

RESEARCH ARTICLE

Spatiotemporal dynamics in caddisfly (Insecta: Trichoptera) of a Cerrado stream, Brazil

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Abstract – Knowing the patterns and mechanisms that regulate spatiotemporal dynamics in aquatic communities is a great challenge. Theoretically, the distribution of aquatic insects is related to food and shelter availability, and/or to dispersal. In this perspective, we analyzed the spatiotemporal variation of Trichoptera communities of a Cerrado stream for 3 years. The longitudinal and temporal distribution provided a good explanation of the variation of the Trichoptera species composition. Specifically, 21.4 and 11.5% of the variation in composition was explained by longitudinal and temporal variation, respectively, and 8.3% by the interaction of both factors. The variation of environmental conditions (pH, total dissolved solids and dissolved oxygen) and temporal autocorrelation were the most important predictors for the distribution of Trichoptera communities. Accordingly, it is possible to assume that seasonal variation throughout the year is also an important factor for this aquatic community, in addition to water quality, as is widely known. Therefore, climate change should affect both temporal and spatial patterns of Trichoptera communities present in Cerrado streams. Consequently, such effect should be expected to occur in other regions with more marked seasons.

Keywords: aquatic insects / temporal dynamics / seasonality / tropical biodiversity

1 Introduction

Aquatic systems are considered open ecosystems, with continuous longitudinal and temporal variations with respect to the import and export of nutrients and sunlight variations (Allan and Castillo, 2007). The trophic energy of the streams varies spatially, being at first mostly allochthonous (upstream) and gradually becoming autochthonous (downstream) (Vannote *et al.*, 1980). On a temporal perspective, a prominent lateral contribution of nutrients is observed when the water level retracts after a flood pulse, importing organic particles into the streams (Junk *et al.*, 1989). In both processes (longitudinal and temporal), abiotic dynamics modulate species diversity through time and space (Vannote *et al.*, 1980; Junk *et al.*, 1989; Brasil *et al.*, 2017).

One of the most important predictors of variation in the aquatic communities is a set of climatic conditions (Allan, 2004). The central region of Brazil has well-defined dry and rainy seasons (Ratter *et al.*, 1997). This climatic seasonality changes the water flow, dissolved oxygen rates, water temperature, and the litter contribution to the stream channel throughout the year (Giehl *et al.*, 2015), and it leads to a greater habitat heterogeneity in the dry season. Therefore, the greatest diversity of aquatic insects occurs in the dry period (Bispo *et al.*, 2006; Yokoyama *et al.*, 2012). In addition, water quality is an important factor for the distribution of these organisms (Rosenberg and Resh, 1993). The Ephemeroptera Plecoptera and Trichoptera (EPT), for example, are sensitive to changes in water quality (Martins *et al.*, 2017). This is because they lack the physiological plasticity to withstand sudden changes in pH, oxygen, and water temperature (Poff and Ward, 1990). Therefore, in places with changes in water quality, the individuals and/or species of these sensitive groups (EPT) are

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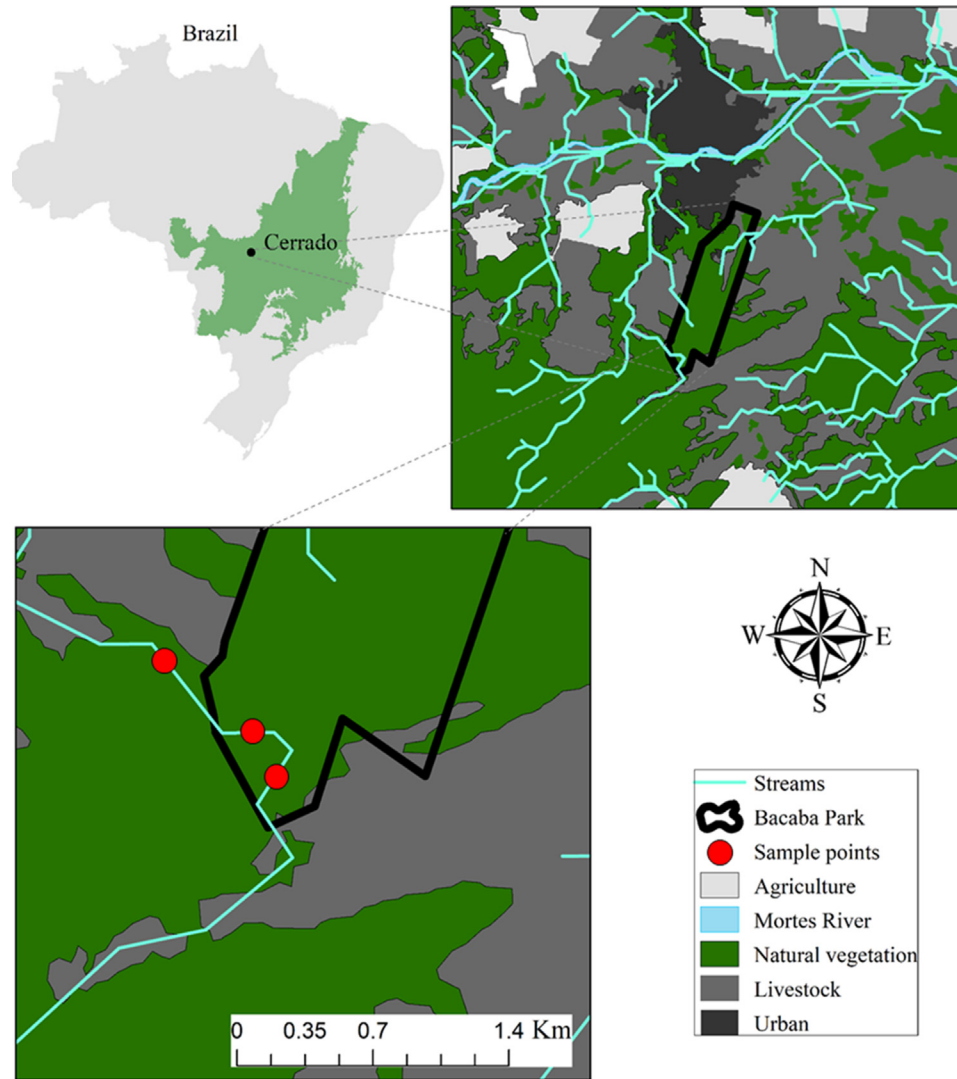


Fig. 1. Sampling sites at the Bacaba Stream, Nova Xavantina, state of Mato Grosso, Brazil.

gradually replaced by more tolerant groups, for example, the Diptera (Martins *et al.*, 2017).

The Trichoptera stand out among the various aquatic organisms for being sensitive to environmental changes (Morse, 2009). These insects are locally abundant, well distributed, and highly diverse in their trophic status and function, allowing them to inhabit tropical and subtropical watercourses, from their headwaters to their mouths, in many regions (Bispo *et al.*, 2001). The key role of Trichoptera is in aquatic ecosystems as fundamental links in the trophic web, and their contribution to the processing of organic material in the ecosystem (Dos Santos and Rodrigues, 2015). In Cerrado streams, the distribution of Trichoptera is related to the natural variation in environmental conditions (throughout the year) (Yokoyama *et al.*, 2012), and spatially the natural environmental variations and/or anthropogenic, for example, changes in land use (Nogueira *et al.*, 2011). Both (temporal and spatial environmental variations) cause changes in the physico-chemical conditions of the water, but changes of anthropic origin may be more intense and/or more frequent, damaging the biotic integrity of the communities (Karr, 1991).

Our objective was to evaluate temporal (along 3 years) and longitudinal variations (along the stream) in the Trichoptera community of a Cerrado stream, Brazilian Midwest region. Our hypothesis is that there is an important interaction between spatial and temporal factors in determining community composition in these environments, given to the influence of climatic seasonality on the entrance of energy and microhabitat formation along the streams.

2 Material and methods

2.1 Study area

Bacaba stream is a second-order stream located in the municipality of Nova Xavantina southwestern of Mato Grosso, Brazil. This stream is part of the Tocantins basin, between the coordinates 14°36' to 14°44' S and 52°22' to 52°17' W (Fig. 1) with 5 km length, surround by natural vegetation (Marimon *et al.*, 2002) and headwaters close to the Mario Viana Municipal Park (Bacaba Park) (Bleich *et al.*, 2009). The Bacaba Park is composed by a mosaic of different Cerrado

forms (grasslands, typical cerrado, cerrado sensu stricto, and cerrado woodlands) (Abad and Marimon, 2008) with predominance of livestock surrounding it (Bleich *et al.*, 2009). There is a waterfall and rocks upstream of the site 1 (P1). In the streambed of the site 2 (P2) are large rocks interspersed with sand. Site 3 (P3) is located near the edge of the park with sandy streambed (Raimundi *et al.*, 2017).

2.2 Data sampling

We analyzed the larvae of the order Trichoptera found in the Bacaba Stream, based on samples of the substrate of the margins. We collected specimens over a 3-year period, in a monthly frequency during the first year, and bimonthly during the following years, at three sites along the stream continuum (Fig. 1), in the upstream (P1), intermediate (P2), and downstream (P3) sectors. We demarcated a linear transect of 100 m, which was subdivided into 20 segments of 5 m at each site, establishing permanent plots with metallic stakes placed on the right margin of the stream. To collect specimens, we used a hand sieve with a diameter of 18 cm and mesh of 250 μm , which was passed three times along the margin of each segment, to provide a single subsample. At the end, the three subsamples collected in the 20 sequences amounted to 60 subsamples of substrate collected at each site, for each date.

The specimens collected were sorted and fixed in 85% alcohol in the field and were identified to the genus level in the laboratory using the keys of Angrisano (1995), Angrisano and Korob (2001), Pes *et al.* (2005), Wiggins (1996), and the morphospecies descriptions found in the “James A. Ratter” Collection and the Collection at the Nova Xavantina University of the State of Mato Grosso (UNEMAT), where the material is deposited.

The environmental variables were measured at 25 m intervals along with the biotic samples, either in situ or in the laboratory. Electrical conductivity, pH, and dissolved oxygen were measured with a Horiba multiparameter probe, water temperature with a digital thermometer, and turbidity, with a desktop turbidimeter.

2.3 Data analysis

A total of 63 sample units were used for all analyses, of which 36 were collected in the first year (monthly in P1, P2, and P3), 18 in the second year (bimonthly in P1, P2, and P3), and 9 in the third (quarterly in P1, P2, and P3) (Supplementary 1). We used a PERMANOVA with two factors to test our hypothesis that the spatiotemporal variation would explain the composition of Trichoptera species. The PERMANOVA tests differences based on randomization of test F (pseudo-F) models (Anderson and Walsh, 2013). With this approach, we partition the variation among time (throughout the years), longitudinal variation (along the stream), and the interaction between space and time (spatiotemporal variation). On the two factors of Permanova, the temporal factor was the season of the year: rainy (January, February, and March), ebb (April, May, and June), dry (July, August, and September), and early rainy (October, November, and December). The second factor (longitudinal) were the collection points: upstream (point 1), intermediate (point 2), and downstream (point 3).

Table 1. Multivariate distance matrix regression between species composition and environmental and temporal variables.

| | F model | R^2 | Pr(>F) |
|-------------------------|---------|-------|---------------------|
| pH | 7.071 | 0.082 | 0.0001 ^a |
| Electrical conductivity | 1.401 | 0.016 | 0.183 ^{NS} |
| Turbidity | 1.781 | 0.021 | 0.078 ^{NS} |
| Total dissolved solids | 2.09 | 0.024 | 0.049 ^b |
| Water temperature | 0.671 | 0.007 | 0.698 ^{NS} |
| Dissolved oxygen | 3.364 | 0.039 | 0.005 ^c |
| PCNM 1 | 2.535 | 0.029 | 0.022 ^b |
| PCNM 2 | 2.704 | 0.031 | 0.018 ^b |
| PCNM 5 | 2.605 | 0.03 | 0.021 ^b |

We used a multivariate distance matrix regression (MDMR) (Anderson, 2001) using environmental and temporal predictors and the composition of Trichoptera species to verify the important mechanisms for spatiotemporal variation. The environmental variables were electrical conductivity, pH, dissolved oxygen, water temperature, and turbidity. The temporal variables were calculated using a principal coordinate analysis of neighbor matrices (PCNM) (Dray *et al.*, 2006) as “temporal filters” to understand how much of the community variation was explained by the temporal distance among samples (temporal autocorrelation) (Brasil *et al.*, 2017). We used the function “pcnm” of the package vegan (Oksanen *et al.*, 2013) to calculate the PCNMs, where the vectors represented the sampling dates (month and year). Subsequently, we conducted a selection to use only the PCNMs needed to solve the temporal autocorrelation bias using the forward.sel of the package packfor (Blanchet *et al.*, 2008).

3 Results

A total of 1202 Trichopteran larvae were collected, representing six families, 10 genera, and 42 morphotypes. The most abundant families were Hydropsychidae ($n=605$ specimens) and Odontoceridae ($n=353$), while the least abundant were Leptoceridae ($n=19$) and Helicopsychidae ($n=3$). The most abundant genera were *Marilia* ($n=354$) and *Leptonema* ($n=320$), and the least abundant were *Macronema* ($n=9$), *Helicopsyche* ($n=3$), and *Oecetis* ($n=2$). The most abundant morphospecies were *Marilia* sp.1 ($n=353$) and *Phylloicus* sp.1 ($n=151$), while nine morphospecies showed only one specimen (Supplementary 2).

The longitudinal distribution (sites) along with the temporal variation (seasons) explained 41.2% of the spatiotemporal variation of the composition of Trichoptera species, of which 21.4% was explained exclusively by longitudinal variation (pseudo- $F=10.945$, $R^2=0.214$, $p=0.001$), 11.5% by temporal variation (pseudo- $F=3.927$, $R^2=0.115$, $p=0.001$), and 8.3% by an interaction between spatial and temporal variation (pseudo- $F=1.418$, $R^2=0.083$, $p=0.046$). Three environmental predictors and three important temporal predictors were observed when we evaluated the environmental and temporal mechanisms predictors of the variation of the Trichoptera species composition. The main environmental predictors were pH, total dissolved solids and dissolved oxygen, and the temporal predictors PCNMs 1, 2, and 5 (Tab. 1).

4 Discussion

The longitudinal distribution of the sites as well as the temporal distribution of the samples were important for the distribution of Trichoptera species in the 3 years evaluated. This corroborates our hypothesis that there is an important interaction between spatial and temporal factors in determining community composition in these environments. Other studies carried out in the same stream but with other taxonomic groups have found similar results of the longitudinal distribution on the distribution of a Heteroptera population (Giehl *et al.*, 2015), and of the temporal variation on rare and common Ephemeroptera communities (Brasil *et al.*, 2017). In addition to a temporal evaluation of zooplankton of reservoirs in the Cerrado (Lodi *et al.*, 2014), these previous evidences along with our results indicate a certain level of synchrony in the spatiotemporal distribution of aquatic species in the Cerrado.

The longitudinal variation occurs due to changes in environmental conditions along the stream. Site 3 (downstream) is environmentally more dissimilar than sites 1 and 2 (headwater and intermediate regions), where light input and depth are greater (Giehl *et al.*, 2015). The river continuum concept theory (Vannote *et al.*, 1980) posits that environments near the source and with great light input are trophically more heterogeneous and combine allochthonous energy derived from the stream banks, with autochthonous energy related to light input (algae and periphyton). It is expected that this point has differences in the Trichoptera community due to loss of environmental integrity and water quality (Pereira *et al.*, 2012), which are common in environments with these characteristics of use of the land (livestock) (Brasil *et al.*, 2014a; Leal *et al.*, 2016).

Communities of aquatic insects from Cerrado streams have higher diversity values in the driest season (Bispo *et al.*, 2001; Yokoyama *et al.*, 2012). This is because the stream channel accumulates more leaf banks in this period, providing an increased heterogeneity (Baptista *et al.*, 2001). Simultaneously, more rare species, which live for only few months of the year as immature individuals, are recorded in the driest season (Brasil *et al.*, 2017). In this work and others (e.g., Bispo *et al.*, 2006; Yokoyama *et al.*, 2012; Brasil *et al.*, 2017), the relation of communities with the variation in the physico-chemical conditions of water was evident, mainly between dry and rainy seasons (Bleich *et al.*, 2009). In addition, there are also intrinsic factors of the species such as the eclosion time of eggs, larval births, and voltinism that are important for its distribution throughout the year (Cayrou and Céréghino, 2005). However, this intrinsic information is totally or partially nonexistent for aquatic insects in the Brazilian Cerrado.

The physical and chemical conditions of the water are very important to jointly evaluate this spatiotemporal variation, since they vary in both time and space (Bleich *et al.*, 2009; Giehl *et al.*, 2015) and are important conditions for the establishment of aquatic insect communities (Couceiro *et al.*, 2012). This was clear in our study when we observed that both the physical and chemical variables of the water, and the temporal filters, were related to Trichoptera composition (Tab. 1). The relation of the communities with the variation of dissolved oxygen and pH is well known (Rosenberg and Resh, 1993). In general, it is expected that Trichoptera live in well-oxygenated

water (Philipson, 1954). Naturally, dissolved oxygen and pH fluctuate throughout the year, especially during the dry season (Bleich *et al.*, 2009; Giehl *et al.*, 2015). In addition, spatially the oxygen in the water decreases and the pH increases in anthropogenic areas (Couceiro *et al.*, 2007; Martins *et al.*, 2017) as in point 3. The total dissolved solids tend to increase in the rainy period due to the entrance of sediments of the margins, and spatially increase in anthropic places where the margins are unprotected by the riparian forests (Johnson *et al.*, 1997). All the mechanisms mentioned above are known to be important for the spatiotemporal distribution of Trichoptera communities.

Among the most abundant families of this work, Hydropsychidae and Odontoceridae, the first has the highest number of individuals and species richness in the study region (Nogueira *et al.*, 2011) and is distributed in different habitat types throughout the neotropical region (Wiggins, 1996; Flint *et al.*, 1999). In Cerrado streams, the family Hydropsychidae has taxa distributed in lentic and lotic environments, and even in anthropized streams (Nogueira *et al.*, 2011), and are abundant during all seasons of the year (Bispo and Oliveira, 2007). The second most abundant family (Odontoceridae) was represented only by genera *Marilia*, which is common in streams with preserved riparian forest (Nogueira *et al.*, 2011; Pereira *et al.*, 2012). This is because they are shredders that depend on the leaves coming from the margins to feed themselves (Brasil *et al.*, 2014b). Therefore, even though the second most abundant taxon in our work, *Marilia* almost did not occur in the anthropized point: abundance of *Marilia* point 1 (276 individuals or 78%), point 2 (73 individuals or 21%), and in point 3 only (5 individuals or 2%) (Supplementary 2).

Our results indicate that the composition of the Trichoptera communities has great spatiotemporal dynamics in the Cerrado streams. The variation of the environmental conditions of the water and the temporal autocorrelation were the most important factors to explain the spatiotemporal dynamics observed. From these indications, it is possible to suppose that seasonal variation throughout the year is also an important factor for these aquatic communities, in addition to their known importance in management of water quality (bioindicators). Therefore, if climate change predictions are correct, spatiotemporal patterns of Trichoptera communities of Cerrado streams will probably be affected, a result that can be extrapolated to other savanna regions with a marked seasonal climate.

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