



# Partitioning taxonomic diversity of aquatic insect assemblages and functional feeding groups in neotropical savanna headwater streams



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## ABSTRACT

Biological diversity can be divided into: alpha ( $\alpha$ , local), beta ( $\beta$ , difference in assemblage composition among locals), and gamma ( $\gamma$ , total diversity). We assessed the partitioning of taxonomic diversity of Ephemeroptera, Plecoptera and Trichoptera (EPT) and of functional feeding groups (FFG) in neotropical savanna (southeastern Brazilian cerrado) streams. To do so, we considered three diversity components: stream site ( $\alpha$ ), among stream sites ( $\beta_1$ ), and among hydrologic units ( $\beta_2$ ). We also evaluated the association of EPT genera composition with heterogeneity in land use, instream physical habitat structure, and instream water quality variables. The percentage of EPT taxonomic  $\alpha$  diversity (20.7%) was smaller than the  $\beta_1$  and  $\beta_2$  diversity percentages (53.1% and 26.2%, respectively). The percentage of EPT FFG collector-gatherer  $\alpha$  diversity (26.5%) was smaller than that of  $\beta_1$  diversity (55.8%) and higher than the  $\beta_2$  (17.7%) diversity. The collector-gatherer FFG was predominant and had the greatest  $\beta$  diversity percentage among stream sites ( $\beta_1$ , 55.8%). Our findings support the need for implementing regional scale conservation strategies in the cerrado biome, which has been degraded by anthropogenic activities.

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## 1. Introduction

Whittaker (1960) first proposed the concepts of alpha ( $\alpha$ ), beta ( $\beta$ ), and gamma ( $\gamma$ ) diversities. In general terms, alpha diversity corresponds to local diversity, beta diversity corresponds to difference in assemblage composition among locals, and gamma diversity corresponds to total regional diversity. In the additive partitioning of species diversity,  $\alpha$  diversity is typically expressed as the mean number of taxa observed at any given scale (Lande, 1996; Veech et al., 2002; Anderson et al., 2011).  $\beta$  diversity is the difference in the  $\alpha$  diversities between two scales in the spatial hierarchy, and  $\gamma$  diversity represents the sum of the  $\alpha$  diversity and all involved  $\beta$  diversities within a given region (Jost et al., 2010). Know-

ing how the taxa of a regional pool are distributed among multiple scales is an important issue in ecology (Jankowski et al., 2009; Heino et al., 2015a). Therefore, evaluating the pattern of diversity distribution through additive partitioning is important when determining scales of major interest for conserving and rehabilitating aquatic ecosystems (Diniz-Filho et al., 2009; Molozzi et al., 2013). Determining the scale where most biological variability occurs helps managers and conservationists focus their efforts and resources where they are most likely to have the greatest effect.

Recent studies focusing on the additive partitioning of species diversity have sought to understand the distribution patterns of assemblages at several spatial scales (Frissell et al., 1986; Rietkerk et al., 2002; Jost et al., 2010; Ligeiro et al., 2010; Ávila et al., 2011). Such studies are needed because ecological processes and distribution patterns vary with the scale of spatial observation, which can range from centimeters to kilometers (Allan and Castillo, 2007). In addition, enhancing the understanding of spatial differences in

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organism interactions with their habitats and the processing of food resources facilitates the refinement of biomonitoring programs. For example, Boyero (2003) showed that assemblages of Ephemeroptera, Plecoptera and Trichoptera (EPT) varied substantially among habitats, streams and basins. So, biotic indices and ranges of measures must be analyzed and calibrated at different scales to adjust for such geographic differences if one wishes to increase the sensitivity of those indices (Stoddard et al., 2008a). Similarly, several authors have shown that habitat heterogeneity, which supports biological diversity in aquatic ecosystems, is organized in a spatial hierarchy (Cortes et al., 2010; Ligeiro et al., 2010; Ávila et al., 2011; Hepp et al., 2012). Determining how biological traits and ecological processes vary with spatial scale aids managers and conservationists in refining biological metrics and indices and in separating natural variability from anthropogenic disturbances.

In lotic ecosystems, local scales show heterogeneity in assemblage structure and abiotic conditions (Ligeiro et al., 2010; Macedo et al., 2014; Heino et al., 2015a). Taxonomic surveys, the evaluation of functional feeding groups (FFGs), and studies of the heterogeneity and distribution of assemblage characteristics among discrete sites are all important for elucidating how taxonomic diversity and biological traits are distributed in ecosystems (Boyero, 2003). In particular, including functional aspects of biological assemblages is important for making more comprehensive assessments of ecological condition than are possible with taxonomic assessments alone. Although FFGs are essential for understanding many processes in aquatic ecosystems, studies of the distribution of the taxonomic composition of functional feeding groups (e.g., predators, shredders, collectors, and scrapers) across spatial scales are lacking for tropical regions (Boyero, 2005). Each of these groups relies on specific food resources, which are in turn influenced by different habitat characteristics. For instance, collector-gatherers feed on fine particulate organic matter (FPOM), and are more common in fine substrates and still waters, whereas collector-filterers position themselves on substrates exposed to flowing water, from which they sieve FPOM that is suspended in the water (Cummins et al., 2005; Merritt et al., 2008). Thus, differences in resources and habitat characteristics (Boyero, 2003) are likely to produce differences in the proportions of various functional feeding groups. Studies dealing only with assemblage taxa richness miss important variations in the functional composition of those assemblages (Marzin et al., 2012; Leitão et al., 2016).

The EPT are generally sensitive to changes in aquatic environments (Bonada et al., 2006; Stoddard et al., 2008a). Because of their sensitivity to anthropogenic disturbances, the EPT are among the most commonly used ecological indicators in large-scale (regional and national) biological assessments (e.g. Stoddard et al., 2008a; Moya et al., 2011; Chen et al., 2014). Therefore, it is useful to evaluate how geographic scale and functional feeding groups (FFGs) affect EPT diversity.

In this study we evaluated how the taxonomic composition of whole EPT assemblages and of individual FFG are distributed among spatial scales, using a hierarchical series of three diversity components in neotropical savanna streams: stream site ( $\alpha$ ), among stream sites ( $\beta_1$ ), and among hydrologic units ( $\beta_2$ ). We evaluated two hypotheses: (i)  $\beta$  diversity is not evenly distributed among spatial scales. Environmental variables at the local scale (e.g., substrate type, current velocity, width and water depth) greatly influence biological communities (Ligeiro et al., 2010; Hepp et al., 2012) and for this reason we expected that taxonomic composition and FFG would show greater variability among sites than among hydrologic units. (ii) Taxonomic diversity distribution follows distinct patterns among the different FFG. Considering that food resources and habitat availability vary at different scales (Boyero, 2003), we expected that individual FFG would display distinct  $\alpha$  and  $\beta$  diversities

and that the partition pattern of whole EPT assemblages would be defined by the partition of the most abundant FFG.

## 2. Material and methods

### 2.1. Study area and site selection

We sampled 160 wadeable stream sites (stream orders ranging from 1 to 3 on 1:100,000 scale maps) (Strahler, 1957) belonging to the Araguari, São Francisco, Rio Grande, and Paranaíba River Basins in the states of Minas Gerais, São Paulo, and Goiás, southeastern Brazil (Fig. 1). The hydrologic units (Seaber et al., 1987) were defined as the contributing drainage areas within 35 km upstream of each of four major hydropower reservoirs (Nova Ponte, Três Marias, Volta Grande, São Simão). The sites are all located in the neotropical savanna, which has a humid tropical and seasonal climate with approximately 1600 mm mean annual rainfall (Brasil, 1992). Regional climate is characterized by a dry season from May–September, with monthly precipitation between 10 and 55 mm, and a rainy season between October–April, with monthly precipitation between 100 and 300 mm. The neotropical savanna, which is one of the most threatened biomes worldwide, is a priority hotspot for biodiversity conservation (Myers et al., 2000). Since the 1950s, agriculture and pasture have progressively replaced natural areas (Diniz-Filho et al., 2009), resulting in clearing of more than half of the original  $\sim 2$  million km<sup>2</sup> forested area (Klink and Machado, 2005; Wantzen et al., 2006). We selected sampling sites by using a randomized, spatially balanced, systematic sample design adapted from one the U.S. Environmental Protection Agency developed for its National Rivers and Streams Assessment (Olsen and Peck, 2008). Each year (2009–2012) during the dry season, we sampled 40 wadeable stream sites in one of the four regions for a total of 160 sites.

### 2.2. Catchment land use and land cover

We classified land use and cover within the catchment upstream of each site by interpreting a combination of high-resolution satellite images (0.6–5.0 m spatial resolution, Google Earth data: Google 2010) and Landsat multispectral satellite images (R4G3B2 false color band combination). This method is very accurate because the high-resolution satellite images better distinguish the shape of units, while multispectral images better distinguish vegetation leaf structure (e.g., more- or less-dense canopy and biomass concentration) (Macedo et al., 2014). We identified four natural vegetation cover types (woodland savanna, grassy-woody savanna, parkland savanna, and wetland palm swamps) and four land uses (pasture, agriculture, *Eucalyptus* forest, and urban areas) in the 160 catchments.

### 2.3. Site physical habitat structure and water quality

We characterized physical habitat structure and water quality at each sampling site with standardized field methods (Kaufmann et al., 1999; Peck et al., 2006); this included multiple metrics of channel morphology, riparian structure, flow type, substrate type, and instream habitat cover (Kaufmann et al., 1999, 2008). Metrics were selected from a master list (see Table 1) by removing redundant metrics through use of correlation analysis and principal component analysis (PCA; Ferreira et al., 2014). To assess water quality, we measured temperature ( $^{\circ}\text{C}$ ), electrical conductivity ( $\mu\text{S cm}^{-1}$ ), pH, turbidity (NTU), and total dissolved solids ( $\text{mg L}^{-1}$ ) in situ with a multi-probe (YSI, 650 MDS, model 6920). Total nitrogen ( $\text{mg L}^{-1}$ ) and dissolved oxygen concentrations ( $\text{mg L}^{-1}$ ) were

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