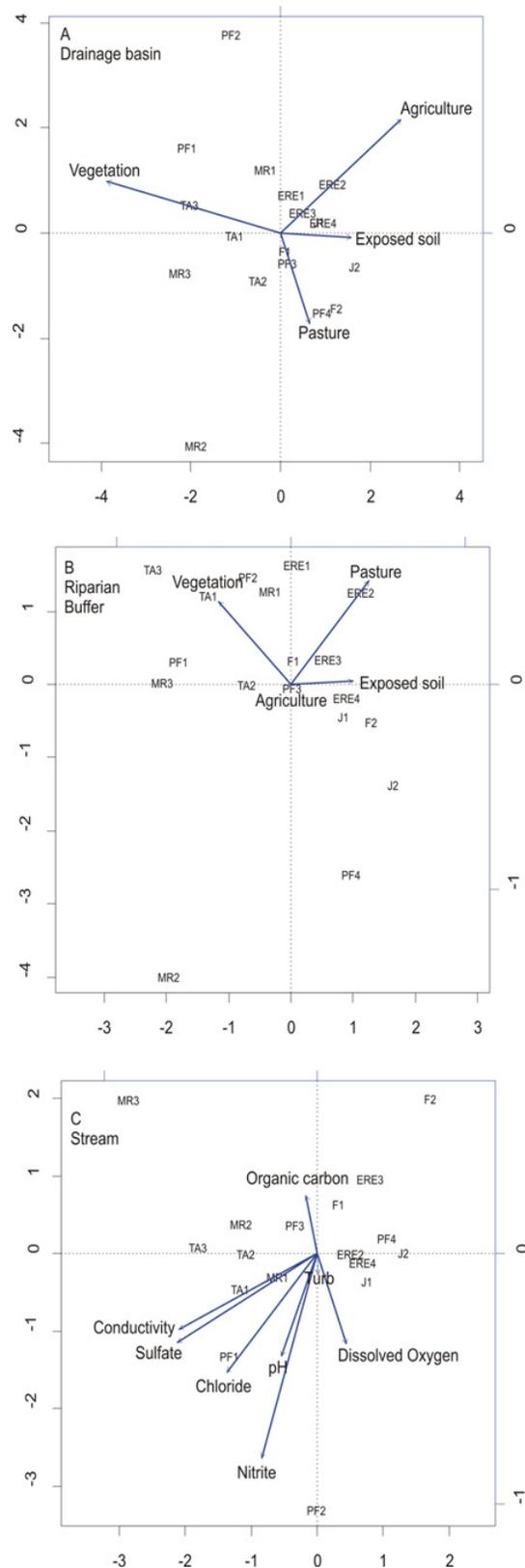
Fig. 3. Diagram biplot of the pCCA between the biological matrix and (a) landscape attribute drainage basin, (b) landscape attribute riparian area and (c) physical–chemical variables in streams.

vegetation and land use have a strong relationship with community composition, with both being related to the habitat.

The streams with higher percentages of vegetation generally showed a dominance of the genus *Lopescladius*, which tended to be related to the drainage basins with the largest degree of native vegetation. The presence of preserved riparian vegetation confers great stability and a more-structured fauna, with the presence of stenobiont or less pollution-tolerant groups, such as *Lopescladius* (Henriques-Oliveira *et al.*, 1999).

Thus, riparian vegetation can significantly influence invertebrate assemblage and proved to be decisive in the composition of aquatic fauna in the present study. Riparian vegetation influences benthic organisms and is an important factor for the colonization of some taxa (Sponseller *et al.*, 2001). The vegetation provides substrate, influencing the composition of benthic macroinvertebrates, including chironomid assemblage (Benstead *et al.*, 2003).

Cricotopus was influenced by the occurrence of catastrophic percentages of agriculture, sites where the streams flowing through the exposed soil areas with no riparian vegetation receive more solar irradiation and, thus, have increased incidence of algal blooms. According to Pinder (1986), members of *Cricotopus* are tolerant to adverse conditions and may indicate disturbances in the environment. *Cricotopus* occur mainly in headwaters with little current flow, periphyton or macrophytes and their greater abundance in this study reflected the input of organic matter in the stream.

Thienemanniella and *Rheotanytarsus* were also positively correlated with agriculture and exposed soil. Members of *Thienemanniella* are shredders and collectors (Merritt and Cummins, 1996), and several studies have associated *Thienemanniella* with leaf substrates, in contrast to the present study, which found a negative correlation between this genus and vegetation (Armitage *et al.*, 1995; Henriques-Oliveira *et al.*, 2003). When analysing the benthic macrofauna of rivers under the influence of sugar-cane cultivation in southeastern Brazil, Corbi and Trivinho-Strixino (2008) found *Rheotanytarsus* in sites with comparatively better water quality. Conversely, some authors have stated that the reason for the high abundance of *Rheotanytarsus* is unclear but that there is a positive relationship with high levels of water pollution (Simião-Ferreira *et al.*, 2009). In general, the benthic fauna reflects water quality and land use (Resende *et al.*, 2010), and the removal of riparian vegetation strongly influences benthic assemblages (Benstead *et al.*, 2003). For Chironomidae in particular, Benstead and Pringle (2004) argued that the removal of local riparian vegetation adversely affects chironomid assemblage because of decreased food supply.

In conclusion, the variables at the local scale (stream) were responsible for a major change in the community. However, the landscape attributes at larger scales (drainage basin and riparian buffer) generated significant effects on Chironomidae fauna. We observed a strong relationship between the characteristics of the drainage basin and riparian buffer. Although some streams have an extensive drainage basin, the occurrence of vegetation in the drainage basin is important for maintaining stream quality. Only three genera comprised more than 75% of the total individuals sampled, and these genera were influenced by the negative characteristics of the drainage basins and riparian buffer (percentage of exposed soil and agriculture). *Cricotopus* proved to be a good indicator of agricultural conditions, whereas *Thienemanniella* and *Rheotanytarsus* reflected the presence of exposed soil. In contrast, the more-sensitive genus *Lopescladius* was positively correlated with the presence of vegetation on both of the large scales studied (drainage basin and riparian buffer). Vegetation in the drainage area of a stream is important when the watershed is heavily degraded. In these cases, riparian vegetation alone is not sufficient to maintain the environmental quality of the streams.

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