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Structure of macroinvertebrate communities in riffles of a Neotropical karst stream in the wet and dry seasons

Estrutura das comunidades de macroinvertebrados em corredeiras de um riacho cárstico Neotropical nas estações seca e chuvosa

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Abstract: Aim: Our study evaluated the effects of physical and chemical variables and seasonality on diversity and structure of the macroinvertebrate fauna in riffles of a Neotropical chalk stream; **Methods:** Sampling was performed during the dry (September 2003) and rainy (March 2004) seasons, in five sites. Five samples were taken at each point with a Surber sampler. Physical and chemical variables were also evaluated; **Results:** Temperature, pH, orthophosphate and total nitrogen were very similar for both seasons, while riffle length, conductivity, alkalinity, ammonia, phosphorus and leaf litter had different values. The total number of organisms collected was 25114 belonging to at least 50 families. Insects dominated in the samples. The highest abundance was found for the dry period. Temporary stretches were sampled in rainy season in order to complement the faunal inventory; **Conclusions:** The environmental seasonality was an important factor for structuring the macroinvertebrate fauna, with a significant difference between the invertebrate compositions in the sampling periods. The results of this study demonstrate the influences of seasonality on the temporal variation of communities.

Keywords: aquatic macroinvertebrates, seasonality, Neotropical chalk stream, riffle, intermittent habitat.

Resumo: Objetivos: Este estudo avaliou os efeitos das variáveis químicas e físicas e da sazonalidade na diversidade e estrutura da fauna de macroinvertebrados em corredeiras de um riacho cárstico Neotropical; **Métodos:** As coletas foram realizadas durante as estações seca (Setembro 2003) e chuvosa (Março 2004), em cinco pontos de amostragem. Em cada ponto foram coletadas cinco unidades amostrais utilizando um amostrador Surber. Variáveis químicas e físicas também foram avaliadas; **Resultados:** Temperatura, pH, ortofosfato e nitrogênio total foram muito similares entre as estações, enquanto os valores de comprimento da corredeira, condutividade, alcalinidade, amônia, fósforo total e a quantidade de folhiço variaram. O número total de organismos coletado foi 25114 pertencentes, a pelo menos, 50 famílias. Insetos constituíram o grupo dominante nas amostras. Trechos temporários foram amostrados na estação chuvosa, com o intuito de complementar o inventário faunístico; **Conclusões:** A sazonalidade ambiental foi um fator importante na estruturação da fauna de macroinvertebrados, onde uma diferença significativa entre a composição dos macroinvertebrados aquáticos nos períodos amostrados foi observada. Os resultados deste estudo demonstram a influência da sazonalidade na variação temporal da comunidade.

Palavras-chave: macroinvertebrados aquáticos, sazonalidade, riacho cárstico Neotropical, corredeira, habitat intermitente.

1. Introduction

Aquatic macroinvertebrates are important components in the ecological dynamics of lotic environments. These organisms play significant roles in energy fluxes and nutrient cycling (Wallace and Webster, 1996). They are also widely used in biomonitoring (Sandin and Hering, 2004).

According to Church (1996), variations in catchment geology, channel morphology, discharge and sediment transport determine streambed structure and create distinct morphological units such as riffles and pools within streams. Riffles are normally perceived as homogeneous morphological units, consisting of coarse substrata. In streams, macroinvertebrate distribution is regulated by interaction among substrate type (Buss et al., 2004), allochthonous matter (Cummins and Klug, 1979), water temperature (Merritt and Cummins, 1996), hydraulic conditions (Statzner et al., 1988), disturbance (Siegfried and Knight, 1977) and biotic interactions (Kohler, 1992).

In Brazil, much of the research on benthic macroinvertebrates has been taxonomic in nature (Froehlich, 2007). Although, in recent years, the number of ecological works on macroinvertebrates communities in lotic environments has increased (e.g. Baptista et al., 2000; Melo and Froehlich, 2001; Kikuchi and Uieda, 2005), there are still many ecoregions and ecosystem types poorly studied such as the centre-west (Favero and Conte, 2003; Tanaka et al., 2006).

Hydrological variability within aquatic ecosystems is one of the primary factors controlling the distribution of lotic fauna (Townsend et al., 1987; Wood et al., 2001; Smith et al., 2003). This hydrological variability can be an important factor leading to decreases in macroinvertebrate abundances in both tropical and temperate streams (Dudgeon, 1999; Death, 2008). Thus, various studies have found decreased abundances in macroinvertebrate communities in the wet season, and this has generally been attributed to the scouring effects of increased flow (Flecker and Feifarek, 1994; Bispo et al., 2001). Karst streams and rivers are particularly prone to hydraulic extremes of drought and floods (Jennings, 1985; Meyer et al., 2003; Smith et al., 2003; Stubbington et al., 2009). These landscapes are characterized by efficient flow of groundwater through conduits that become larger as the bedrock dissolves. In karst areas, water commonly drains rapidly into the subsurface at zones of recharge and then through a network of fractures, partings, and caves, and emerges at the surface in zones of discharge at springs, seeps, and wells (Ford and Williams, 2007). Karstic landscapes usually include temporary lotic ecosystems (Meyer et al., 2003).

Water pH is considered to be an important factor influencing the community composition of macroinvertebrates (Wright, 1995). Karst systems have characteristically high levels of water hardness, alkalinity and pH (Jennings, 1985); the degree to which this is reflected in the nature of their macroinvertebrate communities requires investigation.

The aim of this study was to carry out an inventory of the macroinvertebrate fauna and evaluate the effects of physical and chemical parameters and seasonality (dry and rainy seasons) on community structure, at five riffle sites in a karst stream, located in the center-west of Brazil.

2. Material and Methods

2.1. Study area

The study area was a section of the Salobrinha Stream, municipality of Bodoquena in Mato Grosso do Sul State, Brazil (56° 45' 50.3" W and 20° 40' 00.3" S). The stream originates at an altitude of circa 600 m, near the western border of the Bodoquena plateau, is 22 km long, and runs mainly through a narrow and deep valley. At an altitude of 170 m it joins the Salobra River, which in turn is a tributary of the Miranda River, in the Paraguay River Basin. According to Boggiani (1999), the plateau is sustained by Precambrian carbonate rocks, and shows characteristics of initial phases of karstic development such as areas of water penetration and sub-surface outflow. Due to the karstic nature of the region, the stream has intermittent surface flow in at least half its length. The water is very clear, becoming turbid after heavy rains. Flash floods occur several times during the rainy season. In this period the stream width increases, making available habitats to be colonized, called here "temporary stretches". The climate is tropical, characterized by the presence of two marked seasons: a rainy period, from October to March, and a dry one from April to September. The regional vegetation is Semi-deciduous Forest with species typical of riparian habitats occurring in the narrow valley floor (Damasceno Jr. et al., 2000). Five sampling sites were chosen along 7 km of Salobrinha stream. In this section, the stream order varied from 3rd to 4th, without large flow variation (Figure 1). This stretch

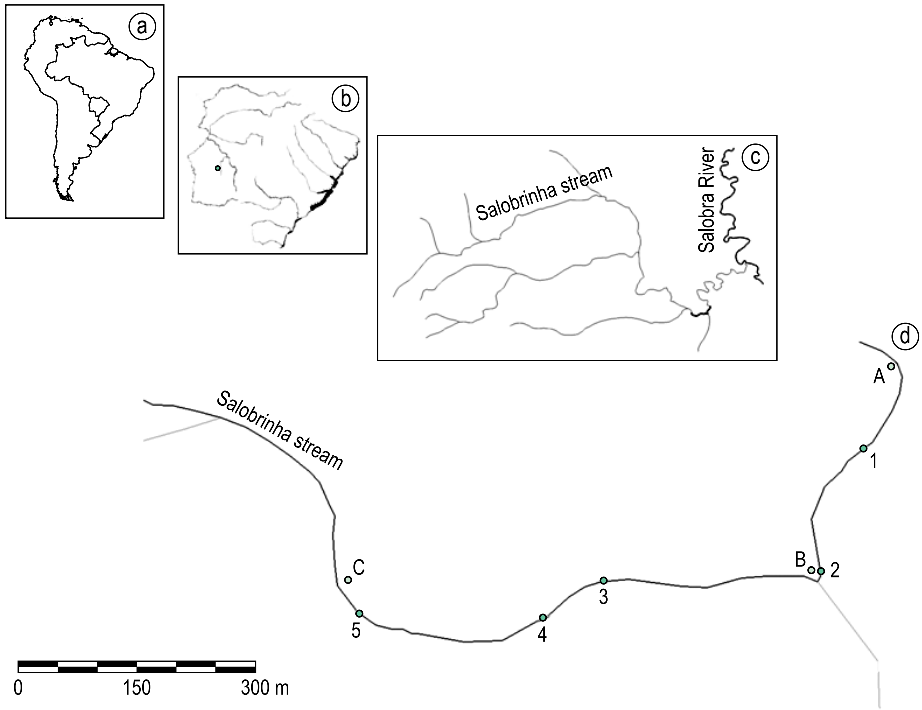

Figure 1. Map showing the localization of study area: a) within of South America, outlines of Brazil and Mato Grosso do Sul State; b) precise localization of Salobrinha Stream on Paraguay River Basin; c) bold line indicating the studied stretch; and d) distribution of sampled points inside studied stretch: 1-5) riffles sampled twice and A-C temporary riffles sampled along rainy period.

was chosen for being perennial, easily accessed and by presenting preserved riparian vegetation.

2.2. Collection and identification

Sampling was carried out during dry (September 2003) and rainy (March 2004) periods. At each sample site, water depth, riffle width, riffle length, pH, water temperature, dissolved oxygen, and conductivity were recorded. In addition, a sample of water was taken for laboratory analysis of each of the following physical and chemical variables: alkalinity, phosphorus, ammonia, total nitrogen, soluble reactive phosphorus, turbidity, total suspended solids and volatile suspended solids. The macroinvertebrates were collected with a Surber sampler (area of 0.1224 m^2 and 0.250 mm mesh); at each point five sampling units were collected along the riffles. In order to complement the inventory effort, additional three sampling units were collected at temporary stretches in the rainy period. All samples were fixed with 10% formalin. In the laboratory, the material was sorted using a stereomicroscope, and the organisms preserved in 80% ethanol. The leaf litter contained in each sample was sorted, dehydrated at 60 °C during 96 hours and then weighed. Invertebrates were identified to family level when possible. The following identification keys were used: Costa et al. (2006); Fernández and Domínguez (2001); Froehlich (1984); Merritt and Cummins (1996) and Nieser and Melo (1997).

2.3. Data analysis

Data from temporary stretches were analyzed separately, and not included in the following analysis. These data are presented for inventory purposes (qualitative data). Seasonal differences in the values of the physical and chemical variables were examined using one-way ANOVA. Indicator taxon analysis was performed following the method described by Dufrêne and Legendre (1997) using the software PC-ORD 4.1 McCune and Mefford (1999).

NMDS was used to assess temporal differences in species assemblages onto two-dimensional plot and was based on a Bray-Curtis similarity matrix. The NMDS stress was calculated to indicate the representativeness of this analysis. Stress values below 0.2 represent a good adjustment of the ordination (Clarke and Warwick, 2001). One-way ANOSIM was used to test for differences in the macroinvertebrate fauna composition between sampled periods using the software Primer v5 Clarke and Gorley, 2001. Log(x+1) transformed abundances were used to calculate a similarity matrix used in NMDS and ANOSIM. The log(x+1) transformed abundance matrix and standardized environmental matrix were submitted to Canonical Correspondence Analysis (CCA) to estimate the relationships between the physical and chemical variables, the sampling sites and the invertebrate groups using the software MVSP v3.13 Kovach Computing Service (2006). Explanatory variables were assessed for multicollinearity before the analysis. High correlation (> 0.7) was verified between water temperature, riffle width, alkalinity, Ammonia, SRP, total suspended solids, leaf litter with conductivity. Therefore, conductivity, riffle length, Phosphorus, total Nitrogen and volatile suspended solids were included in the CCA.

3. Results

The studied stretch was characterized by rocky substrate, clear water, high conductivity, high pH, high alkalinity, low turbidity and high dissolved oxygen concentrations (Table 1). Higher ammonia and total nitrogen concentrations were found in the dry period, as well as greater quantities of accumulated leaf litter. On the other hand, phosphorus concentrations were lower in this period. Phosphorus concentrations and total suspended solids did not vary significantly between the sampled periods. ANOVA indicated that values of riffle length, conductivity, alkalinity, ammonia, phosphorus, volatile suspended solids and leaf litter varied as a function of the sampling period (Table 1).

A total of 25114 macroinvertebrates were collected, belonging to at least 50 families (Table 2). Aquatic insects were the dominant group, with 43 families distributed in 12 orders. The dry period presented the highest abundance with 23043 individuals (7530 individuals per m^2) being collected, belonging to 48 taxa. The family Chironomidae presented the greatest abundance, followed by Elmidae and Leptophlebiidae. Oligochaeta, Curculionidae, Culicidae, Gerridae, Mesoveliidae, Veliidae, Pyralidae and Odontoceridae were found only in this period (Table 2). In the rainy period 2071 individuals (677 individuals per m^2) were collected, belonging to 42 taxa. Only two taxa were found exclusively in this period, namely Tabanidae and Leptoceridae. The more abundant taxa were the same as for the dry period, but the family Elmidae presented the greatest abundance, followed by Leptophlebiidae and Chironomidae (Table 2).

A total of 402 specimens (209 individuals per m^2) were collected in the temporary stretches, representing 25 of the 50 taxa recorded herein (Table 2). No taxon was exclusive of the temporary stretches. The families Elmidae, Leptophlebiidae, Helicopsyche and Chironomidae were most common in these habitats.

Oligochaeta, Hydracarina, Elmidae Isotomyidae, Ceratopogonidae, Chironomidae, Empididae, Simuliidae, Tipulidae, Leptohyphidae, Leptophlebiidae, Gerridae, Perlidae, Hydropsychidae and Hydroptilidae were the 15 taxa that indicated the dry period. No taxon was an indicator of the rainy period (Table 2).

The Non-metric Multidimensional Scaling analysis showed a clear separation of the invertebrate community compositions in the two distinct periods. The one-way ANOSIM test showed that the macroinvertebrate fauna composition differed significantly among the sampled periods ($R = 0.716$; $p < 0.01$) (Figure 2).

The first three axes of the CCA explained 62% of the variation in the data set (Table 3). The invertebrate communities in the rainy period were most correlated with riffle length. In the dry period, these communities were correlated with total nitrogen and conductivity (Figure 3).

4. Discussion

The results of the present study indicate the influences of seasonality on the communities, specifically, low abundance in the rainy season.

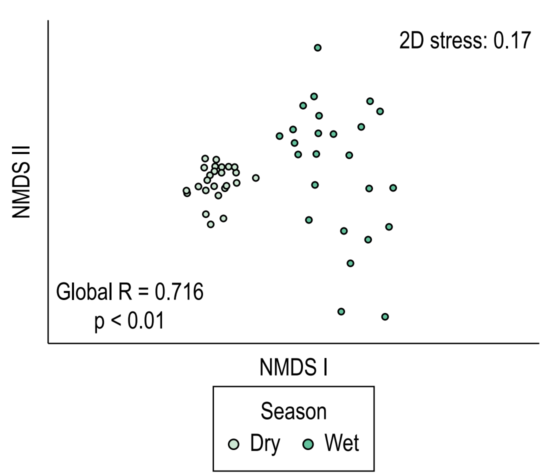

Figure 2. Two-dimensional non-metric multidimensional scaling (NMDS) of sample periods in the Salobrinha stream, Bodoquena, Mato Grosso do Sul State.

Table 1. Values of the physical and chemical environmental variables and their respective results of ANOVA for the sampling sites in dry (September 2003) and rainy (March 2004) periods in the Salobrinha stream, Bodoquena, Mato Grosso do Sul State.

Environmental variables	Dry period					Rainy period					$F_{1,8}$	p
	1	2	3	4	5	1	2	3	4	5		
Water temperature (°C)	23.0	24.0	23.0	22.0	21.0	23.6	24.3	23.5	23.1	23.1	2.744	0.136
Riffle length (m)	8.5	9.5	4.4	5.6	2.9	9.8	13.2	7.6	6.8	6.3	85.114	< 0.001
Riffle width (m)	1.0	1.0	1.7	1.0	0.8	4.3	4.1	5.9	5.9	4.7	1.513	0.254
Riffle depth (m)	-	-	-	-	-	0.40	0.37	0.50	0.45	0.30	-	-
Conductivity (µS.cm^{-1})	400.0	400.0	400.0	400.0	410.0	350.0	370.0	330.0	350.0	360.0	52.083	< 0.001
pH	8.1	8.1	7.9	7.9	7.9	7.9	7.9	8.0	8.0	7.9	0.000	1.000
Alkalinity (mg $CaCo_3$.l^{-1})	236.8	236.8	234.7	236.8	239.0	201.5	201.5	203.7	206.9	204.7	729.168	< 0.001
SRP (mg PO_4^{-3}.l^{-1})	0.017	0.028	0.029	0.033	0.014	0.015	0.019	0.025	0.030	0.028	0.001	0.978
Ammonia (mg NH_3.l^{-1})	0.14	0.14	0.11	0.14	0.11	0.06	0.04	0.04	0.05	0.02	75.469	< 0.001
Total nitrogen (mg N.l^{-1})	2.4	3.7	1.8	2.0	2.6	1.8	1.9	2.0	1.5	1.9	3.939	0.0822
Phosphorus (mg P.l^{-1})	0.018	0.033	0.038	0.044	0.067	0.100	0.070	0.080	0.070	0.090	17.982	0.003
Turbidity (NTU)	1.41	1.36	1.59	1.87	2.50	-	-	-	-	-	-	-
Total Suspended Solids (mg.l^{-1})	2.30	0.92	2.75	1.81	3.27	1.90	1.75	2.05	2.20	2.30	0.168	0.693
Volatile Suspended Solids (mg.l^{-1})	2.30	0.92	2.75	1.81	3.27	1.30	1.00	1.30	1.65	1.45	163.333	< 0.001
Leaf litter (g)	29.3	19.9	32.7	28.3	61.1	3.9	2.1	5.1	2.0	6.4	21.881	0.002
Dissolved Oxygen (mg.l^{-1})	7.5	7.5	7.7	8.0	7.5	-	-	-	-	-	-	-
Oxygen saturation (%)	100	103	104	105	100	-	-	-	-	-	-	-

Table 2. Densities of macroinvertebrates (individuals per m^2) collected in dry (September 2003) and rainy (March 2004) periods in the Salobrinha stream, Bodoquena, Mato Grosso do Sul State. IV = indicator value, P = p-value obtained from 5000 permutations; * indicates an indicator taxon; D = dry and R = rainy periods; + indicates taxa recorded in temporary stretches.

Taxa	Dry	Rainy		IV (%)	P	Indicator
Oligochaeta*	3.9	0	+	100.0	0.0076	D
Hydracarina*	231.0	9.5	+	96.1	0.0076	D
Arachnida	1.0	1.3		34.3	0.9246	R
Curculionidae	0.3	0		20.0	1.000	D
Dryopidae	2.6	4.6	+	38.2	0.8144	R
Dytiscidae	6.2	0.7		72.4	0.0678	D
Elmidae*	1511.8	348.7	+	81.3	0.0076	D
Hydrophilidae	2.0	2.0	+	40.0	0.9276	D
Psephenidae	4.2	4.9	+	42.9	0.7396	R
Isotomidae*	10.5	0		80.0	0.0494	D
Entomobryidae	7.8	1.3		34.3	0.5500	D
Ceratopogonidae*	28.8	4.6	+	86.3	0.0240	D
Chironomidae*	4702.3	56.9	+	98.8	0.0076	D
Culicidae	0.3	0		20.0	1.000	D
Empididae	101.3	4.9		95.4	0.0076	D
Simuliidae*	54.9	1.0		98.2	0.0076	D
Stratiomyidae	1.3	0.7		53.3	0.5148	D
Tabanidae	0	0.7		20.0	1.000	R
Tipulidae*	40.8	2.3	+	94.7	0.0076	D
Baetidae	109.5	25.8	+	80.9	0.2418	D
Caenidae	0.3	1.0	+	45.0	0.5340	R
Leptohyphidae*	35.0	5.2	+	87.0	0.0156	D
Leptophlebiidae*	309.8	92.2	+	77.1	0.0162	D
Hebridae	2.0	0.7		45.0	0.4142	D
Gerridae*	4.2	0		80.0	0.0442	D
Naucoridae	3.9	2.6		60.0	0.4540	D
Mesoveliidae	0.3	0		20.0	1.000	D
Veliidae	1.6	0.3		33.3	0.4322	D
Hymenoptera	0.7	0		40.0	0.4474	D
Pyralidae	2.3	0		40.0	0.4428	D
Corydalidae	1.3	2.9	+	55.4	0.3916	R
Calopterygidae	2.6	1.6		49.2	0.6270	D
Coenagrionidae	6.9	3.9	+	63.6	0.3900	D
Gomphidae	16.7	2.9	+	85.0	0.0874	D
Libellulidae	0.3	0.7	+	26.7	1.000	R
Orthoptera	1.0	0		20.0	1.000	D
Perlidae*	91.2	19.6	+	82.3	0.0076	D
Ecnomidae	4.6	2.0	+	56.0	0.3078	D
Glossosomatidae	1.3	2.0	+	48.0	0.5142	R
Helicopsychidae	1.6	11.4	+	70.0	0.1300	R
Hydropsychidae*	151.3	26.1		85.3	0.0234	D
Hydroptilidae*	28.8	3.9	+	88.0	0.0076	D
Leptoceridae	0	0.3		20.0	1.000	R
Odontoceridae	0.3	0		20.0	1.000	D
Philopotamidae	23.9	14.4	+	62.4	0.2904	D
Polycentropodidae	2.9	1.6	+	51.4	0.5980	D
Planorbidae	2.3	0.3		35.0	0.4492	D
Thiaridae	5.9	1.3		65.5	0.1388	D
Hydrobiidae	2.9	5.2		51.2	0.5784	R
Planariidae	3.9	4.9	+	44.4	0.7316	R
Total	7530	677				

Table 3. Canonical Correspondence Analysis results for the three first axes. Variables and sampling sites both in dry (September 2003) and rainy (March 2004) periods in the Salobrinha stream, Bodoquena, Mato Grosso do Sul State.

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.037	0.013	0.009
Percentage	38.588	13.984	9.575
Cumulate Percentage	38.588	52.572	62.147
Canonical coefficients			
Condutivity	-0.890	-0.368	-0.108
pH	-0.700	1.682	-2.528
Riffle length	1.685	-1.717	3.357
Phosphorus	0.562	-0.910	0.638
Total Nitrogen	1.229	-0.924	3.347
Total Suspended Solids	1.516	-1.116	3.075
Correlation coefficients			
Condutivity	-0.945	0.058	0.126
pH	0.028	0.744	-0.220
Riffle length	0.603	0.211	-0.193
Phosphorus	-0.027	-0.546	-0.602
Total Nitrogen	-0.428	0.543	0.212
Total Suspended Solids	-0.197	-0.094	0.238

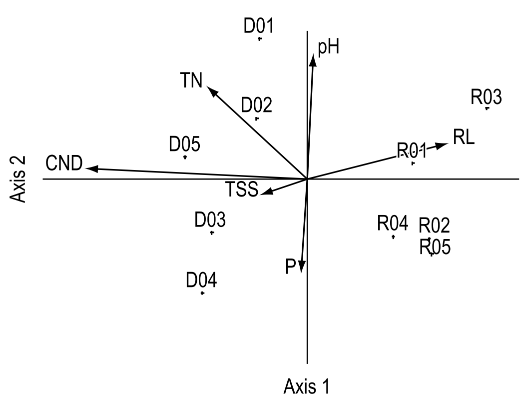

Figure 3. Relationships between the macroinvertebrates communities of the sampling sites and selected environmental variables as shown by Canonical Correspondence Analysis. The environmental variables are indicated as follows: Conductivity = CND, Riffle length = RL; Phosphorus = P; Total Nitrogen = TN; Total Suspended Solids = TSS.

This is in accordance with previous studies done in Cerrado vegetation of central Brazil (Oliveira et al., 1997; Bispo and Oliveira, 1998; Bispo et al., 2004). In studying structure of benthic invertebrate communities in karst systems, Smith et al. (2003) and Barquín and Death (2004) found, similarly, that flow variability may lead to significant temporal variability in aquatic community abundance and structure. In fact, the rainy period of the region under study is characterized by intense periods of rainfall, with rapid increases of water current velocity and flow, with water levels rising up to 3 m above base-flow. These large flow and current velocity increases might lead to the removal of benthic fauna through physical disturbance of the substrate (Flecker and Feifarek, 1994).

Temporary stretches were distinguished by reduced species richness and abundance compared to sites with flow permanence, a pattern that has been reported for many other systems, including both karst and chalk streams in temperate regions (Meyer and Meyer, 2000; Stubbington et al., 2009). The relatively impoverished communities of temporary stretches reflect the inability of many taxa to maintain populations in these sites due to the fluctuation of the height of the water column. The absence of studies in karst tropical regions avoids direct comparison of our results with other studies. Therefore, understanding how this dynamic environment works will only be possible with further studies.

Food availability and shelter could have been more available in the dry season. In the present study, availability of leaf litter, potential food and substrate for the macroinvertebrates (Crisci-Bispo et al., 2007), was higher in the dry period. It is probable that, in the wet period, such material is transported downstream by the current. There is also the possibility that more litter is produced during the dry season through increased rates of leaf-fall from the riparian vegetation (Wantzen et al., 2008).

The high abundance of organisms during periods of low flow may also be related to the reduced availability of habitat area and the consequent increase in individuals' aggregation (Dudgeon, 1997; Diniz-Filho et al., 1998; Bispo et al., 2004).

According to Dudgeon (1997), even if there were no reduction in fauna due to increased removal of organisms in the rainy season, the fact that the available area is decreased in the dry seasons would be sufficient to increase density.

Phosphorous concentration differed between seasons. This nutrient can affect periphyton productivity, and thus food availability, and different concentrations of ammonia could imply differing levels of toxicity (Arthur et al., 1987). However, phosphorus levels were highest and ammonia levels lowest in the wet season, when macroinvertebrates were scarcer, which is the opposite to be expected if periphyton productivity was lower and toxicity higher in the dry period.

Of the most abundant taxa found, Chironomidae is often the numerically dominant component of the benthos (Rabeni and Wang, 2001), while Elmidae is a common family in the tropics (Ramirez and Pringle, 1998; Dudgeon, 1999; Passos et al., 2003). The mayfly family Leptophlebiidae is associated with fast-flowing clean waters (Armitage et al., 1983), and Hydracarina are also common members of the benthos. The absence or scarcity of crustaceans and molluscs is of note, as such organisms are generally favoured by high alkalinity (Giller and Twomey, 1993; Wright et al., 2003). A possible reason for this low degree of representation might be the unstable hydraulic conditions exhibited by this stream (see above). Mollusca and Amphipoda can be more sensitive to removal by floods than other groups such as insects (Death, 2008), although the general poor representation of Amphipoda in tropical streams (Dobson et al., 2002) has also been, at least partially, attributed to low palatability of leaf litter in such systems (Wantzen et al., 2002). Floods have been implicated in reductions of snail density (Holomuzki and Biggs, 1999; Suren and Jowett, 2006). Previous results suggest that snails move to areas of low flow as a response to floods (Holomuzki and Biggs, 1999; Biggs, 2000). However, as revealed by the Indicator Species Analysis, snails were not abundant in the dry season.

The present study is a preliminary description of the macroinvertebrate communities of a karst stream in the center-west of Brazil. This type of environment as well as this region has been very poorly studied to date. These data should provide a basis for future studies, leading to a better understanding of the structure of these aquatic communities.

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