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Distribution of benthic communities in relation to the environmental integrity of subtropical streams

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Abstract. The benthic macroinvertebrate community structure is directly related to environmental factors such as water characteristics, habitat availability and substrate heterogeneity. This study had the purpose of characterizing the benthic macroinvertebrate community and compare its attributes in streams located inside (preserved area) and outside (altered area) the Iguaçu National Park, in the west of Parana, Brazil, in two season (dry and rainy). Three replicates per site were obtained through the Surber collector in four microhabitats (litter pool, litter riffle, substrate pool and substrate riffle). There was significant discrimination in the benthic fauna composition among the study areas (Wilks=0.091; $F_{272,746}$= 2.249; P<0.0001). The taxa Corbiculidae, Hyalellidae and Trichodactylidae characterized the Macuco Stream; Talitridae, Libellulidae and Naucoridae characterized Poço Preto and Dourado stream; Oligoneuridae, Leptoceridae and Hydropsychidae characterized Apepu stream, and Tubificidae, Corduliidae and Elmidae were grouped in Tamanduá stream. Significant differences were observed in the mean density and richness (P<0.05) among the streams from both preserved and altered areas, with the highest richness recorded in the preserved area and litter pool microhabitat. The RDA Analysis separated the streams and organisms according to the environmental variables. The attribute differences were related to the preservation conditions of the riparian forest, whose presence in the preserved streams provided greater diversity of habitats and contributed to the presence of organisms on the substrate. On the other hand, several of impacts attributed to the agrochemical contaminants, soil disturbation and degradation of the riparian vegetation may be considered as factors which contributed to the differences among the analyzed streams.

[Keywords: aquatic macroinvertebrates, Iguaçu National Park, agricultural impact, riparian vegetation, habitat heterogeneity]

Resumen. Distribución de comunidades bentónicas en relación a la integridad ambiental de arroyos subtropicales. La estructura de la comunidad de macroinvertebrados bentónicos está directamente relacionada con factores ambientales tales como las características del agua, la disponibilidad de hábitats y la diversidad de sustratos. El objetivo de este estudio fue caracterizar la comunidad de macroinvertebrados bentónicos y comparar los atributos de esta comunidad en los arroyos internos (zona preservada) y externos (zona alterada) del Parque Nacional Iguazú, al oeste de Paraná, Brasil, en dos períodos estacionales (seco y húmedo). Se tomaron tres repeticiones por sitio, con colector Surber, en cuatro microhábitats (hojas en remanso, hojas en la corriente, sedimentos en remanso y sedimentos en la corriente). Se encontró una discriminación significativa en la composición de la fauna bentónica entre las áreas de estudio (Wilks=0.091; $F_{272,746}$=2.249, P<0.0001). Las taxa Corbiculidae, Hyalellidae y Trichodactylidae caracterizaron al arroyo Macuco; Talitridae, Libellulidae y Naucoridae caracterizaron a los arroyos Poço Preto y Dourado; Oligoneuridae, Leptoceridae y Hydropsychidae caracterizaron al arroyo Apepu, y Tubificidae, Corduliidae y Elmidae caracterizaron al arroyo Tamanduá. Se observaron diferencias significativas (P<0.05) en la densidad media y la riqueza, y entre los arroyos de las dos regiones (externas e internas). La mayor riqueza se registró en la zona preservada y en microhábitats de hojas en remanso. El análisis RDA separó los arroyos preservados e impactados y los organismos, de acuerdo con las variables ambientales. Las diferencias estuvieron relacionadas con las condiciones de conservación del bosque ripario, cuya presencia en los arroyos conservados proporcionó una mayor diversidad de hábitats; esto contribuyó al patrón de distribución de los organismos sobre el sustrato. Por otro lado, se puede citar una cantidad de impactos atribuidos a los contaminantes agroquímicos, al suelo alterado y a la degradación de la vegetación ribereña como factores que contribuyeron a las diferencias entre los arroyos analizados.

[Palabras clave: macroinvertebrados acuáticos, Parque Nacional de Iguazú, impacto agrícola, vegetación riparia, heterogeneidad del hábitat]

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INTRODUCTION

The impacts on freshwater ecosystems due to human activity (Ferreira et al. 2011) and inappropriate land use (Hepp and Santos 2009) are the most responsible aspects for the constant changes in aquatic ecosystems and water quality. The conversion of forests into farming areas and the ensuing removal of riparian vegetation alter water resources, causing impacts and losses in aquatic communities (Ledger et al. 2012; Mintenbeck et al. 2012).

The benthic macroinvertebrate community is a very heterogeneous group which lives associated with the aquatic ecosystems substrate (Mugnai et al. 2010). The distribution and diversity of these organisms in lotic environments are directly modified by the hydrological regime and habitat conditions (Ligeiro et al. 2013) such as food availability, substrate type, presence and extent of riparian forest (Ward et al. 1994; Galdean et al. 2000).

Headwater regions are strongly influenced by the presence of riparian vegetation and consequent input of allochthonous organic material (Vannote et al. 1980). The presence of this material contributes to different microhabitats availability (Hirabayashi and Wotton 1998; Allan and Castillo 2007), whose heterogeneity promotes occupation of the aquatic environment by different invertebrate species as well as shelter and food (Silveira 2004).

Thus, the integrated analysis of benthic invertebrates and chemical and physical variables can provide efficient assessment of habitat conditions in the aquatic ecosystems' quality and integrity (Yung-Chul et al. 2011). Furthermore, according to the invertebrate sensitivity, which is influenced by each group's physiology and habitat preference (Goulart et al. 2003), the prevalence and distribution of some organisms may suggest the magnitude of environmental impact in the aquatic environment and water quality conditions (Rosenberg and Resh 1993; Dolédec et al. 2011).

Therefore, the aim of this study was to characterize the benthic community structure through the richness and evenness, and to compare these attributes between preserved and agricultural impacted streams, in the hydrological regime of rain and drought, and among microhabitats. It has been hypothesized that: 1) in altered environments, there is a higher density and dominance of resistant taxa to anthropogenic changes; 2) in microhabitats constituted by litter pools, higher density values are expected, compared to regions with sediment deposition; 3) in the areas constituted by litter pool, elevated richness and low evenness of organisms might be noticed when comparing to other sampled microhabitats.

MATERIALS AND METHODS

Study area

The study was conducted in six streams, 1st and 2nd order (Strahler 1952), three of them distributed among the inner boundaries of the Iguaçu National Park (Macuco, 1 and 2 Poço Preto streams), and the other three within adjacent areas to the Conservation Unit (CU), exposed to anthropogenic interference (Tamanduá, Apepu and Dourado streams) (Figure 1). Water bodies cross entirely or partially through the boundaries of this CU and are considered as a reference in the structure of local aquatic ecosystems because there is a biodiversity hotspot (Rylands and Bradown 2005).

The Iguaçu National Park, located in western Paraná (25°05′ to 25°41′ S and 53°40′ to 54°38′ W) is the largest remaining contiguous areas and preserves Atlantic Forest of interior, in southern Brazil. In the surrounding areas of this CU occurs an extensive use of the land for agricultural activities. The climate in Foz do Iguaçu is humid subtropical, considered of great rainfall, with frequent rains distributed throughout the months. Increased precipitation is historically recorded for the month of October, while periods of lower intensity rainfall are recorded for July and August (IBAMA 1999).

Data collection

Samples were taken in February (rainy period) and August (dry period) of 2010. Two sampling sites for each stream have been selected taking spacial variability into account. At each point, three sediment samples were collected with the Surber collector (0.04 m^2 and 200 μm of mesh size) in four different microhabitats for biological analysis: litter pool (LP, deposit of leaves at sites with little or no flow, near banks), litter riffle (LR, deposit of leaves retained in areas with rapids), substrate pool (SP, deposit of sediments at sites with little or no flow, near banks) and substrate riffle (SR, sediments and material attached or deposited

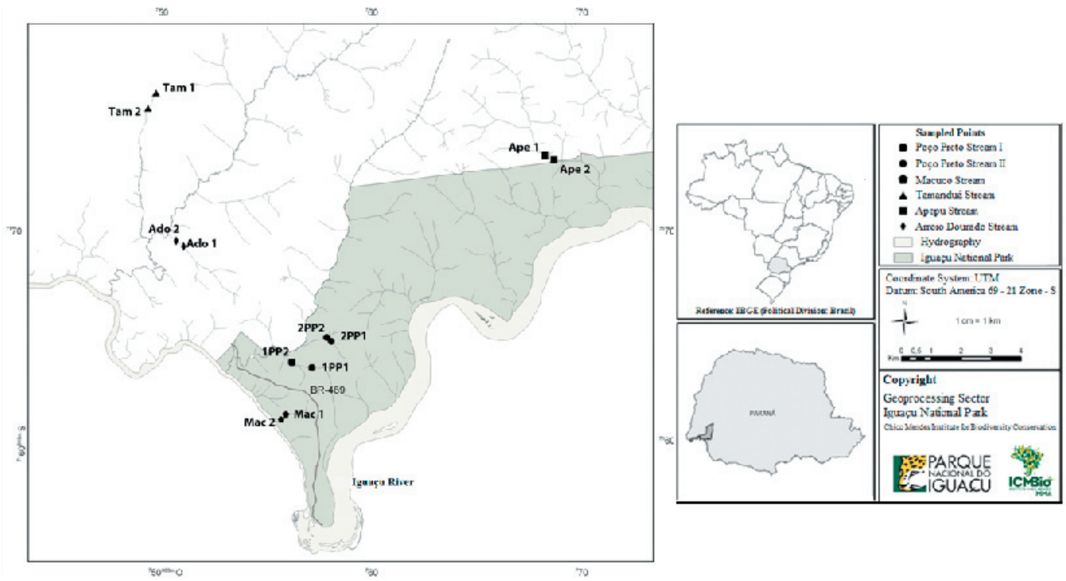

Figure 1. Location of sampling points of internal and external streams to the Iguaçu National Park. MAC1 and MAC2: 1 and 2 points from Macuco stream; 1PP1 and 1PP2: 1 and 2 points from the first stream of Poço Preto; 2PP1 and 2PP2: 1 and 2 points from the second stream of Poço Preto; TAM1 and TAM2: 1 and 2 points from Tamanduá; APE1 and APE2: 1 and 2 points from Apepu; ADO1 and ADO 2: 1 and 2 points from Dourado.

Figura 1. Localización de los puntos de muestreo de los arroyos internos y externos al Parque Nacional Iguazú. MAC1 y MAC2: sitios 1 y 2 en el arroyo Macuco; 1PP1 y 1PP2: sitios 1 y 2 a partir del primer arroyo de Poço Preto; 2PP1 y 2PP2: sitios 1 y 2 a partir del segundo arroyo de Poço Preto; TAM1 y TAM2: 1 y 2 puntos del arroyo Tamanduá; APE1 y APE2: 1 y 2 puntos de arroyo Apepu; ADO1 y ADO 2: 1 y 2 puntos del arroyo Dourado.

on rocks located in areas with rapids). An additional sediment sample were collected for particle size analysis, representing 13 samples per point, and 26 samples per stream sample period.

At each point, physical and chemical variables were measured for environmental characterization: water temperature (°C), electrical conductivity (µS/cm), width (m), depth (m) and flow (m/s), dissolved oxygen (mg/L) and pH. For biological analysis the substrate was rinsed in running water in a set of sieves of different mesh size (2.0, 1.0 and 0.2 mm) and preserved in 70% ethanol for later screening at a stereoscopic microscope. Aquatic invertebrates were identified to the family level with dichotomic keys (Maccfferty 1981; Pérez 1988; Lopretto and Tell 1995; Merritt and Cummins 1996; Wiggins 1996; Nieser and De Melo 1997; Costa et al. 2004; Mugnai et al. 2010).

Statistical analysis

Community attributes were analyzed according to the individuals found per square meter (density), by dividing the number of collected individuals by the Surber sampler area (0.04 m^2). In order to characterize temporal and spatial variations of the community, data were converted into logarithm (log10(x+1)), and the following metrics were considered: taxonomic richness (S), evenness (E) (Pielou 1975), using the PC-ORD 5.0 program (Maccune and Mefford 2002). Differences among community attributes regarding streams, microhabitats and temporal variables were tested through non-parametric variance analysis (Kruskal-Wallis) with Dunn 5% post-test using the program STATISTICA 7.1® (Statsoft Inc. 2005).

To compare the data of taxa abundance between the studied streams, a linear discriminant analysis (LDA) was performed, which is a method used to find a linear combination of features which characterizes objects or events categories (McLachlan 2004). We used all taxa for the LDA; the Wilks method was used to select the predictor variables using the stepwise selection method. Multivariate normality was tested by the Mardia test and homoscedasticity by the Bartlett test before the LDA. The significance of the vectors was analyzed by the Wilks Lambda method, considered as an input criterion for variables with $P<0.05$ (Hair et al. 2009).

The environment-species relationship was tested using redundancy analyses (RDA) with Hellinger transformation to the abiotic data matrix and the standardized environmental variables (root square). The global significance of the RDA axes was analyzed by a permutation test (Legendre and Legendre 2012). RDAs were developed with R software version 3.2.5 (2016-04-14) (R Core Team 2016) using the VEGAN package (Oksanen et al. 2011).

RESULTS

The physical and chemical metrics were measured in each sampling period, as shown in Table 1. For streams Apepu and Dourado (external streams), lower values were recorded for dissolved oxygen in the rainy season (February). However, for the preserved streams, low values of dissolved oxygen during the rain period were observed, probably due to variations caused by higher water volume in this month.

A total of 13313 benthic macroinvertebrates were collected and distributed in three phyla (Anellida, Mollusca, Arthropoda), 13 orders and 56 families. In all streams, we usually found the Nematoda, Mollusca, Annelida, Platyhelminthes and Arthropoda groups. The latter phylum represented 82.34% of all the organisms listed, and the most representative class was Insecta, consisting of 10 orders and 48 families.

Significant differences of the centroids between taxa abundance in the six studied environments were identified (Pillai and Wilks Method; $P<0.05$), mainly due to the taxa Corbiculidae, Hyalellidae, Trichodactylidae, Hydrophilidae, Ceratopogonidae, Talitridae, Perlidae, Leptohyphidae, Caenidae, Hydroptilidae, Calopterigidae, Libelullidae, Naucoridae, Chironomidae, Ephydridae, Simulidae, Oligoneuridae, Leptoceridae, Hidropsychidae, Gomphidae, Dytiscidae, Tubificidae, Corduliidae, Elmidae, Helotrephidae, Stratiomidae and Dryopidae.

We found a significant discrimination between the study areas (Wilks=0.11; $F_{120,1130}=5.19$; $P<0.0001$) (Table 2). The eigenvalue of the first component was 1.237, explaining 42.1% of the variability between the environments, represented by Macuco stream, which has had as discriminant taxa Corbiculidae, Hyalellidae, Trichodactylidae, Hydrophilidae and Ceratopogonidae. The second component showed an eigenvalue value of 0.811 and explained 27.6% of the variability. This component represented Dourado and Poço Preto streams, with the highest abundance of the taxa Talitridae, Perlidae, Leptohyphidae, Caenidae, Hydroptilidae, Calopterigidae, Libelullidae, Naucoridae, Chironomidae, Ephydridae and Simuliidae. The third component presented an eigenvalue of 0.450 and explained 15.3% of the variability, represented by Apepu stream, and with Oligoneuridae, Leptoceridae, Hidropsychidae, Gomphidae and Dytiscidae as abundant taxa. The fourth component showed an eigenvalue of 0.347, explained 11.9% of the data variability and was represented by Tamanduá stream, highlighting Tubificidae, Corduliidae, Elmidae, Helotrephidae, Stratiomidae and Dryopidae (Table 3).

Higher densities of organisms were recorded for microhabitats with litter pool at the external streams (Table 4). In these streams, Ostracoda and Chironomidae were observed in higher density in microhabitats of litter pool and Elmidae in litter riffle microhabitats. Moreover, higher abundances in preserved streams were recorded for Hydroptilidae and Corduliidae in microhabitat of litter riffle and Hyalellidae in substrate pool (Table 4).

Table 1. Mean of physical and chemical parameters measured in each stream during the rainy (February) and dry (August) periods. MAC: Macuco stream; 1PP: first stream from Poço Preto; 2PP: second stream from Poço Preto; TAM: Tamanduá; APE: Apepu; ADO: Dourado.

Tabla 1. Media de los parámetros físicos y químicos medidos en cada arroyo durante los períodos lluvioso (febrero) y seco (agosto). MAC: arroyo Macuco; 1PP: primer arroyo de Poço Preto; 2PP: segundo arroyo de Poço Preto; TAM: Tamanduá; APE: Apepu; ADO: Dourado

Stream	Dissolved oxygen (mg/L)		Medium width (m)		Depth (m)		Temperature (°C)		Conductivity (µm/s)	
	Rain	Dry	Rain	Dry	Rain	Dry	Rain	Dry	Rain	Dry
MAC	6.29	8.28	3.55	2.70	0.09	0.10	25.15	19.58	25.15	19.58
1 PP	5.74	9.36	2.75	3.00	0.10	0.10	21.43	21.25	22.40	15.60
2 PP	5.55	8.43	2.59	2.80	0.14	0.09	19.58	22.40	23.75	18.37
TAM	6.16	8.85	2.65	2.60	0.16	0.13	21.25	19.35	23.15	12.03
APE	4.87	9.10	4.13	4.08	0.26	0.31	22.40	15.60	24.55	14.92
ADO	4.23	10.12	2.85	3.55	0.20	0.54	19.35	19.80	27.75	10.87

Table 2. Factor loadings of the main components of the discriminant analysis.

Tabla 2. Factor de cargas de los componentes principales del análisis discriminante.

	F1	F2	F3	F4
Macuco	2.528	-0.527	0.206	-0.049
Poço Preto 1	-0.176	1.183	0.199	0.146
Poço Preto 2	-0.145	1.047	0.201	0.114
Tamanduá	-0.885	-0.582	0.335	-1.364
Apepu	-0.330	-0.363	-1.805	0.166
Dourado	-1.035	-1.205	0.715	1.017

Table 3. Standard coefficients of canonical discriminant functions. P-value of unidimensional test of equal class means (considering the Bonferroni correction factor).

Tabla 3. Coeficientes estándar de las funciones discriminantes canónicas. Valor de P de la prueba unidimensional de medias de igual clase (considerando el factor de corrección de Bonferroni).

	F1	F2	F3	F4	*P*
Corbiculidae	0.482	-0.027	0.242	0.069	<0.0001
Tubificidae	-0.145	0.183	0.174	-0.232	0.047
Hyalellidae	0.446	-0.107	0.142	-0.043	<0.0001
Talitridae	0.331	-0.547	0.014	-0.105	<0.0001
Trichodactylidae	0.258	-0.111	0.030	0.062	0.018
Perlidae	0.215	0.476	0.082	-0.165	0.004
Leptohyphidae	-0.053	0.391	-0.077	0.141	0.014
Oligoneuridae	-0.130	0.098	-0.387	0.035	0.022
Caenidae	-0.018	0.641	0.177	0.005	0.046
Leptoceridae	-0.056	0.076	0.225	0.143	0.045
Hydroptilidae	-0.066	0.245	0.086	-0.137	0.023
Hidropsychidae	-0.267	-0.259	0.372	0.221	0.001
Gomphidae	0.093	0.001	-0.482	0.053	0.000
Calopterigidae	0.042	-0.322	-0.058	0.168	0.006
Libelullidae	0.048	0.179	0.166	0.019	0.020
Corduliidae	-0.124	0.092	0.022	0.382	0.012
Elmidae	-0.218	-0.193	-0.288	0.829	0.001
Dytiscidae	0.187	0.084	0.191	-0.001	0.002
Hydrophilidae	0.370	0.088	0.150	-0.022	0.002
Helotrephidae	-0.109	-0.064	0.026	-0.292	<0.0001
Naucoridae	-0.094	0.361	-0.076	0.040	0.038
Ceratopogonidae	0.248	0.126	-0.039	0.065	0.000
Chironomidae	-0.248	-0.461	0.174	-0.201	<0.0001
Empididae	0.468	0.703	0.039	-0.517	0.038
Simuliidae	-0.234	-0.601	0.085	0.196	0.027
Stratiomyidae	0.088	0.064	0.063	0.292	0.002
Dryopidae	-0.232	-0.235	0.245	0.495	0.011

Among the six streams, the highest average density values of benthic invertebrates were recorded in the Dourado stream (H=11.88, *P*=0.04) (Figure 2a). The highest number of density was observed in microhabitats of litter riffle (H=19.61, *P*<0.01) (Figure 2b). Considering the temporal variables, higher median values were recorded in the dry season (H=16.28, *P*<0.01) (Figure 2c). In the Dourado stream, Simulidae (2.204 individuals/m²), Chironomidae (1.913 individuals/m²) and Elmidae (1.683 individuals/m²) were the most abundant taxa.

Higher values of richness were found in preserved streams, Macuco and Poço Preto (H=44.82, *P*<0.01) (Figure 2d), even in the dry season (H=6.80, *P*<0.01) (Figure 2f). Macuco stream presented a taxonomic richness of 42 taxa, and Poço Preto 1 and 2, 34 and 35 taxa, respectively (Figure 2d). Higher evenness values were found in preserved streams (H=13.03, *P*=0.02) (Figure 2g) and in the rainy season (H=9.29, *P*=0.01) (Figure 2i), especially in Poço Preto 2 (Figure 2g) and microhabitats composed by substrate riffle (H=7.85, *P*=0.04) (Figure 2h).

Regarding the RDA analysis, the dissolved oxygen, flow, water temperature and sediment were the most important variables to describe the gradients of the benthic communities, between the impacted and preserved streams (Figure 3). The coarse sediment type (i.e., pebble, granule, very coarse sand, medium sand) was important to characterize the preserved environments, while the fine sediments characterized most of the points in the impacted streams. The flow was important to the Corduliidae family, and the fine sediment, to the Chironomidae (both with a positive correlation). On the other hand, the dissolved oxygen was negatively correlated with Elmidae, and fine sediment with the Corbiculidae taxa (Figure 3).

Table 4. Rank of values of average density (individuals/m²) of the dominant benthic macroinvertebrates found in different microhabitats. SP: substrate pool; SR: substrate riffle; LP: litter pool; LR: litter riffle. Density: *=0-100; **=100-500; ***=500-1000; ****=above 1000.

Tabla 4. Rank de valores promedio (individuos/m²) de los macroinvertebrados bentónicos dominantes que se encuentran en diferentes microhábitats. SP: sustrato en remanso; SR: sustrato en corriente; LP: hojarasca en remanso; LR: hojarasca en corriente. Densidad: *=0-100; **=100-500; ***=500-1000; ****=superior a 1000.

Stream	Habitat	Ostracoda	Hyalellidae	Hydroptilidae	Corduliidae	Elmidae	Chironomidae
Preserved	SP	***	***	*	**	**	*
Altered	SP	***	*	*	*	***	***
Preserved	SR	*	*	**	**	**	*
Altered	SR	*	*	*	**	**	***
Preserved	LP	**	**	*	**	***	*
Altered	LP	****	*	*	**	****	****
Preserved	LR	**	*	***	**	***	*
Altered	LR	*	*	**	**	****	****

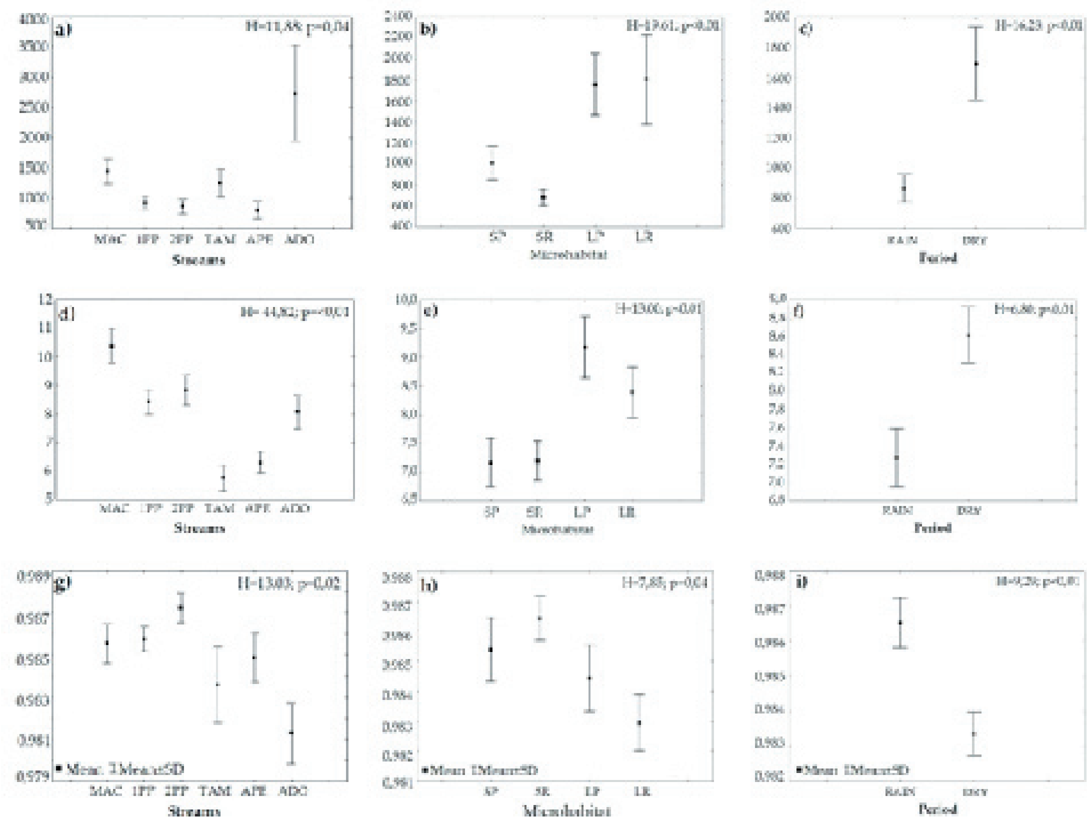

Figure 2. Density (a, b, c), taxa richness (d, e, f) and evenness (g, h, i) of the community of aquatic invertebrates sampled in streams, microhabitat and period of collection. MAC: Macuco; 1PP: first stream from Poço Preto; 2PP: second stream from Poço Preto; TAM: Tamanduá; APE: Apepu; ADO: Dourado.

Figura 2. Densidad (a, b, c), riqueza de taxones (d, e, f) y equitatividad (g, h, i) de la comunidad de invertebrados acuáticos muestreada en los arroyos, microhábitat y período de colecta. MAC: Macuco; 1PP: arroyo 1 del Poço Preto; 2PP: arroyo 2 del Poço Preto; TAM: arroyo Tamanduá; APE: arroyo Apepu; ADO: arroyo Dourado.

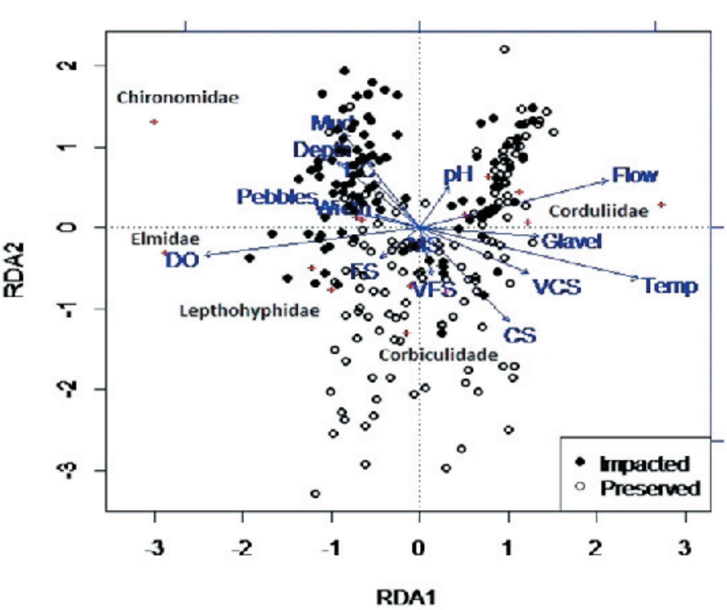

Figure 3. Biplot species-environment of the redundancy analysis for the collection points sampled in the impacted and preserved streams. De: average depth; Do: dissolved oxygen; Ec: electrical conductivity; pH: hydrogen potential; Temp: water temperature; CS: coarse sand; VCS: very coarse sand; VFS: very fine sand; FS: fine sand; MS: medium sand; PEB: pebble; MUD: mud; WID: width; FLO: flow.

Figura 3. Biplot especies-ambiente del análisis de redundancia de los puntos de colección de muestras en los ríos impactados y conservados. De: profundidad media; Do: oxígeno disuelto; Ec: conductividad eléctrica; pH: potencial de hidrógeno; Temp: temperatura del agua; CS: arena gruesa; VCS: arena muy gruesa; VFS: arena muy fina; FS: arena fina; MS: arena media; PEB: guijarro; MUD: barro; WID: ancho; FLO: corriente.

Discussion

Our results indicate some differences between the preserved and altered streams, both regarding the biological community and the physical and chemical variable of the water and sediment. The highest abundance of the family Chironomidae in altered streams were due to the fact that these streams are placed in areas of extensive land use, mostly for agricultural and livestock practices. In these environments, the riparian vegetation degradation has been contributing to the habitat diversity reduction and banks stability. As a result, these streams might become considerably vulnerable to erosion and amount of sediments and agricultural effluents, causing changes to the substrate and the physical and chemical characteristics of the water.

The dominance of Chironomidae in altered streams was associated to the recognized ecological diversity and taxonomy from this family (Harabach 2011; Trivinho-Strixino 2011). This may also be explained by these organisms' rapid growth (Jacobsen and Encalada 1998), combined with a great competitive capacity (Nessimian 1995), allowing them to colonize different habitats because of their wide physiological adaptability (Courtney and Merritt 2008).

Although Chironomidae was dominant in altered environments, its occurrence was observed in preserved environments, as well. In these sites, the presence of vegetation cover provided a greater stability in terms of flow (Suarino and Gessner 2004) and habitat heterogeneity (Kon and Korukura 2011). Such characteristics may have contributed to the greater variability of genera occurrence of this family, with diverse ecological requirements and wide distribution (Amorim et al. 2004; Brown 2007). However, in the altered streams, the chironomid assembly composition has probably consisted of a few tolerant genera distributed in large densities, as evidenced by Gurski et al. (2014) in a study conducted in the same streams, which may have collaborated on the pattern of abundance observed in the present study.

On the other hand, some studies pointed out the dominance of Hydroptilidae and the presence of some Ephemeroptera, Plecoptera and Trichoptera (EPT) families as indicators of preserved environment. Scientific literature considers it as an important tool in the evaluation of water quality because this group of organisms is an indicator of environmental integrity in stream ecosystems (Moreno et al. 2009; Manko et al. 2012). The presence of this taxa in the internal streams UC was probably favored by the presence of preserved riparian vegetation and environmental geomorphological features. This allowed the contrast of areas of pool and rifle, enabling a greater diversity of organisms with distinct morphology, physiological and biological needs (Moretto et al. 2012).

The distribution of Hydroptilidae (Trichoptera) was higher in the rainy season, which was probably influenced by the flow boost in streams, which has risen the dissolved oxygen concentrations due to greater aeration of the water column (Palhares et al. 2007). According to Callisto et al. (2001), Trichoptera is commonly associated with clean, well oxygenated and oligotrophic water. However, studies have shown that some families may be found in altered areas designed to agricultural practices (Arias et al. 2007; Konig et al. 2008); it is the case of Hydroptilidae family, whose presence was recorded for preserved and altered streams.

The results in this study point out meaningful differences between the communities of benthic macroinvertebrates and environmental variables in preserved and altered areas. The differences have been related to the atypical rainfall pattern in 2010 in western Paraná, during the winter season. The wide distribution of opportunistic fauna like Chironomidae, Simuliidae and Elmidae was possibly favored by frequent rains, not expected in August. The rainfall increase in the region was responsible of increasing streams average depth and width, as well as a greater sludge dump in the winter season. The increase of these variables and the loading of allochthonous material into the sediment streams provided greater habitats availability and a high number of organisms colonizing the substrate bodies (Callisto et al. 2001).

Density differences of the taxa, considered abundant and frequent regarding the environmental variables, among the streams analyzed were well represented in the plot of the RDA analysis. The results show, in general, a spatial separation between the preserved and impacted streams. Higher values of flow and water temperature were found in collections during the rainy season and also with fine sediments. The taxa Hyalellidae, Hydroptilidae, Tipulidae and Corbiculidae were the most abundant taxa. Such values are typical of the summer season, when there's plenty of rainfall in the region. With these analyses, we have also verified that the different sediment types were important to assort some taxa, as Chironomidae and Leptohyphidae (fine sand), and dissolved oxygen (Elmidae).

According to our hypothesis, the greatest richness would reflect the highest degree of environmental integrity in protected areas, as Iguaçu National Park. In addition to the presence of integrated riparian vegetation, these sites suffer less pressure from anthropic activities and their substance presence, such as contaminants and agrochemicals (which contribute to a higher incidence of sensitive taxa). Ruaro et al. (2016) tested which metrics are better to distinguish impacted and preserved environments using macroinvertebrates and fish. The authors found that some attributes of the macroinvertebrate community were more effective than fish in distinguishing these kinds of environments. Moreover, a large taxonomic diversity and the presence of indicator organisms, such as insects belonging to EPT group, considered the most sensitive to aquatic environments changes, is expected in preserved streams (Rosenberg and Resh 1993; Roche et al. 2010).

The highest density and richness found during the dry season possibly occurred due to the higher habitats availability and stability, despite the amount of rainfall, unexpected for the season. In these conditions, microhabitats with litter deposited in pool have been more attractive to macroinvertebrates, and this preference might be attributed to the flow stability in this time, contributing to the benthic organism colonization and establishment (Baptista et al. 2001). Our second and third hypothesis were also accepted because litter pool microhabitats provided higher abundance, richness and evenness than others. In addition, allochthonous decaying material sedimentation offered shelter and food source for many species of several habits, thereby reinforcing their contribution to the increase in density and diversity of the benthic macroinvertebrates community (Gordon et al. 1992; Baptista et al. 2001; Kikuchi and Uieda 2005; Gonçalves-Júnior et al. 2014).

Furthermore, recent studies showed the importance of allochthonous organic matter to the nutrients cycle and metabolism maintenance and a series of ecological processes in aquatic ecosystems, besides housing a richer and more varied fauna (Tonello et al. 2014; Boyero et al. 2015), and regarding the autochthonous leaf material, especially used in building shelters and feeding (Saito et al. 2015). These findings confirm the results of this study about the microhabitats with litter deposition and riparian vegetation attached to streams.

It has been evident the riparian vegetation integrity was an important factor to the benthic community distribution, seeing that a higher richness was found in microhabitats with more organic material, if compared to others. On the other hand, a lot of impacts attributed to the presence of agrochemical contaminants, altered soil and degradation of the riparian vegetation can be mentioned as factors contributing to the differences among the analyzed streams. In this sense, environmental preservation areas decisively contribute to the integrity of aquatic ecosystems, allowing the maintenance of structural patterns and habitat heterogeneity, which reflect the increasing richness and taxonomic diversity of aquatic invertebrates.

The differences were due to the preservation conditions of the riparian forest, whose presence in the preserved streams provided greater habitat diversity and contributed to the organisms' distribution pattern on the substrate. On the other hand, a lot of impacts were attributed to the agrochemical contaminants. Soil alteration and riparian vegetation degradation can be cited as factors that contributed to the differences among the analyzed streams.

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References

Addinsoft. 2016. XLStat Registered Version 2016.02.27913, data analysis and statistics with Microsoft Excel. New York.

Allan, J. D., and M. M. Castillo. 2007. Stream Ecology: Structure and Function of Running Waters. Springer: Dordrecht, The Netherlands.

Amorim, R. M., A. C. Henrique-Oliveira, and J. L. Nessimian. 2004. Distribuição espacial e temporal das larvas de Chironomidae (Insecta: Diptera) na sessão ritral do rio Cascatinha, Nova Friburgo, Rio de Janeiro, Brasil. Lundiana **5**:119-127.

Arias, A. R. L., D. F. Buss, C. Albuquerque, A. F. Inácio, M. M. Freire, M. Egler, R. Mugnai, and D. F. Baptista. 2007. Utilização de bioindicadores na avaliação de impacto e no monitoramento da contaminação de rios e córregos por agrotóxicos. Ciênc Saúde Colet **12**:61-72.

Baptista, D. F., D. F. Buss, L. F. M. Dorvillé, and J. L. Nessimian. 2001. Diversity and habitat preference of aquatic insects along the longitudinal gradient of the Macaé river basin, Rio de Janeiro, Brazil. Rev Bras Biol **61**:249-258.

Boyero, L., R. G. Pearson, M. O. Gessner, D. Dudgeon, A. Ramírez, C. M. Yule, M. Callisto, C. M. Pringle, A. C. Encalada, M. Arunachalam, J. Mathooko, J. R. Helson, J. Rincón, A. Bruder, A. Cornejo, A. S. Flecker, C. Mathuriau, C. M'erimba, J. F. Gonçalves Jr; M. Moretti, and T Jinggut. 2015. Leaf-litter breakdown in tropical streams: is variability the norm? Freshwater Science **34**(2):759-769.

Brown, B. L. 2007. Habitat heterogeneity and disturbance influence patterns of community temporal variability in a small temperate stream. Hydrobiologia **586**:93-106.

Callisto, M., M. Moretti, and M. Goulart. 2001.Macroinvertebrados bentônicos como ferramenta para avaliar a saúde de riachos. Rev Bras Recur Hídr **6**:71-82.
Costa, J. M., L. O. I. Souza, and B. B. Oldrini. 2004. Chave para identificação das famílias e gêneros das larvas conhecidas de Odonata do Brasil: comentários e registros bibliográficos (Insecta, Odonata). Publ Avul Mus Nac **99**:3-42.

Courtney, G. W., and R. W. Merrit. 2008. Aquatic Diptera. Part one. Larvae of aquatic Diptera. Pp, 687-722 *in* Merrit, R. W., K. W. Cummins and M. B. Berg (eds.). An Introduction to the Aquatic Insects of North America. 4ª ed. Kendall/ Hunt Publishing Co. Dubuque, Iowa.

Dolédec, S., N. Phillips, and C. Townsend. 2011. Invertebrate community responses to land use at a broad special scale: trait and taxonomic measures compared in New Zealand rivers. Freshw Biol **56**:1670-1688.

Ferreira, W. R., L. T. Paiva, and M. Callisto. 2011.Development of a benthic multimetric index for biomonitoring of a neotropical watershed. Braz J Biol **71**:15-25.

Galdean, N., M. Callisto, and F. A. R. Barbosa. 2000. Lotic Ecosystems of Serra do Cipó, southeast Brazil: water quality and a tentative classification based on the benthic macroinvertebrate community. Aquat Ecosys Health Manage **3**: 545-552.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream Hydrology: An Introduction for Ecologists. Wiley and Sons, Chichester, England.

Gonçalves-Júnior, J. F., R. T. Martins, B. M. P. Ottoni, and S. R. M. Couceiro. 2014. Uma visão sobre a decomposição foliar em sistemas aquáticos brasileiros. Pp. 89-116 *in* N. Hamada, J. L. Nessimian and R. B. Querino (eds.). Insetos aquáticos na Amazônia brasileira: taxonomia, biologia e ecologia Manaus. Editora do INPA.

Gonçalves-Júnior, M. Moretti, and T. Jinggut. 2015. Leaf-litter breakdown in tropical streams: is variability the norm. Freshw Sci **34**:759-769.

Goulart, M. D., and M. Callisto. 2003.Bioindicadores de qualidade de água como ferramenta em estudos de impacto ambiental. Revista FAPAM **2**:78-85.

Gurski, F. A., G. D. Pinha, Y. Moretto, A. M. Takeda, and N. C. Bueno. 2014. Effect of habitat heterogeneity in the composition and distribution of Chironomidae (Diptera) assemblage in different microhabitats of preserved streams in the Brazilian Atlantic Forest. Acta Limnol Bras **26**:163-175.

Hair Jr., J. F., W. C. Black, B. J. Babin, R. E. Anderson, R. L. Tathan, et al. 2009. Análise multivariada de dados. 6. ed. Porto Alegre: Bookman. Pp. 688.

Harabach, R. E. 2011. Mosquito Taxonomic Inventory. URL: mosquitotaxonomic-inventory.info/family-culicidae-meigen-1818 Acesso em: 19 dez. 2013.

Hepp, L. U., and S. Santos. 2009. Benthic communities of streams related to different land uses in a hydrographic basin in southern Brazil. Environ Monit Assess **15**:305-318.

Hirabayashi, K., and S. R. Wotton. 1998. Organic matter processing by chironomid larvae (Diptera: Chironomidae). Hydrobiologia **382**:151-159.

IBAMA, Instituto Brasileiro do Meio Ambiente. 1999. Plano de Manejo do Parque Nacional do Iguaçu: Encarte 6. Brasília. URL: www.ibama.gov.br/siucweb/listaUcCategoria.php?abrev=PARNA. Acesso em: 14 abr. 2016.

Jacobsen, D., and A. Encalada. 1998. The macroinvertebrate fauna of Ecuadorian highland streams in the wet and dry season. Archiv fur Hydrobiologie **142**:53-70.

Legendre, P., and L. Legendre. 2012. Numerical Ecology. 3rd English ed. Elsevier.

Kikuchi, R. M., and V. S. Uieda. 2005. Composição e distribuição dos macroinvertebrados em diferentes substratos de fundo em um riacho do município de Itatinga, São Paulo, Brasil. Entomología y Vectores **12**:193-231.

Kon, K., and H. Kurokura. 2011. Influence of a microhabitat on the structuring of the benthic macrofauna community in a mangrove forest. Hydrobiologia **617**:205-216.

Konig, R., C. R. H. Suzin, R. M. Restello, and L. U. Hepp. 2008. Qualidade das águas de riachos da região norte do Rio Grande do Sul (Brasil) através de variáveis físicas, químicas e biológicas. Panam J Aquat Sci **3**:84-93.

Ledger, M. E., R. M. L. Harris, P. D. Armitage, and A. M. Milner. 2012. Climate change impacts on community resilience: experimental evidence from a drought disturbance experiment. Adv Ecol Res **46**:211-258.

Ligeiro, R., R. M. Hughes, P. R. Kaufmann, D. R. Macedo, F. R. Firmiano, W. R. Ferreira, D. Oliveira, and M. Callisto. 2013. Defining quantitative stream disturbance gradients and the additive role of habitat variation to explain macroinvertebrate taxa richness. Ecol Indic **25**:45-57.

Lopretto, E. C., and G. Tell. 1995. Ecosistemas de Águas Continentales. Metodologías para su estudio. Tomo III, ediciones Sur. La Plata, Argentina.

Magurran, A. E. 1988. Ecological Diversity and its Measurement. First Edition. Chapman and Hall, London.

Manko, P., J. Kosko, L. Kosuthová, D. Barhbas, and J. Lescová. 2012. Aquatic invertebrates in Olsava river (Slovakia): what they tell us about the river catchment? Acta Oecol Carpat **V**:115-127.

Maccafferty, W. P. 1981.Aquatic entomology: The fishermen's and ecologist's illustrated guide to insects and their relatives. First Edition. Jones and Bartlett Learning. Boston, USA.

McCune, B., and M. J. Mefford. 2002. PC-ORD. Multivariate Analysis of Ecological Data, Version 5.0, Gleneden Beach, Oregon.

Merrit, R. W., and K. W. Cummins. 1996. An introduction to the aquatic insects of North America. Second edition. Kendall/Hunt Publishing Company, Dubuque, Iowa, USA.

McLachlan, G. J. 2004. Discriminant Analysis and Statistical Pattern Recognition. Wiley Interscience. ISBN 0-471-69115-1. MR 1190469.

Mintenbeck, K., E. R. Barrera-Oro, T. Brey, U. Jacob, R. Knust, F. C. Mark, E. Moreira, A. Strobel, and W. E. Arntz. 2012. Impact of Climate Change on Fishes in Complex Antarctic Ecosystems. Adv Ecol Res **46:**351-426.

Moreno, P., J. S. França, W. R. Ferreira, A. D. Paz, I. M. Monteiro, and M. Callisto. 2009. Use of the BEAST model for biomonitoring water quality in a neotropical basin. Hydrobiologia **630**:231-242.

Moretto, Y., R. L. Delariva, and J. Higuti. 2012. Macroinvertebrate community structure in a stream of the north-west region of Paraná State, Brazil. Biota Neotrop **12**:307-317.

Mugnai, R., J. L. Nessimian, and D. F. Baptista. 2010.Manual de Identificação de Macroinvertebrados Aquáticos do Estado do Rio de Janeiro. First Edition. Technical, Rio de Janeiro, Brasil.

Nessimian, J. L. 1995. Abundância e biomassa de macroinvertebrados de um brejo de dunas no litoral do Estado do Rio de Janeiro. Rev Bras Biol **55**:661-683.

Nieser, N., and A. L. Melo. 1997.Os heterópteros aquáticos de Minas Gerais. First Edition, UFMG, Belo Horizonte, Brasil.

Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'Hara, G. L. Simpson, R. Solymos, M. H. H. Stevens, and H. Wagner. 2011. VEGAN: Community Ecology Package. URL: cran.r-project.org.

Palhares, J. C. P., C. Ramos, J. B. Klein, J. M. M. Lima, S. Muller, and T. Cestonaro. 2007. Medição da Vazão em Rios pelo Método do Flutuador. Embrapa-Comunicado técnico**,** Concórdia (SC). URL: ainfo.cnptia.embrapa.br/digital/bitstream/item/58075/1/CusersPiazzonDocuments455.ppdf. Acesso em: 10. dez. 2013.

Pérez, G. R. 1988. Guía para el Estudio de los Macroinvertebrados Acuáticos del Departamento de Antioquia. First Edition. Editorial Presencia Ltda. Bogotá, Colombia.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: www.R-project.org.

Roche, K. F., E. P. Queiroz, K. O. Righi, and S. G. Mendes. 2010.Use of BMWP and ASPT indexes for monitoring environmental quality in a neotropical stream. Acta Limnol Bras **22**:105-108.

Rosenberg, D. M., and V. H. Resh. 1993.Freshwater biomonitoring and benthic macroinvertebrates. First Edition. Chapman and Hall, New York, USA.

Ruaro, R., E. A. Gubiani, A. M. Cunico, Y. Moretto, and P. A. Piana. 2016. Comparison of fish and macroinvertebrates as bioindicators of Neotropical streams. Environ Monit Assess **188**(1):45.

Rylands, A. B., and K. Brandon. 2005. Unidades de conservação brasileiras. Megadiversidade **1**(1):27-35.

Saito, V. S., T. Siqueira, and A. A. Fonseca-Gessner. 2015. Should phylogenetic and functional diversity metrics compose macroinvertebrate multimetric indices for stream biomonitoring? Hydrobiologia **745**:167-179.

Silveira, M. P. 2004. Aplicação do Biomonitoramento Para Avaliação da Qualidade da Água em Rios. Embrapa Meio Ambiente. Documento 36. Pp. 68. URL: www.cnpma.embrapa.br/download/documentos_36.pdf Acesso em: 12. ago. 2015.

STATSOFT Inc. 2005. Statistica (data analysis software system). Version 7.1. URL: www.statisoft.inc. Acesso em: 20 out. 2007.

Suarino, M. T., and A. A. Gessner. 2004. Chironomidae (Diptera) larvae in stream of Parque Estadual de Campos do Jordão, São Paulo State, Brasil. Acta Limnol Bras **16**:126-136.

Strahler, A. N. 1952. Hypsometric (area-altitude) - analysis of erosion al topography. Geological Society of America Bulletin **63**(10):1117-1142.

Trivinho-Strixino, S. 2011. Larvas de Chironomidae: Guia de identificação. Departamento Hidrobiologia/ Laboratório de Entomologia/ UFCAR, São Carlos, SP. v.1, 2, 3. Pp. 371.

Tonello, G., R. C. Loureiro, P. Krause, C. da Silva, M. R. Ongaratto, S. Sepp, R. M. Restello, and L. U. Hepp. 2014. Colonização de invertebrados durante a decomposição de diferentes detritos vegetais em um riacho subtropical. R bras Bioci **12**:98-105.

Vannote, R. L, G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980.The river concept. Can J Fish Aquat Sci **37**:130-137.

Ward, D., N. Holme, and P. José. 1994. The New Rivers and Wildlife Handbook. First Edition. RSPP, NRA, The Wildlife Trusts, Bedfordshire.

Wiggins, G. B. 1996. Larvae of the North American Caddisfly Genera (Trichoptera), Second edition. University of Toronto Press, Toronto, Canada.

Yung-Chul, J., K. Nan-Young, K. Soon-Jock, H. Sueng-Chul, and H. In-Chul. 2011.Effects of land use on benthic macroinvertebrates communities: Comparison of two mountain stream in Korea. Ann Limnol **47:**35-49.