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# Abrupt change of a stream ecosystem function along a sugarcane-forest transition: Integrating riparian and in-stream characteristics

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ABSTRACT

Forest remnants can locally improve water quality of deforested streams in a reset effect, but few studies evaluated if leaf breakdown rates respond to forest remnants or, at a finer spatial scale, to riparian forest structure. We studied leaf breakdown rates along a deforested Neotropical stream as it flowed through a sugarcane/forest remnant transition; we adjusted a non-linear model to describe this relationship, and evaluated whether this model was further related to the effects of riparian forest structure, stream physical characteristics and shredder abundances. Modeled leaf breakdown rates rapidly increased as the stream entered the forest remnant, stabilizing in the forest interior after about 100 m. Observed leaf breakdown rates deviated from the model within the forest remnant. This unexplained residual variation was related to riparian forest structure, which was heterogeneous within the remnant. Leaf breakdown rates were not related to stream physical characteristics, but were significantly related to the abundance of shredders, especially with the dominant leaf-mining Chironomidae. Abundances of leaf-mining Chironomidae were strongly related to both distance along the forest remnant and riparian forest structure. Therefore, higher leaf breakdown rates as the stream flowed through the forest remnant were possibly due to increases in abundances of leaf-mining Chironomidae, which responded to variation at both spatial scales studied. These results suggest that forest remnants are important in rural landscapes not only by improving stream water quality but also by restoring ecosystem functions.



## 1. Introduction

Leaf litter decomposition is an important process in ecosystems and, together with other functional variables, is commonly used to evaluate ecosystem health (Clapcott et al., 2010; Tank et al., 2010). Leaf breakdown rates can respond to gradients of human disturbance in both terrestrial and aquatic systems, and have been used as indicators of changes in ecosystem functions (Gessner and Chauvet, 2002; Young et al., 2008; Silva-Junior et al., 2014). In stream ecosystems, leaf breakdown rates are an important functional variable, since changes in these processes can indicate both changes in the structure of aquatic communities and stream water quality (Webster et al., 1999; Tank et al., 2010). These responses can be integrated at different spatial scales, within streams, among streams, and among watersheds (Tiegs et al., 2009). As the vegetation structure of the riparian zone can strongly influence the aquatic communities by changing physical and chemical characteristics of the stream water and habitat (Storey and Cowley, 1997; Souza et al., 2013), land use changes both at the scales of the stream and watershed can have diverse effects on community structure and ecosystem functions (Kreutzweiser et al., 2008; McKie and Malmqvist, 2009; Clapcott et al., 2012).

Several studies evaluated the relationship between land use and leaf breakdown rates in stream ecosystems, with variable results. For example, leaf breakdown rates can be slower in agriculture streams when compared with forested streams due to the negative effects of pesticides and stream habitat simplification on aquatic organisms (Rasmussen et al., 2012), or because of lower shredder abundances (Piscart et al., 2009; Encalada et al., 2010; Lecerf and Richardson, 2010). On the other hand, leaf breakdown rates in clearcut, agriculture or urban streams can be higher due to nutrient enrichment, higher microbial activity, higher shredder biomass, and higher storm runoff (Paul et al., 2006; Mckie and Malmqvist, 2009). Some studies found similar leaf breakdown rates between reference and impacted streams. Fleituch (2013) found that in reference streams leaf breakdown rates were

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determined mainly by small shredders (e.g., stoneflies), whereas in impacted streams leaf breakdown rates were determined by larger gammarids or dipterans; thus, the reduction of small shredders in impacted streams was balanced by the increase of other shredder groups, enabling the maintenance of this function. Similar leaf breakdown rates between forested and impacted streams were also detected due to differences in the composition of decomposer communities (shredders vs microbes), with greater effects of shredders in forested streams, but higher effects of microbial breakdown in pasture (Hladyz et al., 2010) or agriculture streams (Hagen et al., 2006; Huryn et al., 2002). These results refer to comparisons among streams, but leaf breakdown rates can respond to land use within the riparian corridor, and not necessarily respond to land use at the scale of the watershed, both in temperate (e.g., Sponseller and Benfield, 2001) and tropical systems (Silva-Junior et al., 2014). Also, leaf breakdown rates can differ between streams with similar land use (as in forested watersheds) but distinct structure and composition of riparian forests, even with no changes to the instream fauna (Kominoski et al., 2011).

Within a stream, some studies suggest that reaches with higher proportion of riparian forests upstream (thus with differences in land use) may have higher leaf breakdown rates than downstream, pasture-dominated streams, due to higher abundances of decomposer species, higher dissolved oxygen (DO) concentrations, and lower sedimentation rates (Sponseller and Benfield, 2001; Encalada et al., 2010). However, the characteristics of streams in deforested areas can change as they flow through forest remnants, with changes in stream physicochemistry, and composition and structure of macroinvertebrate communities, sometimes with a local “reset effect” in stream water quality (Harding et al., 2006; Fernandes et al., 2014; Goss et al., 2014; Suga and Tanaka, 2013). These characteristics can also be locally influenced by the structure of the riparian forest, mainly in relation to tree density, mean trunk diameter, and total basal area (Souza et al., 2013). In fact, Fernandes et al. (2014) found that as a tropical deforested stream flows through a forest remnant, DO and nutrient concentrations increase and electric conductivity (EC) decreases but, except for DO concentrations, these variables were also influenced by riparian forest structure, which was not homogeneous along the forest remnant. On the other hand, Goss et al. (2014) found decreased nutrient concentrations as the agricultural streams flowed through forest remnants in Ohio, but no relationship was found between leaf breakdown rates and distance within the remnants. To our knowledge, there are no studies that simultaneously evaluated the effects of the presence of a forest remnant and riparian forest structure on leaf breakdown rates within the same stream.

In this study we sampled the same stream studied at the same time by Fernandes et al. (2014) and Suga and Tanaka (2013) to test the hypotheses that (1) leaf breakdown rates vary as a deforested stream flows through a forest remnant, reducing the effects of deforestation, and (2) that this variation would be related to shredder abundance. As the forest structure was not related to the distance along the forest remnant (Fernandes et al., 2014), we tested the hypothesis that (3) at a finer spatial scale, leaf breakdown rates would be locally influenced by the structure of the riparian forest, stream physical characteristics, and macroinvertebrate shredder communities.

## 2. Methods

### 2.1. Study site

This study was carried out in Vassununga State Park (21°20′–21°55′S, and 47°32′–47°40′W), which is located in the Mogi-Guaçu River watershed in São Paulo state, SE Brazil. The park is subdivided in six main units, which are inserted in a matrix predominantly used for perennial cultures, sugar cane, and pasture (Korman, 2003). We studied the Córrego da Gruta stream, whose source is located within sugar cane, hundreds of meters upstream a forest remnant that constitutes one of the six park units (Capetinga Oeste), with an area of 327.83 ha. Córrego da Gruta is a first-order stream that initially flows through active sugar cane plantation, than abandoned sugar cane plantation, before entering the Capetinga Oeste unit, where it flows through about 1 km along the forest remnant, before reaching the Mogi-Guaçu River. The climate of the region is Cwa according to Köppen classification, with mean annual temperatures between 17.6 °C (July) and 23.5 °C (February), and mean annual rainfall = 1478 mm concentrated in the austral summer months (Setzer, 1966).

### 2.2. Sampling

We sampled three reaches upstream the forest remnant at 150, 100, and 50 m from the remnant edge (denominated in this study −150, −100, −50, respectively), one reach just upstream the border of the forest remnant (point 0), and nine reaches downstream the border, within the forest remnant, at distances 50, 100, 150, 200, 250, 300, 400, 500 and 600 m. Each reach comprised a 50 m stretch of the stream from points −150 to 300, and a 100 m stretch from points 300 to 600 m; a detailed description of the area and sampling points can be found in Fernandes et al. (2014). Stream water characteristics were studied by Fernandes et al. (2014), and macroinvertebrate community structure by Suga and Tanaka (2013). Briefly, the effects of the forest remnant was to increase DO and phosphorus concentrations, decrease electric conductivity, increase macroinvertebrate total abundance but decrease taxon richness and diversity due to an increasing dominance by Chironomidae larvae (Table 1).

Leaf breakdown rates were estimated using 10 × 15 cm nylon bags, with 5.0 mm mesh size. We collected leaves directly from trees of *Cecropia pachystachya* Trécul (Urticaceae), a common tree species in riparian forests of the region; each litter bag was filled with 5.0 g of previously dried leaves. Five litter bags were fixed in the bottom of the stream bed, independently of the mesohabitat present, exactly at each sampling point; each litter bag was placed 5 m from each other. Litter bags were retrieved after 28 days by carefully enclosing each bag in a plastic bag underwater and taken to the laboratory where each sample was washed on a 500 μm sieve to separate the macroinvertebrates from the remaining leaf detritus. Two litter bags were lost, one from the sampling point 300 m and other from the point 500 m. The leaf detritus samples were oven-dried at 70 °C until leaf mass stabilized. Remaining leaf mass was determined with a digital scale (precision = 0.001 g). Leaf breakdown rates were estimated by the proportion of leaf mass loss (% LML) after 28 days as % LML = 1 – (remaining leaf mass/initial leaf mass), following Niu and Dudgeon (2011). The macroinvertebrates were classified to family and categorized in shredders following Cummins et al. (2005); leaf-mining Chironomidae (*Stenochironomus* spp.) were classified as shredders following Chará-Serna et al. (2012) and Henriques-Oliveira et al. (2003).

The structure of the riparian forest was estimated in each reach defined by the sampling points. Four 10 × 10 m plots adjacent to the stream were randomly marked, two in each margin. Within each plot, all trees with diameter at breast height (DBH) ≥ 3.0 cm were measured: circumference at breast height with a measuring tape, and canopy height with a laser hypsometer. The following variables were obtained from each plot: tree density, mean DBH, mean canopy height, total basal area, and vertical canopy structure (estimated by the coefficient of variation of canopy heights within each plot). Forest structure data were analyzed by Fernandes et al. (2014), who carried out a principal components analysis on the five variables to evaluate