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The effects of land use at different spatial scales on instream features in agricultural streams

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ABSTRACT

The conversion of forests into agriculture has been identified as a key process for stream homogenization. However, the effects of this conversion can be scale-dependent. In this context, our aim was to identify the influence of different land uses at different spatial scales (catchment, drainage network and local) on instream features in agricultural streams. We defined six classes of land use: native forest, reforestation, herbaceous and shrubs, pasture, sugarcane and other categories. We obtained 22 variables related to instream, riparian area, stream morphology and water physicochemical characteristics in 86 stream reaches. To identify and isolate the effect of different land uses at different spatial scales on instream features, we performed a partial redundancy analysis (p-RDA). Different land uses and scales influenced instream features and defined two stream groups: (i) homogeneous streams with a higher proportion of sand substrate and instream grasses that were associated with the proportion of herbaceous vegetation at the local scale and with pasture at all scales and (ii) heterogeneous streams with a higher physical habitat integrity associated with the proportion of forest and sugarcane at the local and catchment scales. Land use at the catchment scale affected the physicochemical water properties and stream morphology, whereas stream physical habitat (i.e., substrate, instream cover, marginal vegetation and stream physical habitat condition) was mainly influenced by land use at the local scale (i.e., 150 m radius). Pure catchment, drainage network and local land uses explained 9%, 7% and 4%, respectively, of the total variation of instream features. Thus, to be most effective, stream conservation and restoration efforts should not be limited to only one scale.

1. Introduction

Streams are open systems with a strong relationship with their terrestrial surroundings (Hynes, 1975; Allan, 2004). For this reason, the replacement of native forests by agriculture has been identified as a key driver to stream degradation (Wang et al., 1997; Clapcott et al., 2012). Agricultural practices (e.g., soil tillage and the use of pesticides) affect terrestrial-aquatic interactions by increasing siltation, deteriorating water quality, and diminishing allochthonous input such as wood debris (Allan, 2004; Paula et al., 2013). However, streams can be affected differently by these agricultural practices, depending on the spatial scales (Fausch et al., 2002; Feld, 2013; Dala-Corte et al., 2016). For example, shading may be mostly influenced by local canopy, whereas the loading of allochthonous materials is influenced by local and distant upstream segments (Strayer et al., 2003; Paula et al., 2011, 2013).

In addition to the spatial scale, the main land use in each scale (local, riparian zone and catchment) in agroecosystems can determine the stream water quality and physicochemical features (Rasmussen et al., 2011; Paula et al., 2013; Bu et al., 2014; Mori et al., 2015). For instance, the total dissolved phosphate can be positively related to the proportion of pasture in the catchment (Mori et al., 2015). In contrast, the nitrate concentrations can be positively correlated to the proportion of sugarcane at both catchment and riparian scales (Mori et al., 2015) due to the burning of sugarcane biomass (Martinelli and Filoso, 2008; Mori et al., 2015). In addition, Bu et al. (2014) found that forest proportion in the catchment was positively and negatively correlated with the pH and total nitrogen concentration, respectively. Moreover, Paula et al. (2013) found that the proportion of forest in the catchment was positively correlated to large wood abundance in streams channels. Based on the above information, we can say that the comprehension and prediction of the effects of different land uses at multiple scales on instream features are complex and represent one of the highest challenges for stream ecologists (Strayer et al., 2003; Feld, 2013).

Currently, stream conservation and restoration efforts are concentrated mostly at riparian forest since the presence of a forested riparian buffer can mediate the energetic terrestrial-aquatic interactions,

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promote channel stability and physical habitat heterogeneity, and reduce inorganic sediment input (Pusey and Arthington, 2003; Sweeney and Newbold, 2014). For this reason, in highly modified catchments, the presence and quality of riparian forest can help mitigate the consequences of agricultural practices. In this context, spatial scaling or multi-scale analysis can help identify areas and physical processes that affect stream ecosystems and, consequently, suggest where and how land management or restoration are more likely to influence these ecosystems to conserve aquatic biota and ecological functions (Burnett et al., 2006; Sheldon et al., 2012; Feld, 2013). Despite the great importance of scale-related influences, studies evaluating land use effects on instream features at multiple scales are rare in the Neotropical region (but see Mori et al., 2015; Leal et al., 2016), probably due to the difficulties associated with the acquisition and processing of the landscape metrics in the SIG software.

Thus, our aim was to identify the influence of different land use at the catchment (i.e., land use in the entire catchment area), drainage network (i.e., land use within 30 m buffer zone at each streamside) and local radius (i.e., land use in a 150 m radius circle centered on the georeferenced sampling site) scales on instream reach features in a Neotropical agroecosystem landscape. We expected that different spatial scales (catchment, drainage and local radius) would predict instream environmental characteristics but that the effects could vary across instream variables due to different acting mechanisms (Strayer et al., 2003; Mori et al., 2015; Leal et al., 2016).

2. Material and methods

2.1. Study area

We worked in two different river basins, Turvo-Grande and São José dos Dourados, located in the northwest of São Paulo State, Brazil (Fig. 1). This region belongs to the Serra Geral geological unit, with basaltic and sedimentary rocks from the Bauru and Cauiá groups (IPT, 1999). According to Silva et al. (2007), soil presents high erosive potential, consisting mainly of unconsolidated substrates, such as sand and clay. Climate is tropical and hot, with two defined seasons: a dry period between June and September, with milder temperatures and lower rainfall, and a wet period, with higher rainfall and temperatures between December and February (IPT, 1999). Agriculture in this region is not recent, and landscape here has been historically fragmented since the beginning of the last century (1900) with the development of agricultural crops, such as coffee, livestock grazing, and more recently sugarcane (Silva et al., 2007). Originally, the region was covered by Semi-deciduous Seasonal Forest (a sub type of Atlantic Forest) with patches of Savannah ("Cerrado"), but currently, native vegetation is less than 4% of the original area and is restricted to small and unconnected fragments (Silva et al., 2007; Nalon et al., 2008).

2.2. Site selection and land use characterization

We conducted a pre-selection of catchments with areas between 400 and 1400 ha (first- to third-order streams according to the Strahler system). From this, 171 different catchments were filtered and recognized during the fieldwork. Due to accessibility and owners' consent, we sampled 86 streams reaches from independent catchments in the above-mentioned region. We classified the land use in each catchment by using orthorectified aerial photographs ('orthophotos') with a 1-m spatial resolution (years 2010/2011). Overall, we defined six land-use classes: (i) native forest, (ii) herbaceous and shrub vegetation, (iii) reforestation, (iv) pasture, (v) sugarcane, and (vi) other categories of land use (Table 1).

For the digital preparation, processing and classification of the orthophotos, we used the ERDAS IMAGINE 9.2 and ArcGis 9.3 softwares. We used a digital elevation model (DEM) with the SWAT extension (Soil and Water Assessment Tool; SWAT, 2009) for ArcGis 9.3 to delineate catchments boundaries. DEM was obtained from ASTER Global Digital Elevation Model project (ASTER GDEM). We obtained the orthophotos from Empresa Paulista de Planejamento Metropolitano SA – EMPLASA (CLUN° 060/14). We also used the CANASAT project (sugarcane crop monitoring in Brazil; Rudorff et al., 2010) to identify and quantify the sugarcane areas in São Paulo State for 2012.

2.3. Definition of explanatory variables

We evaluated the effects of land use on instream physical habitat on three spatial scales based on Strayer et al. (2003): (i) catchment, which included land use in the entire catchment area; (ii) drainage network, which comprised land use within 60-m buffer zones at the streamsides, with 30 m on each side of the stream (the width usually established by the current Brazilian Forest Code for streams less than 10 m wide); and (iii) local radius, which included land use in a circle (150 m radius) centered on the georeferenced sampling site (adapted from Strayer et al., 2003) (Fig. 2). In addition, to separate the land-use effects on

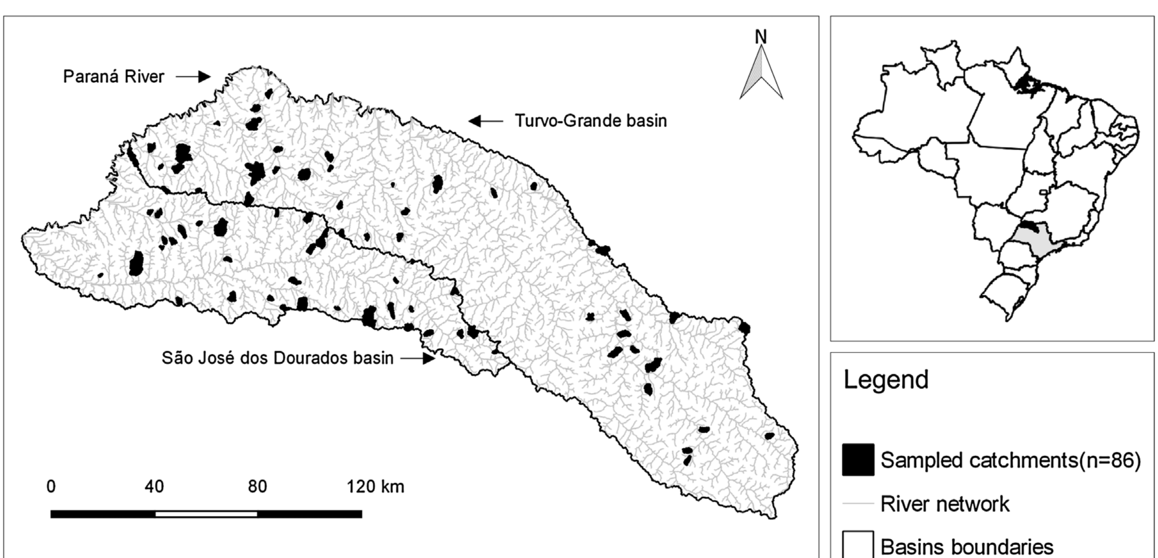

Fig. 1. Location of the sampled catchments in the São José dos Dourados and Turvo-Grande River basins (i.e., 86 independent stream reaches), at the northwest of São Paulo State (black area in the country map), Brazil. Because some catchments are neighbors, they are indistinguishable on the map.