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Effects of forest conversion on the assemblages' structure of aquatic insects in subtropical regions

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ABSTRACT

The effects of forest conversion to agricultural land uses on assemblages of aquatic insects were analyzed in subtropical streams. Organisms and environmental variables were collected in six low-order streams: three streams located in a forested area, and three in areas converted to agricultural land uses. We expected that the aquatic insects' assemblage attributes would be significantly affected by forest conversion, as well as by environmental variables. Streams in converted areas presented lower species richness, abundance and proportion of sensitive insect taxa. The ANOSIM test evidenced strong difference in EPT assemblage structure between streams of forested and converted areas. The ISA test evidenced several EPT genera with high specificity to streams in forested areas and only one genus related to streams in converted areas. Thus, the impacts of the conversion of forested area to agricultural land uses have significantly affected the EPT assemblages, while environmental variables were not affected. We suggest that the effects detected can be influenced by two processes related to vegetation cover: i) lower input of allochthonous material, and ii)increased input of fine sediments in streams draining converted areas.
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Introduction

The conversion of forested areas into agricultural landscapes causes impacts on aquatic ecosystems worldwide (Suga and Tanaka, 2013), especially on small streams, which are among the most threatened habitats due to the extent of agricultural land (Harding et al., 1998). Streams provide habitats for an array of species and have strong biological linkages with entire river systems (Meyer et al., 2007). Furthermore, they maintain a reciprocal connectivity between terrestrial and aquatic ecosystems (Nakano and Murakami, 2001). However, they are small in size and are very sensitive to deforestation and land conversion (Benstead et al., 2003; Kasangaki et al., 2008). The alteration of land cover may increase the rate of superficial runoff, as well as the amount of sediment inflow and nutrients (Kasangaki et al., 2008; Pringle and Benstead, 2001). The superficial runoff in deforested areas and in agricultural crops increases the values of electric conductivity and turbidity of the water in streams (Kasangaki et al., 2008; Sutherland et al., 2002; Trayler and Davis, 1998). Thus, the superficial runoff causes impacts on the physicochemical conditions of the streams, especially in the areas of agricultural crops, affecting the structure of aquatic communities (Benstead et al., 2003; Kasangaki et al., 2008; Roy et al., 2003; Yoshimura, 2012). Furthermore, the conversion of forest areas reduces the input of allochthonous material in the stream, modifying its trophic structure (Abelho and Graça, 1998). Thus, the abundance of species of shredders tends to be higher in forested streams than in streams in areas converted to crops (Encalada et al., 2010; Scrimgeour and Kendall, 2003).

Streams that drain preserved areas in tropical and subtropical regions maintain high diversity of aquatic insects (Crisci-Bispo et al., 2007; Melo and Froehlich, 2001; Siegloch et al., 2012). Streams that present riparian vegetation have higher species richness than streams without such vegetation (Corbi and Trivinho-Strixino, 2008). Land uses in annual crops, such as sugarcane and pasture, cause different impacts on the chemical composition and communities of aquatic invertebrates living in streams (Omento et al., 2000). Studies in tropical streams have documented a decrease in richness of aquatic insects of the orders Ephemeroptera, Plecoptera and Tricoptera (EPT) in streams impacted by land uses (Hepp and Santos, 2009; Hepp et al., 2010; Molozzi et al., 2007; Nessimian et al., 2008; Salvar-

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rey et al., 2014; Siegloch et al., 2014). These three orders are considered the group of aquatic insects most sensitive to human interference (Rosenberg and Resh, 1993) and are among the most used metrics for indices of biotic integrity (e.g., Baptista et al., 2007; Suriano et al., 2011).

The ecological impacts of forest conversion remain unclear, especially on communities of aquatic insects from streams inserted in an originally forested matrix that was converted into agriculture, as occurs in a great part of the southern Brazilian region. This region has been historically used for agriculture, especially the cultivation of soybeans and corn, and its conversion for agriculture dates from the early twentieth century (SEMA, 2005). On the other hand, the existence of protected forest areas allows us to understand how the conversion of soil into contiguous areas of agriculture affects communities of macroinvertebrates in streams draining these areas. Such information is essential for the conservation of aquatic communities of small streams, as well as to the elaboration of policies for the management and conservation of local natural resources.

The aim of this study was to test the impacts of forest conversion to agricultural land uses on the aquatic insects of streams. Thus, we analyzed the difference between EPT assemblages from streams of a large forested area and of an adjacent agricultural converted area. Additionally, environmental variables were recorded. Considering that land uses are important predictors of environmental variables of the streams (Kasangaki et al., 2008) and that EPT are taxa sensitive to environmental changes (Rosenberg and Resh, 1993), it is expected that EPT assemblages attributes will be significantly affected by forest conversion, as well as environmental variables.

Material and methods

Study site

The study was performed at Parque Estadual do Turvo (PET) and surrounding areas belonging to the municipality of Derrubadas, located in northwestern Rio Grande do Sul state (27°14'34.08"S, 53°57'13.74"W). The PET has 17,491 ha and about 90km of perimeter and holds a significant portion of the preserved semi-deciduous forest in the state of Rio Grande do Sul (Oliveira-Filho et al., 2013; Prado, 2000). This vegetation formation originally extended from the state of Paraná to northwestern Rio Grande do Sul (Irgang, 1980). The climate of the study site is characterized as subtropical sub-humid areas with dry summer (ST SB v) (Maluf, 2000). The annual average of rainfall is about 1,665 mm, with well-distributed rainfall throughout the year, although with lower average of rainfall in the months of February, July, August, and December (SEMA, 2005).

The PET is inserted in the basin of the Rio Uruguai region and is drained by this river along its northern boundary. Beyond the Rio Uruguai, the PET is drained by four main tributaries, which can be individualized in four distinct watersheds: Rio Parizinho, Arroio Mairosa, Arroio Calixto, and Rio Turvo (Fig. 1). Only one of the headwaters of the watersheds cited above is totally included within the boundaries of the conservation unit (SEMA, 2005). In general, the streams that drain the PET cover a geomorphologically dissected region, formed by deep valleys carved on basalt flows of the Serra Geral Formation (SEMA, 2005). Thus, the streams have high slopes, strong currents, and rocky substrate.

At the beginning of the 20th century, with the establishment of the immigrant colonies in southern Brazil, the region suffered a heavy deforestation process, which led to the conversion of large forested areas into agricultural landscapes, with annual cultures like soybeans and corn crops (SEMA, 2005). Therefore, streams that have its headwaters in the adjacent areas of the PET are subject to contamination and carrying of sediment generated by human activities in the vicinities.

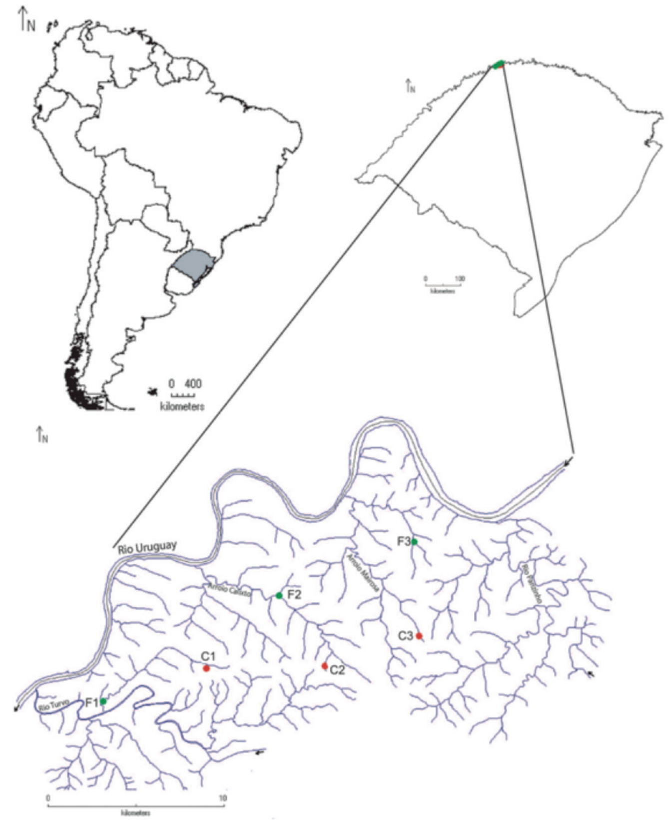

Figure 1. Location of the micro-basin and sampled streams in forested area (F1, F2, and F3) and converted area (C1, C2, and C3) at Parque Estadual do Turvo and adjacent areas, in southern Brazil.

Sampling

The aquatic macroinvertebrates were collected between 23-25 January 2011, in three watersheds: Arroio Mairosa, Arroio Calixto, and Rio Turvo. From these, six low-order streams (1st and 2nd order, according to the classification of Strahler, 1957) were selected for study. Three streams (F1, F2, and F3) are located inside the PET, in a forested area that is completely unchanged, and three (C1, C2, and C3) are located outside of the PET, in the areas converted to agricultural land uses (Fig. 1). Ten samples were collected with a Surber sampler (area of 0.0361 m^2 and mesh of 250 μm) in each stream, five subsamples were collected in riffle streams with leaf litter as substrate, and five were collected in riffle streams with rocky bottom as substrate, so as to obtain a varied sample of EPT (Siegloch et al., 2012; Spies and Froehlich, 2009). The subsamples were obtained within a stretch of about 50 meters for each stream.

The EPT were identified to genera, with taxonomic identification keys (Angrisano and Sganga, 2009 for Trichoptera; Froehlich, 2007, 2009 for Plecoptera; Domínguez and Fernández, 2009 for Ephemeroptera). The other macroinvertebrates sampled were quantified to calculate the proportion of EPT. Voucher material will be deposited in the Collection of Aquatic Insects at Universidade Federal do Pampa, Campus São Gabriel, Rio Grande do Sul.

Additionally, at each sampled stream, the following environmental descriptors were recorded: i) water temperature (°C); ii) electric conductivity (μS/cm); iii) dissolved oxygen (mg/L); iv) turbidity (NTU); v) total of solids (ppt), with a multiparameter probe (Horiba U52); vi) depth of the stream, and vii) width of riparian vegetation.

Data analysis

Due to the effect of abundance on species richness (Gotelli and Colwell, 2001), we used the rarefaction analysis to compare the richness of EPT among samples of streams in forested areas and streams in converted areas. The curves were constructed for samples from 1,000 randomizations and rescaled by abundance, and generated by Ecosim 7.0 software (Gotelli and Entsminger, 2001).

The structure of the EPT assemblage in streams of forested areas and in converted areas was analyzed using the similarity coefficient of Bray-Curtis, with subsequent ordination by non-metric multidimensional scaling (NMDS) (Clarke and Warwick, 2001). The stress was used as a measure of the representativeness of the similarity matrix by the method of NMDS. Stress values below 0.2 correspond to a reasonable fit (Clarke and Warwick, 2001).

The structure of the EPT assemblages in forested streams and in converted areas was tested by an Analysis of Similarity (ANOSIM - one way). The ANOSIM is based on statistical test R, which measures the biological significance of the difference, and varies from –1 to +1. Values near to 1 represent the greatest differences between samples groups, so the samples within each group would be more similar than between groups (Clarke and Warwick, 2001). The R statistic with zero represents no difference between the sample groups (accepts the null hypothesis that there is no difference between samples from different groups, Clarke and Warwick, 2001). The ANOSIM also generates a p value similar to analysis of variance (ANOVA), with $p < 0.05$ indicating a significant difference. The dataset was transformed by Hellinger transformation (Legendre and Gallagher, 2001). Both analyses were performed using Primer v6.2 (Clarke and Gorley, 2006).

The species indicator analysis (ISA) was performed to highlight the genera that preset a close relationship to conservation conditions of the streams tested. The ISA uses abundance and occurrence frequency of species in sample groups established a priori to identify species indicators to those conditions (Dufrêne and Legendre, 1997). In this analysis, the samples of streams in both forested and converted areas were established as the a priori groups. The Monte Carlo test was used to verify significance values, using 4,999 permutations. The analysis was performed using the PC-ORD 4.0 software (McCune and Mefford, 1999).

The proportions of EPT in relation to other macroinvertebrates in streams in the forested areas and streams in converted areas were tested by Binomial test (Callegari-Jacques, 2003). The relationship between abundance and richness of EPT and the environmental variables of the water was tested by the Spearman correlation index, indicated for nonparametric data (Callegari-Jacques, 2003). The tests were performed in the BioEstat Program 5.0 (Ayres et al., 2007).

Results

A dataset of 5,245 individuals belonging to 35 genera of EPT was sampled at the PET and adjacent areas. From these, 13 occurred exclusively in streams of the forested area (*Hagenulopsis*, *Tricorythodes*, *Paracloeodes*, *Baetodes*, *Camelobaetidius*, *Zelusia*, *Anacroneuria*, *Tupiperla*, *Atanatolica*, *Marilia*, *Polyplectropus*, *Polycentropus*, and *Itauara*), while only three genera (*Caenis*, *Homotraulus*, and *Anchitrichia*) were exclusive from streams in the converted area (Table 1). Additionally, a total of 10,135 other aquatic macroinvertebrates was collected, 5,024 in streams of the forested area and 5,111 in streams of the converted ones.

The forested area showed a higher taxonomic richness of EPT than streams in converted areas (Fig. 2; Table 1). The ANOSIM test evidenced strong difference in EPT assemblage structure between streams of forested and converted areas ($R = 0.80$, $p < 0.002$). The NMDS ordination representing the similarity among the samples showed strong segregation of samples of streams in forested areas

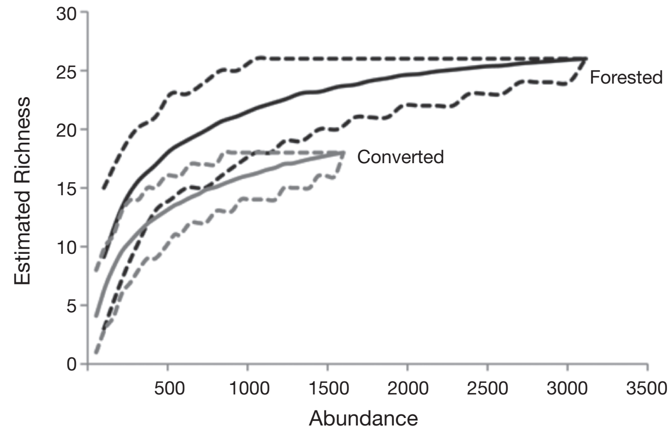

Figure 2. Rarefaction richness of Ephemeroptera, Plecoptera, and Trichoptera assemblages between streams in both forested and converted area. The upper and lower dashed lines indicate the confidence intervals (95%) calculated for each category.

from samples of streams in converted sites (Fig. 3). EPT samples of forested areas showed greater similarity between each other than to converted ones. Moreover, samples of streams in converted areas showed lower similarity.

The results of the ISA highlighted the genera *Thraulodes*, *Farrodes*, *Needhamella*, *Leptohyphes*, *Traveryphes*, *Americabaetis*, *Cloeodes*, *Baetodes*, *Anacroneuria*, *Polyplectropus*, *Itauara*, and *Helicopsyche* as indicators of streams in the forested areas, whereas only *Anchitrichia* was an indicator of streams in the converted areas (Table 1). The indicator values (IV) of all genera were high, demonstrating that these genera have great specificity to the conservation condition of streams (Table 1).

The mean abundance of environmental sensitive taxa (EPT) was lower in converted streams, and the proportion of EPT in relation to the total macroinvertebrates abundance was almost two times higher in streams in forested area than in converted ones ($Z = 22.9$; $p < 0.001$) (Table 1).

Environmental variables measured were only slightly different between streams in forested and converted areas (Table 2). In general, the streams from the PET were characterized by good oxygenation, low electrical conductivity, and turbidity. The streams in converted areas presented lower dissolved oxygen, increased turbidity (C1), and higher electrical conductivity and total solids (C2 and C3)

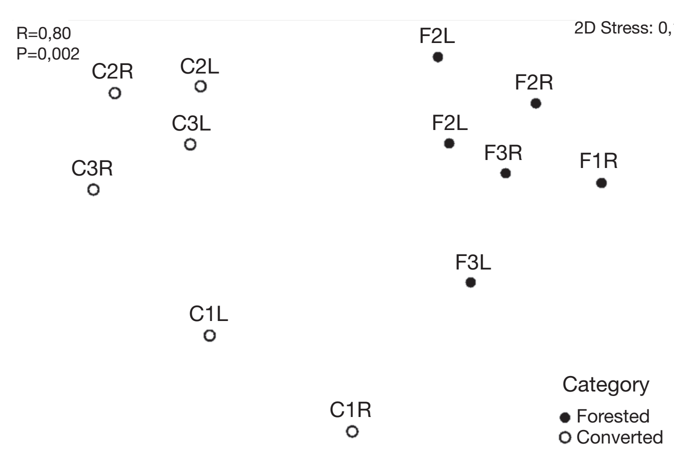

Figure 3. Ordination diagram of NMDS of Ephemeroptera, Plecoptera, and Trichoptera assemblages at streams in forested area (F) and converted area (C). Numbers 1-3 refer to the stream; R refers to rocky bottom substrate, and L refers to leaf litter substrate.

Table 1.
Abundance and richness, functional feeding groups (FFG), and indicator species analysis (ISA) of Ephemeroptera, Plecoptera, and Trichoptera genera and abundance of other macroinvertebrates sampled at streams in forested area (F) and converted area (C). Numbers 1-3 refer to the stream; R refers to rocky bottom substrate, and L refers to leaf litter substrate; IV means Indicator Value.

Taxa	Forested area						Converted area						FFG	IV	ISA	
	F1R	F1L	F2R	F2L	F3R	F3L	C1R	C1L	C2R	C2L	C3R	C3L			p*	Group
Ephemeroptera																
Thraulodes Ulmer, 1920	467	52	119	7	243	8	2	1	5	7	0	0	Collector	98.40	< 0.01	F
Farrodes Peters, 1969	75	74	35	80	45	22	3	1	2	80	1	6	Collector	78.10	0.05	F
Needhamella Domínguez & Flowers, 1989	1	0	32	4	52	3	0	0	0	2	0	0	Collector	81.60	0.02	F
Hagenulopsis Ulmer, 1920	1	0	0	0	0	0	0	0	0	0	0	0	Collector	16.70	1.00	F
Homotraulus Demoulin, 1955	0	0	0	0	0	0	1	0	0	0	0	0	?	16.70	1.00	C
Leptohyphes Eaton, 1882	2	10	85	274	2	0	0	0	1	0	1	2	Scraper	82.40	0.05	F
Traveryphes Molineri, 2001	0	1	31	49	3	3	0	0	1	0	0	1	Scraper	81.50	0.03	F
Tricorythodes Ulmer, 1920	0	0	3	0	0	0	0	0	0	0	0	0	Scraper	16.70	1.00	F
Tricorythopsis Traver, 1958	0	0	0	2	0	1	0	1	0	0	0	0	Scraper	25.00	0.71	F
Americabaetis Kluge, 1992	28	275	44	43	3	1	0	0	5	4	9	8	Scraper	93.80	0.03	F
Cloeodes Traver,1938	8	6	1	0	5	2	1	0	0	0	0	0	Scraper	79.70	0.02	F
Paracloeodes Day, 1955	1	4	1	0	0	0	0	0	0	0	0	0	Scraper	50.00	0.18	F
Baetodes Needham & Murphy, 1924	0	11	51	1	12	0	0	0	0	0	0	0	Scraper	66.70	0.05	F
Camelobaetidius Demoulin, 1966	0	0	1	0	0	0	0	0	0	0	0	0	Scraper	16.70	1.00	F
Zelusia Lugo-Ortiz & McCafferty, 1998	0	0	1	0	3	1	0	0	0	0	0	0	Collector	50.00	0.17	F
Caenis Stephens, 1835	0	0	0	0	0	0	0	1	0	0	0	0	Collector	16.70	1.00	C
Plecoptera																
Anacroneuria Klapálek, 1909	181	73	71	49	105	55	0	0	0	0	0	0	Predator	100.0	< 0.01	F
Tupiperla Froehlich, 1969	0	0	0	1	0	0	0	0	0	0	0	0	Shredder	16.70	1.00	F
Trichoptera																
Triplectides Kolenati, 1859	3	4	0	4	0	4	0	1	1	0	0	0	Shredder	58.80	0.11	F
Atanatolica Mosely 1936	0	12	1	7	0	0	0	0	0	0	0	0	Scraper	50.00	0.18	F
Oecetis McLachlan 1877	1	18	2	0	0	0	2	0	0	0	0	0	Predator	45.70	0.42	F
Marilia Müller, 1880	10	0	0	0	0	0	0	0	0	0	0	0	Shredder	16.70	1.00	F
Chimarra Stephens, 1829	1	0	0	4	11	0	0	1	6	22	0	6	Collector	45.80	0.45	C
Genus not described 1	0	2	0	2	0	0	0	0	0	1	0	0	Collector	26.70	0.45	F
Polyplectropus Curtis 1835	2	2	1	3	2	0	0	0	0	0	0	0	Collector	83.30	0.01	F
Polycentropus Ulmer, 1905	16	0	0	0	0	0	0	0	0	0	0	0	Predator	16.70	1.00	F
Phylloicus Müller, 1880	3	33	3	22	2	23	2	3	5	5	1	26	Shredder	67.20	0.38	F
Itauara Müller, 1888	37	78	1	0	11	1	0	0	0	0	0	0	Scraper	83.30	0.01	F
Helicopsyche Siebold, 1856	19	70	4	7	17	0	10	0	0	0	0	1	Scraper	76.20	0.05	F
Atopsyche Banks 1905	0	1	0	2	0	0	0	0	0	0	2	4	Predator	22.20	0.85	C
Smicridea McLachlan, 1871	13	73	20	36	116	11	2	4	490	598	31	87	Collector	81.80	0.32	C
Leptonema Guérin 1843	0	52	0	2	0	0	0	0	29	56	0	7	Collector	31.50	0.55	C
Neotrichia Morton, 1905	1	4	8	2	5	0	0	0	35	8	0	0	Scraper	26.50	1.00	F
Anchitrichia Flint, 1970	0	0	0	0	0	0	7	1	10	3	14	0	Scraper	83.30	0.01	C
Celaenotrichia Mosely, 1934	0	3	0	0	1	0	0	0	1	0	0	0	Scraper	26.70	0.73	F
Total abundance of EPT	870	858	515	601	638	135	30	14	591	786	59	148				
% EPT abundance			69%							31%						
Richness of EPT	20	22	21	22	21	13	9	8	13	12	7	10				
% EPT taxa			94%							60%						
Other invertebrates	426	1,849	437	1,186	543	583	481	1,033	1,139	1,426	231	801				

Table 2.
Environmental characterization and variables recorded at sampled streams in forested area (F) and converted area (C). Numbers 1-3 refer to the stream.

Variables	Forested area			Converted area		
	F1	F2	F3	C1	C2	C3
Temperature (°C)	25.3	22.27	24.74	26.15	23.36	23.04
Dissolved oxygen (mg/L)	9.14	10.39	9.41	8.42	9.13	9.34
Electrical conductivity (μS/cm)	45	53	58	50	91	79
Turbidity (NTU)	2.6	1.2	0.6	3.27	2.4	2.9
Total solids (ppt)	0.03	0.03	0.04	0.03	0.06	0.05
Width (m)	0.6	1.91	1.62	0.6	1.48	1.17
Depth (cm)	4.9	4.9	6.6	4.5	4.5	6.3
Riparian vegetation (m)	-	-	-	35	60	10
Cultivation	-	-	-	Soybean	Pasture	Soybean

(Table 2). However, a correlation between environmental variables and abundance and richness of EPT assemblages was not recorded ($p > 0.05$).

Discussion

Our results showed that streams draining converted areas sustained an impoverished assemblage of sensitive aquatic insects. EPT values were lower in converted areas than in forested areas, showing that conversion to agricultural uses significantly affects their assemblage structure and limits their occurrence. Significant differences in density and taxonomic richness among preserved areas and land uses have been documented in previous studies performed in Brazil (e.g., Hepp and Santos, 2009; Molozzi et al., 2007; Nessimian et al., 2008; Siegloch et al., 2014). These results also corroborate studies on land uses and their impacts on aquatic insect assemblages performed in temperate regions of the northern hemisphere (Harding et al., 1998; Stone and Wallace, 1998) and in tropical regions (Benstead et al., 2003; Encalada et al., 2010; Kasangaki et al., 2008).

The taxonomic composition was also affected by forest conversion, for there are several exclusive taxa of EPT, or with high specificity to streams in forested areas, as the genera *Anacroneuria, Americabaetis, Baetodes, Thraulodes, Polyplectropus*, and *Itauara*. Some of the indicated genera are considered very sensitive to anthropic impacts (Rosenberg and Resh, 1993), like *Anacroneuria* and *Baetodes*, which are cited only to environments with low human perturbation in the subtropical region (Buckup et al., 2007; Domínguez et al., 2006; Hepp et al., 2010). Other indicated genera, as *Americabaetis*, *Farrodes*, *Itauara*, *Polypelctropus*, and *Helicopsyche* are considered genera with some tolerance and are recorded in environments with human impacts (Salvarrey et al., 2014, Siegloch et al., 2014; Spies et al., 2006). The specificity of these genera to streams in the forested areas brings out the high effect of the agriculture land use on EPT assemblages, since the genera that present some tolerance could not satisfactorily inhabit the streams in the converted areas.

Additionally, the strong segregation and difference of samples of streams in forested areas from those of streams in converted areas reinforce the effects of forested matrix conversion in agricultural land uses. Moreover, samples of streams in forested areas were more similar among each other than samples of streams in converted areas, indicating that EPT assemblages are more structured in streams draining the forested areas than in those draining converted areas, which could be under different degrees of impact in each area.

In this way, we corroborated our hypothesis that EPT assemblage parameters are affected by conversion of the forested matrix to agricultural land uses. The effects herein detected and discussed above could be influenced by the following – and not mutually exclusive – processes related to vegetation cover: i) lower input of allochthonous material, and ii) increased input of fine sediments in streams draining converted areas.

The streams in forested areas are characterized by a large input of allochthonous material (Harding and Winterbourn, 1995; Quinn et al., 1997; Townsend et al., 1997; Wohl and Carline, 1996), and the contribution of this material is essential for the maintenance of several food webs in streams (England and Rosemond, 2004; Wallace et al., 1999; Whiles and Wallace, 1997), because the communities of aquatic invertebrates are structured to use this energy supply (Bispo and Oliveira, 1998). In forested areas, the canopy cover provides shade, reducing the amount of sunlight that reaches the substrate background (Yoshimura, 2012). Thus, in addition to contributing considerably with the input of allochthonous material (e.g., leaves, branches, and twigs) (Vannote et al., 1980; Yoshimura, 2012), the canopy cover may also reduce primary production by shading effects. Thus, the conversion of these areas can strongly influence the sunlight exposure of the streams, reducing the contribution of allochthonous material and causing changes in invertebrate communities (e.g., Quinn et al., 1997), including aquatic insects (England and Rosemond, 2004; Price et al., 2003).

In fact, the EPT samples from streams in forested areas studied here showed higher abundance of genera with shredders and collectors habits than in streams of converted areas, although collectors were also abundant in the converted streams. This dominance may be related to the availability of allochthonous organic detritus from riparian vegetation (Vannote et al., 1980). The higher abundance of the shredders *Phylloicus* and *Triplectides* in forested streams may be associated with differences in rates of decomposition of organic debris in streams from forests and those under land use (Encalada et al., 2010). On the other hand, the lower richness, abundance, and low proportions of EPT recorded in the excerpts C1 and C3 may be related to smaller widths of riparian vegetation at these sites (35 and 10m respectively), which must have determined lower input of allochthonous matter. The point C2, which has a dammed spring (a pond) with fish farming, as well as drainage of sewage from domestic animals (pigs and cattle) showed high abundance of the genus *Smicridea*. A relationship between high abundance of *Smicridea* and organic enrichment has already been reported in previous studies (e.g., Bispo and Oliveira, 1998; Boon, 1984, 1986; Silveira et al., 2006).

Agricultural land use areas may favor the runoff of sediments (Macdonald et al., 2003), which are deposited on the substrate of streams, interfering on the availability of periphyton (Ryan, 1991), the main food source of scraper insects. The accumulation of fine sediment on the substrate generates the behavior of drifting, in which the insects release themselves into the stream seeking better environmental conditions downstream (Larsen and Ormerod, 2010). This process can determine that streams affected by the increased input of fine sediment have lower population density and abundance of macroinvertebrates (Larsen and Ormerod, 2010; Salvarrey et al., 2014). In fact, some taxa of EPT that have scraper habits (e.g., *Baetodes*, *Camelobaetidius*, *Tricorythodes*, *Atanatolica*) were not found in streams located in converted areas, possibly due to sedimentation on periphyton. Sedimentation on the substrates, especially at the rocky substrate, was detected in all the streams of converted areas sampled in this study, noticed by the adhesion and impregnation of fine sediments at the hands in the act of sampling. Another relevant fact is that very fine particles can affect breathing activities of some taxa (physiological stress) by the deposition and adhesion of sediment at respiratory organs (Wood and Armitage, 1997). Changes in macroinvertebrate communities related to the conversion of forested areas into agricultural land use areas have been widely documented (Hepp and Santos, 2009; Hepp et al., 2010; Molozzi et al., 2007; Nessimian et al., 2008; Roque et al., 2003; Salvarrey et al.,2014; Siegloch et al., 2014).

Most environmental variables sampled in this study reflect the physicochemical conditions of the water in streams during the time of sampling (i.e. hours), whereas the biological dataset of the EPT assemblages reflect the environmental conditions in the longer term (e.g., months) (Rosenberg and Resh, 1993). Thus, any significant deposition of pollutants (e.g., pesticides) tends to move quickly through the watercourse, not being detected at the time of sampling by the environmental variables measured in this study. On the other hand, the biological dataset reflects the environmental conditions during the lifetime of the insects. Therefore, the conservation condition of streams (forested area and converted area) better reflects the differences in the assemblage structure of EPT than environmental variables alone. So, our results refuse the hypothesis that the environmental variables sampled in our study were affected by forest conversion to agricultural land uses in the PET and surrounding areas. Furthermore, several studies have shown that differences in physicochemical variables are detected anytime and with strong influence at biotic communities, especially when the impacts are due to urbanization and discharge of domestic and industrial effluents (e.g., Hepp and Santos, 2009; Hepp et al., 2010; Ometo et al., 2000). This apparent contradiction of our results may be related to the nature of the impacts (agriculture land use), which affect more the physical structure of streams than the physicochemical variables measured.

In conclusion, our results indicate that forest conversion influences the structure of assemblages of EPT, leading to changes and reductions (1) in taxonomic richness, (2) abundance of organisms, and (3) the proportion of sensitive taxa. In this way, the present study confirms EPT assemblages as an important tool to assess environmental impacts in streams (e.g., Baptista et al., 2007; Benstead et al., 2003; Harding and Winterbourn, 1995; Kasangaki et al., 2008; Suriano et al., 2011). Despite the existing riparian vegetation at some of the streams of converted areas, the EPT community reflected the damage caused due to conversion of the native forest to agricultural land use. Such results show the importance of the forested area of the Parque Estadual do Turvo to maintain the diversity on aquatic insect assemblages. In this way, our results corroborate the recommendation of SEMA (2005) that the streams outside of the PET (e.g., headwater of Arroio Mairosa, Arroio Calixto, and Arroio Fabio) should be totally included in the protected area of the PET. Additionally, the conservation of riparian vegetation from other watersheds that drain into the PET (Rio Turvo and Rio Parizinho) is also essential for the conservation of aquatic fauna and water resources of the PET. These actions would greatly minimize the sediment carrying, pesticides, and fertilizers in the runoff into the park, and so effectively conserving the aquatic fauna and the water resources of PET.

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Conflicts of interest

The authors declare no conflicts of interest.

References

Abelho, M., Graça, M.A.S., 1998. Litter in first-order stream of a temperate deciduous forest (Margaraça Forest, central Portugal). Hydrobiologia 386, 147-152.

Angrisano, E.B., Sganga, J.V., 2009. Trichoptera. In: Domínguez, E., Fernández, H.R. (eds.). Macroinvertebrados bentónicos sudamericanos. Sistemática y biología. Fundación Miguel Lillo, Tucumán, pp. 255-308.

Ayres, M., Ayres Júnior, M., Ayres, D.L., Santos, A.A., 2007. BIOESTAT 5.0. Aplicações Estatísticas nas Áreas das Ciências Biomédicas. Sociedade Civil Mamirauá, MCT-CNPq, Belém.

Baptista, D.F., Buss, D.F., Egler, M., Giovanelli, A., Silveira, M.P., Nessimian, J.L., 2007. A multimetric index based on benthic macroinvertebrates for evaluation of Atlantic Forest streams at Rio de Janeiro State, Brazil. Hydrobiologia 575, 83-94.

Benstead, J.P., Douglas, M.M., Pringle, C.M., 2003. Relationships of stream invertebrate communities to deforestation in eastern Madagascar. Ecol. Appl. 13, 1473-1490.

Bispo, P.C., Oliveira, L.G., 1998. Distribuição espacial de insetos aquáticos (Ephemeroptera, Plecoptera e Trichoptera) em córregos de cerrado do Parque Ecológico de Goiânia, estado de Goiás. Oecol. Bras. 5, 175-190.

Boon, P.J., 1984. Habitat exploitation by larvae of *Amphipsyche meridiana* (Trichoptera, Hydropsychidae) in a Javanese lake outlet. Freshw. Biol. 14, 1-12.

Boon, P.J., 1986. Net-spinning by *Amphipsyche senegalensis* larvae (Trichoptera: Hydropsychidae) in Lake Kariba (South Central Africa). Aquat. Insects. 8, 59-65.

Buckup, L., Bueno, A.A.P., Bond-Buckup, G., Casagrande, M., Majolo, F., 2007. The benthic macroinvertebrate fauna of highland streams in southern Brazil: composition, diversity and structure. Rev. Bras. Zool. 24, 294-301.

Callegari-Jacques, S.M., 2003. Bioestatística: Princípios e Aplicações. Artmed, Porto Alegre.

Clarke, K.R., Gorley, R.N., 2006. Primer v6: user manual/tutorial. Plymouth Marine Laboratory, Plymouth.

Clarke, K. R., Warwick, R. M., 2001. Change in marine communities: an approach to statistical analysis and interpretation. 2nd Ed. Primer-E, Plymouth.

Corbi, J.J., Trivinho-Strixino, S., 2008. Relationship between sugar cane cultivation and stream macroinvertebrate communities. Braz. Arch. Biol. Technol. 51, 569-579.

Crisci-Bispo, V.L., Bispo, P.C., Froehlich, C.G., 2007. Ephemeroptera, Plecoptera and Trichoptera assemblages in litter in a mountain stream of the Atlantic Rainforest from southeastern Brazil. Rev. Bras. Zool. 24, 545-551.

Domínguez, E., Fernández, H.R., 2009. Macroinvertebrados bentónicos sudamericanos. Sistemática y biología. Fundación Miguel Lillo, Tucumán.

Domínguez, E., Molineri, C., Pescador, M.L., Hubbard, M.D., Nieto, C., 2006. Ephemeroptera of South America (Aquatic Biodiversity of Latin America). Vol. 2. Pensoft Publications.

Dufrêne, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67, 345-366.

Encalada, A.C., Calles, J., Ferreira, V., Canhoto, C.M., Graça, M.A.S., 2010. Riparian land use and the relationship between the benthos and litter decomposition in tropical montane streams. Freshw. Biol. 55, 1719-1733.

England, L.E., Rosemond, A.D., 2004. Small reductions in forest cover weaken terrestrial-aquatic linkages in headwater streams. Freshw. Biol. 49, 721-734.

Froehlich C.G., 2007. Plecoptera. In: Guia *on-line*: Identificação de larvas de Insetos Aquáticos do Estado de São Paulo. Available at: http://sites.ffclrp.usp.br/aguadoce/Guia_online/ [accessed 20 Jan 2014].

Froehlich, C.G., 2009. Plecoptera. In: Domínguez, E., Fernández, H.R. (eds.). Macroinvertebrados bentónicos sudamericanos. Sistemática y biología. Fundación Miguel Lillo, Tucumán, pp. 145-166.

Gotelli, N.J., Colwell, R.K., 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol. Lett. 4, 379-391.

Gotelli, N.J., Entsminger, G.L., 2001. EcoSim: Null models software for ecology. Version 7.0. Acquired Intelligence Inc. & Kesey-Bear. Available at: http://homepages.together.net/~gentsmin/ecosim.htm [accessed 10 Mar 2014].

Harding, J.S., Benfield, E.F., Bolstad, P.V, Helfman, G.S., Jones, E.B.D., 1998. Stream biodiversity: the ghost of land use past. Proc. Natl. Acad. Sci. USA. 95, 14843-14847.

Harding, J.S., Winterbourn, M.J., 1995. Effects of contrasting land use on physico-chemical conditions and benthic assemblages of streams in a Canterbury (South Island, New Zealand) river system. N. Z. J. Mar. Freshwater Res. 29, 479-492.

Hepp, L.U., Santos, S., 2009. Benthic communities of streams related to different land uses in a hydrographic basin in southern Brazil. Environ. Monit. Assess. 157, 305-318.

Hepp, L.U., Milesi, S.V., Biasi, C., Restello, R.M., 2010. Effects of agricultural and urban impacts on macroinvertebrates assemblages in streams (Rio Grande do Sul, Brazil). Zoologia. 27, 106-113.

Irgang, B.E., 1980. A mata do alto Uruguai no RS. Ciênc. Cult. 32, 323-324.

Kasangaki, A., Chapman, L.J., Balirwa, J., 2008. Land use and the ecology of benthic macroinvertebrate assemblages of high-altitude rainforest streams in Uganda. Freshw. Biol. 53, 681-697.

Larsen, S., Ormerod S.J., 2010. Low-level effects of inert sediments on temperate stream invertebrates. Freshw. Biol. 55, 476-486.

Legendre, P., Gallagher, E., 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129, 271-280.

Macdonald, J.S., Beaudry, P.G., MacIsaac, E.A., Herunter, H.E., 2003. The effects of forest harvesting and best management practices on stream flow and suspended sediment concentrations during snowmelt in headwater streams in sub-boreal forests of British Columbia, Canada. Can. J. For. Res. 33, 1397-1407.

Maluf, J.R.T., 2000. Nova classificação climática do Estado do Rio Grande do Sul. RBA. 8, 141-150.

McCune, B., Mefford, M.J., 1999. PC-ORD. Multivariate Analysis of Ecological Data. Version 4.0.

Melo, A.S., Froehlich, C.G., 2001. Evaluation of methods for estimating macroinvertebrate species richness using individual stones in tropical streams. Freshw. Biol. 46, 711-721.

Meyer, J.L., Strayer, D.L., Wallace, J.B., Eggert, S.L., Helfman, G.S., Leonard, N.E., 2007. The contribution of headwater streams to biodiversity in river networks. J. Am. Water Resour. Assoc. 43, 86-103.

Molozzi, J., Hepp, L.U., Dias, A.S., 2007. Influência da cultura de arroz sobre a comunidade bentônica no vale do Itajaí (Santa Catarina, Brasil). Acta Limnol. Bras. 19, 383-392.

Nakano, S., Murakami, M., 2001. Reciprocal subsidies: dynamic interdependence between terrestrial and aquatic food webs. Proc. Natl. Acad. Sci. USA. 98, 166-170.

Nessimian, J.L., Venticinque, E.M., Zuanon, J., De Marco Jr., P., Gordo, M., Fidelis, L., et al., 2008. Land use, habitat integrity, and aquatic insect assemblages in Central Amazonian streams. Hydrobiologia. 614, 117-131.

Oliveira-Filho, A.T., Budke, J.C., Jarenkow, J.A., Eisenlohr, P.V., Neves, D.R.M., 2013. Delving into the variations in tree species composition and richness across South American subtropical Atlantic and Pampean forests. J. Plant Ecol. 6, 1-23.

Ometo, J.P.H.B., Martinelli, L.A., Ballester, M.V., Gessner, A., Krusche, A.V., Victoria, R.L., et al., 2000. Effects of land use on water chemistry and macroinvertebrates in two streams of the Piracicaba river basin, south-east Brazil. Freshw. Biol. 44, 327-337.

Prado, D.E., 2000. Seasonally dry forests of tropical South America: from forgotten ecosystems to a new phytogeographic unit. Edinb. J. Bot. 57, 437-461.

Price, K., Suski, A., McGarvie, J., Beasley, B., Richardson, J.S., 2003. Communities of aquatic insects of old-growth and clearcut coastal headwater streams of varying flow persistence. Can. J. For. Res. 33, 1416-1432.

Pringle, C.M., Benstead, J.P., 2001. The effects of logging on tropical river ecosystems. In: Fimbel, R.A., Grahal, A., Robinson, J.G. (eds.). The Cutting Edge: Conserving Wildlife in Logged Tropical Forests. Columbia University Press, New York, pp. 305-325.

Quinn, J.M., Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C., Williamson, R.B., 1997. Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. N. Z. J. Mar. Freshwater Res. 31, 579-597.

Roque, F.O., Trivinho-Strixino, S., Strixino, G., Agostinho, R.C., Fogo, J.C., 2003. Benthic macroinvertebrates in streams of the Jaragua State Park (Southeast of Brazil) considering multiple spatial scales. J. Insect Conserv. 7, 63-72.

Rosenberg, D.M., Resh, V.H., 1993. Freshwater monitoring and benthic macroinvertebrates. Chapman & Hall, New York.

Roy, A.H., Rosemond, A.D., Paul, M.J., Leigh, D.S., Wallace, J.B., 2003. Stream macroinvertebrate response to catchment urbanisation (Georgia, U.S.A.). Freshw. Biol. 48, 329-346.

Ryan, P.A., 1991. Environmental effects of sediment on New Zealand streams: A review. N. Z. J. Mar. Freshwater Res. 25, 207-221.

Salvarrey, A.V.B., Kotzian, C.B., Spies, M.R., Braun, B., 2014. The influence of natural and anthropic environmental variables on the structure and spatial distribution along longitudinal gradient of macroinvertebrate communities in southern Brazilian streams. J. Insect Sci. 14, 13. doi:10.1673/031.014.13.

Scrimgeour, G.J., Kendall, S., 2003. Effects of livestock grazing on benthic invertebrates from a native grassland ecosystem. Freshw. Biol. 48, 347-362.

SEMA. 2005. Plano de Manejo do Parque Estadual do Turvo. Secretaria Estadual do Meio Ambiente.

Siegloch, A.E., Froehlich, C.G., Spies, M.R., 2012. Diversity of Ephemeroptera (Insecta) of the Serra da Mantiqueira and Serra do Mar, southeastern Brazil. Rev. Bras. Entomol. 56, 473-480.

Siegloch, A.E., Suriano, M., Spies, M., Fonseca-Gessner, A., 2014. Effect of land use on mayfly assemblages structure in Neotropical headwater streams. An. Acad. Bras. Ciênc. doi: 10.1590/0001-3765201420130516.

Silveira, M.P., Buss, D.F., Nessimian, J.L., Baptista, D.F., 2006. Spatial and temporal distribution of benthic macroinvertebrates in a southeastern Brazilian river. Braz. J. Biol. 66, 623-632.

Spies, M.R., Froehlich, C.G., 2009. Inventory of caddisflies (Trichoptera: Insecta) of the Campos do Jordão State Park, São Paulo State, Brazil. Biota neotrop. 9, 211-218.

Spies, M.R., Froehlich, C.G., Kotzian, C.B., 2006. Composition and diversity of Trichoptera (Insecta) larvae communities in the middle section of the Jacuí river and some tributaries, State of Rio Grande do Sul, Brazil. Iheringia, Sér. Zool. 4, 389-398.

Stone, M.K., Wallace, J.B., 1998. Long-term recovery of a mountain stream from clear-cut logging: the effects of forest succession on benthic invertebrate community structure. Freshw. Biol. 39, 151-169.

Strahler, A.N., 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38, 913-920.

Suga, C.M., Tanaka, M.O., 2013. Influence of a forest remnant on macroinvertebrate communities in a degraded tropical stream. Hydrobiologia 703, 203-213.

Suriano, M.T., Fonseca-Gessner, A.A., Roque, F.O., Froehlich, C.G., 2011. Choice of macroinvertebrate metrics to evaluate stream conditions in Atlantic Forest, Brazil. Environ. Monit. Assess. 175, 87-101.

Sutherland, A.B., Meyer, J.L., Gardiner, E.P., 2002. Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. Freshw. Biol. 47, 1791-1805.

Townsend, C., Arbuckle, C., Crowl, T., Scarsbrook, M., 1997. The relationship between land use and physicochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri River, New Zealand: a hierarchically scaled approach. Freshw. Biol. 37, 177-191.

Trayler, K.M., Davis, J.A., 1998. Forestry impacts and the vertical distribution of stream invertebrates in south-western Australia. Freshw. Biol. 40, 331-342.

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

Wallace, J.B., Eggert, S.L., Meyer, J.L., Webster, J.R., 1999. Effects of resource limitation on a detrital-based ecosystem. Ecol. Monogr. 69, 409-442.

Whiles, M.R., Wallace, J.B., 1997. Leaf litter decomposition and macroinvertebrate communities in headwater streams draining pine and hardwood catchments. Hydrobiologia. 353, 107-119.

Wohl, N.E., Carline, R.F., 1996. Relations among riparian grazing, sediment loads, macroinvertebrates, and fishes in three central Pennsylvania streams. Can. J. Fish. Aquat. Sci. 53, 260-266.

Wood, P.J.& Armitage, P.D., 1997. Biological effects of fine sediment in the lotic environment. Environ. Manage. 21, 203-217.

Yoshimura, M., 2012. Effects of forest disturbances on aquatic insect assemblages. Entomol. Sci. 15, 145-154.