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Leaf decomposition and ecosystem metabolism as functional indicators of land use impacts on tropical streams

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ABSTRACT

Organic matter decomposition and ecosystem metabolism have been suggested as promising functional indicators of stream ecosystem integrity, but tests of their applicability to tropical systems are rare. Here, we tested the suitability of the ecosystem processes leaf decomposition (LD), community respiration (CR) and gross primary production (GPP) as functional indicators of catchment and riparian corridor land use impacts on 16 rural, tropical headwater streams. Agricultural and urban land cover contributed 0.0–78.3% and 0.0–8.3%, respectively, to total catchment land cover, and 0.0–61.2% and 0.0–7.8%, respectively, to land cover in a riparian corridor of 20 m width of the investigated streams. Median rates of GPP and CR in the studied streams were 0.4 g O_2 m^{-2} d^{-1} (0.0–1.6, min–max) and 3.3 g O_2 m^{-2} d^{-1} (1.8–15), respectively. According to the double exponential model, median leaf litter decay coefficients of the recalcitrant and the labile litter fraction were 0.006 d^{-1} (−0.017 to 0.016) and 0.15 d^{-1} (0.06–0.86), respectively. While land use in the riparian corridor was correlated to the studied ecosystem processes, whole catchment land use did not exhibit such relations. Nitrogen enrichment and increased CR, both related to urban land use, were the main impacts, indicating that already low levels of urban land cover can have considerable effects on stream integrity in the investigated rural tropical landscape. Although spanning a much wider gradient, agricultural land cover was a less important stressor, and stimulated GPP was related to stream morphology, but not to nutrient enrichment. Leaf decomposition was negatively correlated with both the agricultural and the urban impacts, suggesting that high rates of leaf decomposition are an indicator of pristine conditions in the studied streams. In conclusion, measurements of LD, CR and GPP appear to be suitable, and complementary functional indicators of stream integrity and provided insights into mechanisms of land use impacts on streams in tropical rural catchments.

1. Introduction

Streams and rivers provide important services to society, such as water and food supply, waste processing and opportunities for recreational activities (Postel and Carpenter, 1997; Covich et al., 2004). However, running waters are especially vulnerable to human impacts, particularly to those related to land-use alteration and agricultural intensification (Giller et al., 2004; Vörösmarty et al., 2010). Land use change is a global phenomenon that subjects aquatic ecosystems to a wide range of stressors, such as nutrient enrichment, habitat loss (Giller et al., 2005; Rasmussen et al., 2012) and changes in organic matter and light supply (Postel and Carpenter, 1997; Malmqvist and Rundle, 2002; Snyder et al., 2003). Among the multiple impacts that human activities exert on Neotropical aquatic systems, organic carbon and nutrient enrichment from point sources, as well as physical pollution due to fine sediment inputs from mining activity, and erosion on pastures and crop plantations, appear to be dominant impacts (Martinelli et al., 1999; Mol and Ouboter, 2004; Wantzen, 2006; Gücker et al., 2009).

Running waters are strongly connected to their riparian zone, which usually regulates aquatic carbon metabolism by shading and allochthonous matter input (Wallace et al., 1999) and represents a buffer against nutrient, sediment and contaminant pollution (Sweeney et al., 2004). Accordingly, land use alteration in the riparian zone disrupts the aquatic–terrestrial linkage (Snyder et al., 2003) and can have adverse consequences not just for stream biodiversity, but also for important ecosystem processes, such as primary production, ecosystem respiration and nutrient cycling (Snyder et al., 2003; Sweeney et al., 2004; Lepori et al., 2005).

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Riparian forest protection is thus considered to be necessary to preserve the biological and functional integrity of river systems (Gregory et al., 1991; Sweeney et al., 2004).

To manage and mitigate human impacts on running waters, it is necessary to know how to adequately assess their ecological integrity, as well as understanding the mechanisms involved in the observed modifications, and their whole-system consequences (Young et al., 2008; Palmer and Filoso, 2009; Holt and Miller, 2011). The majority of bioassessment programs are based on structural ecosystem characteristics, such as community composition of macroinvertebrates (Buss and Borges, 2008; Death et al., 2009), algae (Power et al., 2009), fish (Stephenson and Morin, 2009; Friberg et al., 2009) and macrophytes (Friberg et al., 2009), as well as morphological characteristics of the channel and riparian zones (Sirombra and Mesa, 2012). Chemical characteristics of stream water are often used as environmental indicators, but may be inappropriate for the evaluation of ecological aspects of rivers, mainly because they do not adequately represent the temporal dimension of impacts (Rosenberg and Resh, 1993; Holt and Miller, 2011). The use of multiple indicator types, which can have contrasting and complementary responses, is often necessary or advantageous (Bunn et al., 2010; Clapcott et al., 2012).

Functional indicators of stream ecosystem integrity have the potential to provide insights that cannot be gained through structural indices (Niyogi et al., 2013). Nevertheless little attention is given to measures of ecosystem processes in monitoring programs, despite the fact that such measures are often closely related to valuable ecosystem services provided by running waters (Palmer and Filoso, 2009). Ecosystem processes are controlled by a broad range of variables, integrate environmental condition through time, and are the result of numerous interactions between different structural (i.e., biological, chemical and physical) ecosystem components. Accordingly, their potential to detect environmental impacts is high (Gessner and Chauvet, 2002; Young et al., 2008). The use of ecosystem processes as functional indicators has the additional advantages of not being restricted to a set of indicator species, allowing for comparisons between different biogeographic areas (Bunn and Davies, 2000; Clapcott et al., 2010) and that taxonomic expertise is not required. However, the wide response range of functional indicators of ecosystem integrity can lead to difficulties in data interpretation, mainly under multiple stressor scenarios (Gücker et al., 2009), and detailed knowledge on impact mechanisms is thus crucial.

The potential applicability of different ecosystems processes, such as nutrient retention (Gücker et al., 2006; Sobota et al., 2012), ecosystem metabolism (Young et al., 2008; Gücker et al., 2009), secondary production (Buffagni and Comin, 2000; Gücker et al., 2011) and leaf decomposition (Young et al., 2008; Silva-Junior and Moulton, 2011) as ecological indicators of stream integrity is well established. Especially leaf decomposition and ecosystem metabolism appear to respond well to land use alteration (Bunn et al., 1999; Young and Huryn, 1999; McKie and Malmqvist, 2009; Gücker et al., 2009). As both processes are relatively simple to measure and are associated with low measurement costs, they have frequently been recommended for monitoring purposes (Bunn and Davies, 2000; Gessner and Chauvet, 2002; Mulholland et al., 2005; Young et al., 2008).

However, a few studies did not find clear responses of ecosystems processes to land use alterations. Danger and Robson (2004) and Hagen et al. (2006) did not detect differences in decomposition rates between natural and agricultural land use categories, whereas several environmental variables, such as nutrient concentrations, temperature and invertebrate community composition differed. Such lacks of decomposition response have been attributed to the fact that land use changes may simultaneously alter factors that act antagonistically on decomposition rates (Hagen et al., 2006; Pérez et al., 2011; Aristi et al., 2012). Decomposition may also respond differently to environmental factors in different climatic regions, complicating its use as a universal ecological indicator (Pozo et al., 2011; Pérez et al., 2011). Ecosystem metabolism usually responds well to land use alterations, especially in the riparian zone, but limited responses of ecosystem metabolism to land use change (Clapcott et al., 2012), and simultaneously acting antagonistic stressors (Gücker et al., 2009), as well as non-linear response patterns (Young and Collier, 2009) have been reported. The scale of land use change also appears to be an important consideration. Sponseller and Benfield (2001) showed that decomposition responded to land use changes in a 1 km riparian corridor, but not on catchment scale, which may be related to the fact that proximal land use in the riparian corridor affects riparian vegetation structure more strongly than distal land use (Fernandes et al., 2011).

In conclusion, measurements of ecosystem processes may be promising indicators of stream ecosystem integrity, given that stressor interactions, impact mechanisms, response patterns and applicable spatial scales are sufficiently known and considered. The objective of the present work was to test the suitability of ecosystem metabolism and leaf decomposition as functional indicators of land use impacts on tropical headwaters. More specifically, we investigated relationships between (1) land use, both in a 20 m riparian corridor and in the entire catchment, (2) structural ecosystem characteristics, such as stream morphology and water chemistry, and (3) stream ecosystem functioning along a pristine–agricultural–urban land use gradient across 16 rural streams in the transition zone between the Brazilian Cerrado savanna and the Atlantic rainforest.

2. Materials and methods

2.1. Study sites

The investigated headwater streams were located in the Rio das Mortes catchment, a fourth-order tributary to the Rio Grande in the upper Paraná basin. The Rio das Mortes catchment lies in the transition zone between the Cerrado savanna and the Atlantic rainforest biomes in the Federal State of Minas Gerais in southeastern Brazil. The tropical climate of this region is characterized by warm, rainy summers (September–March) and mild, dry winters (March–September). Soils of the region are typically acidic, rich in iron and manganese, and poor in nutrients. Land cover in the catchment is dominated by native vegetation (52.0% of total catchment area), followed by agriculture (mainly pasture, 30.2%; crops, 5.6%; open soil and burnt areas, 7.3%; and eucalyptus, 1.3%) and urban cover (urban areas, 1.2%; roads, 2.0%; railways, 0.2%; and mines, 0.1%) (unpublished data). We selected study sites at 16 headwater streams based on official land use maps and Landsat images. Sites were selected to comprise a wide gradient of predominant land cover in the sub-catchments upstream of study sites, ranging from pristine vegetation to high proportions of agricultural and urban land cover, but also to exhibit longitudinally uniform channel conditions and vegetation cover upstream of each sampling site. Leaf decomposition experiments were performed in the transition between winter and summer (between August 26 and October 17, 2010) to avoid flash floods, and all other measurements were made in the first two weeks of this period.

2.2. Catchment characteristics

Land use characterization of the entire Rio das Mortes catchment was performed with ArcGIS (Esri, Redlands, CA, USA) and ERDAS Imagine (Intergraph, Huntsville, AL, USA) adopting supervised classification techniques (Jensen, 1996; Hirsch, 2003; Landau