

## Effects of agricultural and urban impacts on macroinvertebrates assemblages in streams (Rio Grande do Sul, Brazil)

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**ABSTRACT.** This study evaluates the effects of agricultural and urban activities on the structure and composition of benthic communities of streams in the state of Rio Grande do Sul, Brazil. Benthic macroinvertebrates were collected in streams influenced by urbanization and agriculture and in streams with no anthropogenic disturbances (reference streams). Organism density was superior in urban streams when compared with streams in the other two areas. The taxonomic richness and Shannon diversity index were higher in reference streams. The benthic fauna composition was significantly different among land uses. The classification and ordination analyses corroborated the results of variance analyses demonstrating the formation of clusters corresponding to streams with similar land use. Seasonality was also found to influence the benthic community, though in a lesser degree than land use.

**KEY WORDS.** Biomonitoring; environmental quality; land uses.

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One of the main causes of degradation in aquatic ecosystems is inadequate land use, which affects the characteristics of drainage basins by modifying the physical and chemical characteristics of water bodies and the composition of the aquatic biota (HEPP & SANTOS 2009). Water characteristics are regulated by both natural and anthropogenic factors (BAHAR *et al.* 2008). For example, intense urban and agricultural activities increase the input of organic residues, nutrients and metals into rivers and streams (MILESI *et al.* 2008). Additionally, by removing the riparian vegetation, a very common practice in agricultural areas, anthropogenic activities eliminate a natural protection against erosion, increasing the input of sediments, nutrients and other pollutants (NESSIMIAN *et al.* 2008) into water bodies.

A common result of urbanization and other anthropic activities in stream ecosystems is a reduction in the number of taxa that are less tolerant to modifications in the water quality, together with an increase in the number of pollution-tolerant taxa (SMITH & LAMP 2008), often resulting in the local extinction of native species (ROY *et al.* 2003).

Biomonitoring is a method used to determine water quality using biological communities. Even though a large number of organisms have been used to monitor the effects of pollutants in aquatic ecosystems, environmental agencies have consistently employed benthic macroinvertebrate communities to monitor water bodies (BACEY & SPURLOCK 2007).

Studies in different parts of the world show that benthic macroinvertebrates are generally good bioindicators of water quality in streams impacted by urbanization (ROY *et al.* 2003, BACEY & SPURLOCK 2007, SMITH & LAMP 2008), agriculture

(VONDRACEK *et al.* 2005), pastures (DOLÉDEC *et al.* 2006, MORI & BRANCELJ 2006, McIVER & McINNIS 2007), ions (DOI *et al.* 2007, MILESI *et al.* 2008) and deforestation (MEGAN *et al.* 2007). In Brazil, large-scale (landscape) biomonitoring studies using macroinvertebrates have been carried out in the Southeastern region of the country. Some examples are the study of OMETTO *et al.* (2004) in the Piracicaba River basin, CORBI & TRIVINHO-STRIXINO (2006) in the sugarcane region of São Paulo, BAPTISTA *et al.* (2007) in the region of Atlantic forest and POMPEU *et al.* (2005) in the basin of the Velhas River, Minas Gerais. In northern Brazil, NESSIMIAN *et al.* (2008) used macroinvertebrates to evaluate the effect of different land uses (deforested area)

In a study carried out in southern Brazil, HEPP & SANTOS (2009) evaluated the impact of different land uses on local benthic communities. When streams in conserved areas were compared with streams in urbanized and pasture areas, significant differences in organism density and taxonomic richness were found: in both urban sites and pastures, macroinvertebrate density was higher and species richness was significantly lower than in conserved areas. These results are consistent with those reported by MOLOZZI *et al.* (2007), who studied the effects of different management strategies on the rice fields of Santa Catarina. In their data, species richness was significantly lower in areas where the riparian vegetation had been removed and organic matter input was consequently higher.

Knowing the impacts of anthropic activities on water bodies is crucial for their environmental management, an increasingly important activity due to global demand for water resources (DEWSON *et al.* 2007). The main aim of this study was

to answer the following question: do different kinds of environmental impact cause different types of alterations in the composition and structure of macroinvertebrate communities? We believe that the answer to this question can provide important information to environmental managers and to the public at large, information that can help in the conservation and recovery of natural resources in the North region of the state of Rio Grande do Sul, Brazil.

## MATERIAL AND METHODS

This study was carried out in Erechim, situated in the northern region of the state of Rio Grande do Sul ( $27^{\circ}29'6.13''$  and  $27^{\circ}47'0.97''$ S;  $52^{\circ}21'3.28''$  and  $52^{\circ}8'43.3''$ W). Stretches from first to third orders in the hydrographic basin were selected, corresponding to the different land uses (Tab. I). The geological formation throughout the basins is basaltic and the typical soil is classified as "Ec" (Erechim Latossol Roxo Distrófico). The density drainage in the various sites (see below) was similar, oscillating from  $12.53$  to  $13.01$  m ha<sup>-1</sup> (RAMPAZZO *et al.* 2004). We classified our collecting sites as urban, agricultural, and reference sites, as follows: 1) urban sites consisted of four streams downstream of the urban perimeter. About 90% of the urban perimeter of Erechim is within this hydrographic basin (sites 1, 2, 3 and 4). The substrate is chiefly composed of rocks and leaves; 2) agricultural sites consisted of four sites located within a hydrographic basin where land use (> 95%) is predominantly agricultural (sites 5, 6, 7 and 8); soy (summer) and wheat (winter) are the main crops. The sites are deforested and the substrate is composed of rocks and soil; 3) reference sites, chosen based on their environmental integrity (sites 9, 10, 11 and 12) were characterized as follows: absence of anthropogenic disturbances, presence of native riparian vegetation, variety of habitats on the stream bed, among other aspects. The distribution of the sampling sites is represented in figure 1.

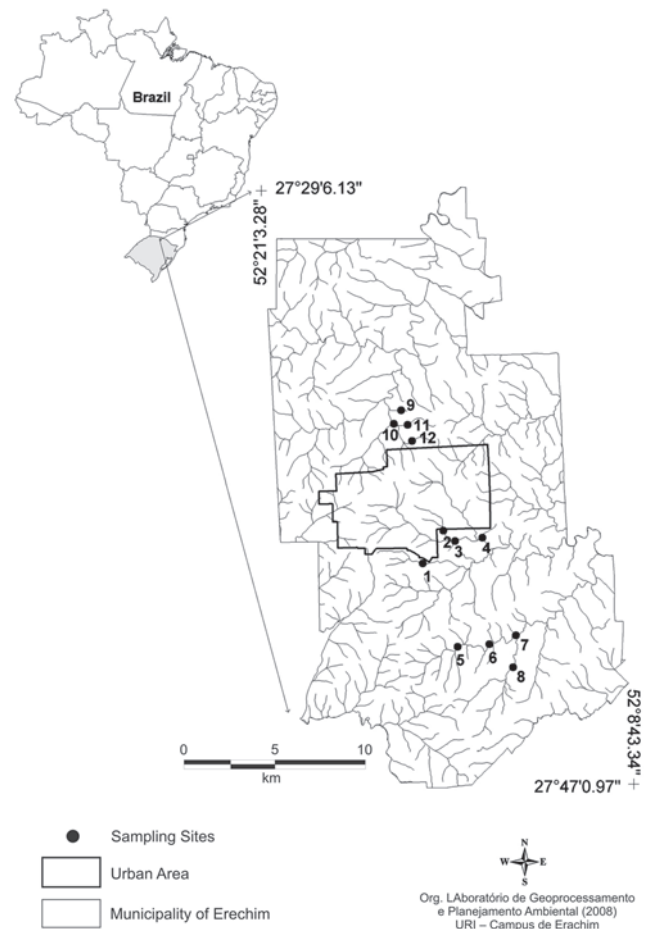


Figure 1. Distribution of the sampling sites in the municipality of Erechim.

Table I. Characteristics of the sampling sites in Erechim, Rio Grande do Sul state.

Sites	Land Use	Geographic Coordinates	Altitud (m)	Order	Width (m)	Deep (m)	Flow (m <sup>3</sup> s <sup>-1</sup> )
1	Urban	$27^{\circ}39'21.1''$ , $52^{\circ}15'0.34''$	694	2sd	1.75 – 0.50	0.12 – 0.03	0.3 – 0.9
2	Urban	$27^{\circ}39'58.1''$ , $52^{\circ}16'35.4''$	644	1st	0.95 – 0.95	0.18 – 0.28	0.4 – 0.2
3	Urban	$27^{\circ}39'41.2''$ , $52^{\circ}14'40.2''$	620	3th	6.50 – 3.50	0.15 – 0.26	0.7 – 0.8
4	Urban	$27^{\circ}39'34.5''$ , $52^{\circ}13'44.5''$	695	1st	6.40 – 5.90	0.15 – 0.15	0.9 – 1.2
5	Agriculture	$27^{\circ}42'50.6''$ , $52^{\circ}14'37.0''$	652	3th	3.28 – 4.70	0.28 – 0.13	0.5 – 0.6
6	Agriculture	$27^{\circ}42'47.4''$ , $52^{\circ}13'32.7''$	658	2sd	2.90 – 3.18	0.13 – 0.17	0.7 – 0.7
7	Agriculture	$27^{\circ}43'29.5''$ , $52^{\circ}12'45.1''$	647	1st	2.57 – 1.78	0.15 – 0.15	0.7 – 0.8
8	Agriculture	$27^{\circ}42'32.1''$ , $52^{\circ}12'38.9''$	620	3th	3.00 – 3.20	0.19 – 0.15	0.4 – 0.5
9	Reference area	$27^{\circ}36'08.6''$ , $52^{\circ}16'12.4''$	605	1st	1.00 – 0.80	0.11 – 0.07	0.2 – 0.4
10	Reference area	$27^{\circ}36'09.2''$ , $52^{\circ}16'12.8''$	601	2sd	1.20 – 1.35	0.07 – 0.10	0.5 – 0.3
11	Reference area	$27^{\circ}35'41.4''$ , $52^{\circ}16'49.1''$	564	1st	0.85 – 1.67	0.03 – 0.05	0.1 – 0.4
12	Reference area	$27^{\circ}36'34.3''$ , $52^{\circ}16'07.0''$	610	2sd	1.32 – 1.55	0.03 – 0.04	0.1 – 0.6

For characterization of the sites, analysis in triplicate of the following environmental variables was carried out in all streams sampled: current velocity (fluxometer), water temperature and dissolved oxygen (in situ, oximeter), pH (in situ, potentiometric method), electric conductivity (in situ, potentiometric method), turbidity (nephelometric method), ammonia and total phosphorus (espectrofotometric method). The methodology used to gather this data is described in Standard Methods (APHA 1998).

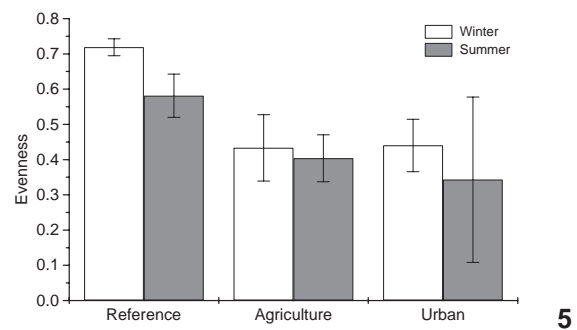
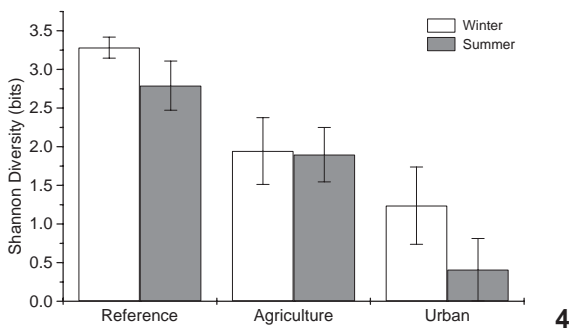
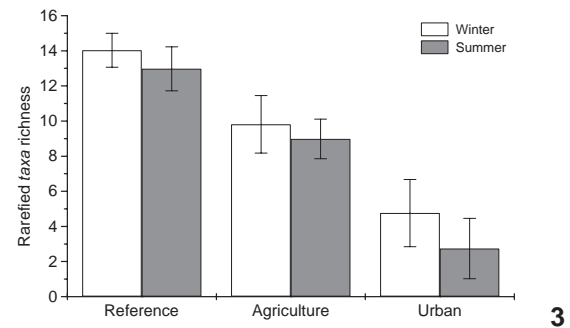
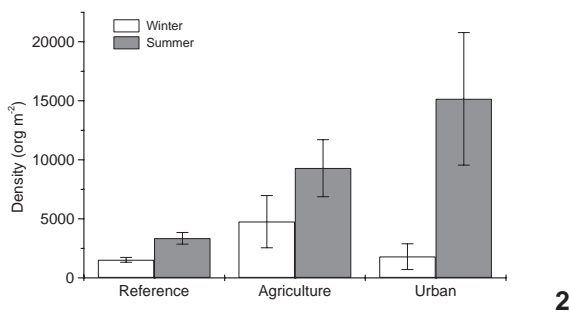
The benthic organisms were sampled in different substrates (leaves, stones and sand) with a Surber sampler (mesh = 225  $\mu\text{m}$ ; area = 0.1  $\text{m}^2$ ) within a 10 m ratio of the chosen site. The biological samples were fixed in the field with 5% formalin and taken to the laboratory for selection and identification. Identification was carried out to the lowest possible taxonomic level based on the available literature (FERNANDEZ & DOMINGUES 2001, MERRITT & CUMMINS 1996). However, according to MELO (2005) and CORBI & TRIVINHO-STRIXINO (2006), family-level identifications of benthic macroinvertebrates for biomonitoring purposes do not compromise the results.

Density (organisms. $\text{m}^{-2}$ ) and taxonomic richness (represented by the number of macroinvertebrate taxa identified) were calculated for each site. Next, rarefaction curves for the estimation of macroinvertebrate taxonomic richness were constructed. The rarefaction was calculated based on the lowest values of organism density obtained in each stream (GOTELLI & COWELL 2001). The standard sample size used for comparison,

when calculating rarefaction, was 100 organisms. This value, which corresponds to the lower density registered in our data (smallest sample size), was obtained in summer, for site 4. The Shannon Diversity index and Pielou Evenness were also calculated (MAGURRAN 2004). To evaluate the differences among the density, rarefied richness, Shannon Diversity index and evenness in streams, an Analysis of Variance was used (ANOVA; GOTELLI & ELLISON 2004). To compare the benthic community composition among the different sites, collecting periods, and collecting dates, a Multivariate Analysis of Variance (MANOVA) was applied to the density  $\log(x + 1)$  transformed. With the density previously ( $\log[x + 1]$ ) transformed, a classification analysis was carried out using UPGMA method with the Bray-Curtis coefficient of dissimilarity. The analyses were carried out using the "vegan" package (OKSANEN *et al.* 2008) of statistical programs R (R DEVELOPMENT CORE TEAM 2008) and Multiv Beta version 2.5 (PILLAR 2001).

## RESULTS

Organism density did not differ among the streams in the winter period. In summer, the urban streams showed the highest densities of organisms (ANOVA,  $F_{2,9} = 5.23$ ,  $p = 0.03$ ). According to the Tukey test, the differences occurred between the reference and urban streams ( $SS = 4.46$ ,  $p < 0.05$ , Figs 2-5). Streams in reference areas presented higher rarefied richness in winter (ANOVA,  $F_{2,9} = 8.88$ ,  $p = 0.007$ , Figs 2-5) and summer (ANOVA,  $F_{2,9} = 13.8$ ,  $p = 0.002$ , Figs 2-5). In winter, differences



Figures 2-5. Average values and standard error ( $\pm$  Standard Error) of density (2), richness (3), Shannon Diversity index (4) and Evenness (5) of benthic macroinvertebrates collected in streams with different land uses in Erechim.

occurred between reference and urban areas (Tukey test,  $SS = 5.95$ ,  $p < 0.01$ ). In summer, differences were observed between reference and urban areas (Tukey test,  $SS = 7.37$ ,  $p < 0.01$ ) and between agricultural and urban areas (Tukey test,  $SS = 4.49$ ,  $p < 0.05$ ). The Shannon diversity index differed among the varied land uses in both seasons (ANOVA,  $F_{2,9} = 7.10$ ,  $p = 0.01$  and  $F_{2,9} = 11.21$ ,  $p = 0.004$ , winter and summer, respectively). In winter, the differences occurred between reference and urban areas (Tukey test,  $SS = 5.24$ ,  $p < 0.05$ ). In summer, differences occurred between reference and urban areas (Tukey test,  $SS = 6.62$ ,  $p < 0.01$ ) and agricultural and urban areas (Tukey test,  $SS = 4.14$ ,  $p < 0.05$ ). The evenness showed differences among the land uses in winter (ANOVA,  $F_{2,9} = 5.32$ ,  $p = 0.02$ ) and summer (ANOVA,  $F_{2,9} = 11.23$ ,  $p = 0.004$ ). The Tukey test demonstrated that in winter the differences occurred between reference and urban areas ( $SS = 4.04$ ,  $p < 0.05$ ). In summer, the differences were between reference and urban areas ( $SS = 6.62$ ,  $p < 0.01$ ) and between agricultural and urban areas ( $SS = 4.21$ ,  $p < 0.05$ ).

In this study, a total of 58 taxa were identified among the Acarina, Crustacea, Mollusca, Annelida and Insecta. In urban streams, the dominance of Chironomidae (Diptera) and Oligochaeta species was evident, accounting for more than 70% of the fauna collected in these streams. The composition of the benthic community showed significant differences among the different land uses in winter (MANOVA,  $SS = 92.37$ ,  $p = 0.001$ , Tab. III) and summer (MANOVA,  $SS = 121.02$ ,  $p = 0.002$ , Tab. III). According to "a posteriori" analyses carried out among the three land uses in winter, significant differences were observed (reference x urban areas:  $SS = 47.7$ ,  $p = 0.03$ ; reference x agriculture areas:  $SS = 36.5$ ,  $p = 0.02$ , agriculture x urban areas:  $SS = 54.3$ ,  $p = 0.02$ ). In summer, differences were significant between reference and urban areas ( $SS = 69.6$ ,  $p = 0.03$ ) and reference and agricultural areas ( $SS = 37.3$ ,  $p = 0.02$ ). However, urban and agricultural areas did not differ in summer with respect to community composition.

The Cluster analysis revealed groups characterized by land use: a group formed by streams located in reference areas; a second group formed by a mixture of streams in reference and agricultural areas; a third group with predominance of agricultural streams; and a fourth group formed by urban streams (Fig. 6).

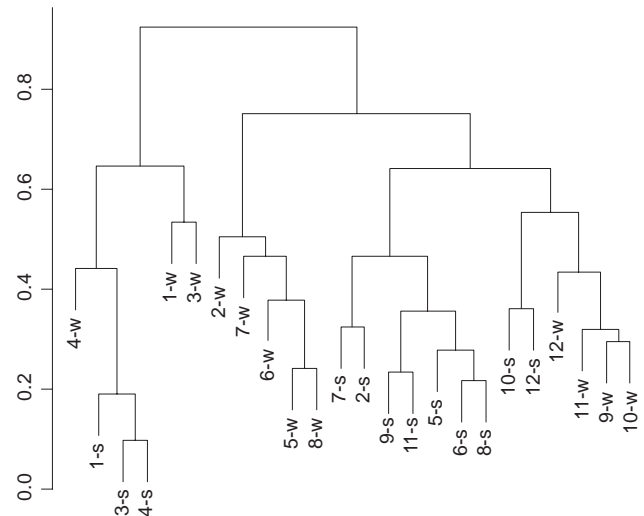


Figure 6. Dendrogram of grouping (UPGMA, Bray-Curtis) in streams with different land uses influence in Erechim. Numbers = sites, w = winter, s = summer. Urban Sites: numbers 1, 2, 3, and 4; Agriculture Sites: numbers 5, 6, 7, and 8; Reference Sites: numbers 9, 10, 11, and 12.

## DISCUSSION

The higher values obtained for nutrients and the lower amounts of dissolved oxygen in urban streams were most likely a consequence of the input of organic materials in the water. Additionally, pollution sources such as sewer discharge and industrial residues seem to have been responsible for the high concentrations of ammonia and total phosphorus. SALOMONI *et al.* (2007), in a study carried out in the Gravataí River (Rio Grande do Sul), pointed out that changes in that river were a consequence of the increased concentration of nutrients discharged in the water column. The contaminants, mainly organic nutrients that are launched in urbanized streams, cause alterations in the physical-chemical characteristics of the water (BAHAR *et al.* 2008).

Table II. Average values and standard deviation of the environmental variables measured in streams (Erechim, Rio Grande do Sul, Brazil).

Variables	Reference Streams		Agriculture Streams		Urban Streams	
	Winter	Summer	Winter	Summer	Winter	Summer
Water Temperature (°C)	14.65 ± 0.63	19.37 ± 0.65	15.90 ± 2.00	26.25 ± 1.61	17.70 ± 1.84	24.50 ± 2.11
pH	7.21 ± 0.29	6.91 ± 0.17	6.72 ± 0.47	6.68 ± 0.31	6.52 ± 0.49	6.62 ± 0.13
Dissolved Oxygen (mg l <sup>-1</sup> )	8.69 ± 0.04	7.79 ± 0.21	8.12 ± 0.41	7.81 ± 0.36	21.67 ± 17.76	5.00 ± 2.15
Electric Conductivity (µS cm <sup>-1</sup> )	59.17 ± 11.48	59.25 ± 3.88	52.30 ± 16.83	6.68 ± 0.31	6.25 ± 1.77	10.84 ± 3.32
Turbidity (NTU)	5.06 ± 2.67	6.17 ± 1.70	8.12 ± 0.41	7.80 ± 0.36	192.18 ± 120.30	128.25 ± 75.19
Ammonia (mg l <sup>-1</sup> )	0.057 ± 0.014	0.020 ± 0.008	0.059 ± 0.021	0.027 ± 0.003	0.841 ± 0.551	0.610 ± 0.388
Total Phosphorus (mg l <sup>-1</sup> )	0.068 ± 0.013	0.106 ± 0.002	0.085 ± 0.012	0.180 ± 0.099	0.350 ± 0.135	0.473 ± 0.119

Table III. Values of organisms density in streams with different land uses influence in Erechim, Rio Grande do Sul state. (■) &lt; 10, (●) 11-50, (▲) 51-100, (◇) &gt; 100.

Taxa	Reference streams		Agriculture streams		Urban streams	
	Winter	Summer	Winter	Summer	Winter	Summer
Platyhelminthes						
Turbellaria	▲	◇	▲	◇	■	■
Annelida						
Hydrudinea	●	●	▲	■	●	■
Oligochaeta	●	▲	▲	▲	◇	◇
Mollusca						
Bivalvia	▲	▲	●		◇	
Gastropoda	◇	◇	●	●	▲	▲
Arachnida						
Acari		●	●	●		
Crustacea						
Aeglidae	■	●	■		■	■
Copepoda			■	■		
Hyalella	●	◇	■			
Insecta						
Collembola						
Isotomidae			◇	●		■
Poduridae		■	◇	■		
Sminthuridae			●			
Hypogastruridae					●	
Ephemeroptera						
Baetidae	◇	■	◇	◇	▲	▲
Caenidae	●	◇	●	◇		●
Leptohyphidae	◇	◇	◇	◇		
Leptophlebiidae	◇	◇	▲	◇	■	■
Odonata						
Calopterygidae	■	■		●		■
Coenagrionidae	■		■	●		
Lestidae				■		
Corduliidae	■	■			■	
Gomphidae		■				■
Libellulidae	■		■			
Plecoptera						
Gripopterygidae	◇	■	●	■		
Perlidae	◇		●	●		
Hemiptera						
Belostomatidae				■		
Corixidae		▲		◇		
Naucoridae						
Veliidae	●					

Continue

Table III. Continued.

Taxa	Reference streams		Agriculture streams		Urban streams	
	Winter	Summer	Winter	Summer	Winter	Summer
Megaloptera						
Corydalidae	■		■	●		■
Coleoptera						
Elmidae	◇	◇	◇	◇	▲	▲
Hydrophilidae	▲	◇	■			
Psephenidae	▲	◇	■	●		
Diptera						
Blephariceridae		●				
Ceratopogonidae	●	▲	●	●	■	■
Chironomidae	◇	◇	◇	◇	◇	◇
Culicidae	■	▲				
Dixidae		■				
Dolichopodidae	■	■			■	
Empididae	■		■			■
Muscidae		●		●		
Psychodidae	■		●		■	■
Sciomyzidae	■	●		●		
Simuliidae	◇		◇		▲	
Stratiomyidae	■	◇		◇	●	◇
Tipulidae	●	■	●			
Lepidoptera	■	▲	▲	■		
Trichoptera						
Calamoceratidae	◇	◇	■	●	■	
Glossosomatidae	■	▲	▲	●		■
Helicopsychidae	■	▲		◇		■
Hydrobiosidae		■		◇		▲
Hydropsychidae	◇	●	◇	●	◇	●
Hydroptilidae	■	●	▲		■	
Leptoceridae		◇		◇		◇
Odontoceridae	■		■			
Philopotamidae	■	●	●	■	■	■
Sericostomatidae	■	●		◇		■

A significant effect on the structure and composition of the benthic macroinvertebrate fauna was observed among the different land uses in this study. The streams located in reference areas with native riparian vegetation, higher diversity of habitats and trophic resources, showed greater taxonomic richness (reflected by the Shannon Diversity index) and lower density of organisms. By contrast, a decreased taxonomic richness

and a correspondingly lower Shannon Diversity index were observed in urban areas (HEPP & SANTOS 2009). In agricultural streams, however, intermediate patterns were observed. NIYOGI *et al.* (2007) mentioned that the density of macroinvertebrates significantly increases in places with higher nutrient concentrations and fine sediments. Streams under urban influence receive considerable amounts of organic residues (ROY *et al.*



2003), whereas agricultural streams receive the input of sediments derived from erosion (LENAT & CRAWFORD 1994). Erosion and the consequent input of sediments can be observed in the streams studied and may have contributed to an incremental increase in organism densities.

Reference and urban sites differed in average values for all variables measured in all seasons, except for density in winter. The agricultural and urban areas showed differences in richness, Shannon diversity index and evenness only in summer. SMITH & LAMP (2008) studied the benthic community structure in agricultural and urban areas in Montgomery Co. (USA) streams and observed results similar to ours. According to LENAT & CRAWFORD (1994), pollution intolerant organisms are frequent and abundant in regions with a higher availability of habitats.

The fauna composition was different among the land uses, a result consistent with the findings of OMETTO *et al.* (2004), who demonstrated that urban streams have lower concentrations of dissolved oxygen and higher concentrations of ammonia, affecting the distribution and occurrence of Ephemeroptera, Plecoptera and Trichoptera (EPT orders). Several studies have highlighted the role of the EPT orders as bioindicators (LENAT & CRAWFORD 1994, DOLEDÉC *et al.* 2006, BACEY & SPURLOCK 2007, MOLOZZI *et al.* 2007, HEPP & SANTOS 2009), because these organisms tend to decrease in numbers or even disappear in regions where sources of (urban) pollution are introduced.

The Cluster analysis showed a pattern of grouping consistent with our expectations. According to SMITH & LAMP (2008), community structure and composition are more strongly influenced by land use than by season. The similar benthic composition of reference and agricultural streams was likely a result of the EPT richness. The urban areas formed a distinct group because of the physical-chemical characteristics of their streams. The clustering of an urban site with a group predominantly composed of agricultural sites can be an indication of a mixed anthropic disturbance. That urban stream is located in an area within the urban perimeter that releases a lower amount of domestic residues, when compared with the remaining urban regions in our data.

The results of this study show a strong influence of point-pollution sources (urban) and a trend of influence by non-point sources (agriculture) on the benthic community. These results demonstrate that urban and agriculture impacts affect the water quality and aquatic diversity. Management activities are necessary for the recuperation and maintenance of the environmental quality in the study region. Our results can contribute to the generation of integrated information about environmental quality. Traditional evaluation measures based on physical, chemical and bacteriological methods are less efficient in the detection of environmental problems of hydrographic basins. The utilization of bioindicators makes it possible to generate a more integrated evaluation of aquatic ecosystems.

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