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ORIGINAL ARTICLE

Organic matter dynamics in a savanna transition riparian zone: Input of plant reproductive parts increases leaf breakdown process

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ABSTRACT

The dynamics of coarse particulate organic matter (CPOM) drives the functioning of most low order freshwater ecosystems. We evaluated plant litter input, litterfall, leaf litter breakdown rates, and the aquatic invertebrate community over the course of one year in a stream situation in a transition zone between savannah and Atlantic forest. Total organic matter input (litter fall) was 335 g m^{-2} yr^{-1}, which was mainly composed of leaves (50%). Higher values are found in the transition from dry to rainy season (September and October), probably in response to water stress. The remaining leaf mass (65% on average) was lowest in May (49%) and highest in August (79%). CPOM productivity in this transition riparian zone is higher than in other savannah systems, but lower than in Atlantic forest. The higher leaf litter breakdown in May was likely accompanied by environmental enrichment due to increase in fruits and flowers (high energy resources). The coefficient of decomposition was classified as fast (k= -0.016) and showed a positive relationship with water flow (increase in physical abrasion). Collected invertebrates were classified as 6% shredders and 12% scrapers. The remaining leaf mass showed a negative relationship with scraper abundance, highlighting the importance of these trophic groups in tropical streams. We can conclude that climate factors (*e.g.*, rainfall) directly affect the input and quality of CPOM and, consequently, leaf decomposition in savanna/Atlantic forest transition zones.

Key words: Decomposition; input of organic matter; mixing of leaves; scraper; shredders; vertical input.

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INTRODUCTION

Riparian vegetation represents a transition zone between terrestrial and aquatic ecosystems (Naiman *et al.*, 2005; Tank *et al.*, 2010). Riparian zones display ecological functions such as bank stabilization, water control (quality and quantity), organic matter (OM) input, and conservation of biological diversity (Allan, 2004; Allan and Castillo, 2007). The vegetation in these areas also serves as a source of energy for aquatic ecosystems by providing allochthonous OM (Webster and Meyer, 1997; Tank *et al.*, 2010). The input of coarse particulate organic matter (CPOM) accounts for approximately 90% of the allochthonous OM in headwater streams (Campbell *et al.*, 1992), mainly in closed canopy areas, by decreasing photosynthetic production (Tank *et al.*, 2010; Graça *et al.*, 2015). Evaluation of CPOM throughout the year is thus important for understanding OM cycling in riparian zones (Abelho, 2001), mainly in tropical streams (Rezende *et al.*, 2016). Studies addressing ecological processes in tropical streams have emerged only in the last decade (Gonçalves *et al.*, 2006a; França *et al.*, 2009; Lisboa *et al.*, 2014; Rezende *et al.*, 2016).

CPOM fractions (leaves, flowers, fruits, and branches) are transformed to fine particulate organic matter (FPOM) and later into dissolved organic matter (DOM) by decomposing organisms (Gessner *et al.*, 1999; Graça *et al.*, 2015). The mineralization of OM by decomposition is a continuous process in trophic webs, which can be influenced by biotic and abiotic factors (Gessner *et al.*, 1999; Graça *et al.*, 2015). For example, higher water nutrient concentrations can increase the rate of leaf litter breakdown by increasing the activity of decomposers (Gonçalves *et al.*, 2007; Rezende *et al.*, 2014). Chemical characteristics of the leaf litter also impact organic matter dynamics and nutrient cycling in these environments (Wantzen *et al.*, 2008; Rezende *et al.*, 2014; Graça *et al.*, 2015). Leaf litter with higher concentrations of secondary compounds (*e.g.*, polyphenols), structural compounds (*e.g.*, lignin and cellulose), and hardness can decrease litter quality and breakdown rates (Wantzen *et al.*, 2008; Rezende *et al.*, 2014; Graça *et al.*, 2015).

Fungi, bacteria, and benthic invertebrates are the main decomposer organisms in the transformation of CPOM to FPOM and DOM (Gessner *et al.*, 1999; Graça, 2001; Graça *et al.*, 2015). Aquatic fungi (*e.g.*, hyphomycetes) can mineralize litter through enzymatic action, driving the breakdown of structural and recalcitrant compounds (*e.g.*, lignin and cellulose). On the other hand, bacteria decompose labile molecules (*e.g.*, secondary metabolites), manly in the initial stage of this process (Gessner *et al.*, 1999; Graça, 2001; Graça *et al.*, 2016). Microbial communities are also responsible for the nutritional enrichment of litter, increasing palatability and facilitating litter use by benthic macroinvertebrate shredders and scrapers (Graça *et al.*, 2015; Sales *et al.*, 2015). Although some tropical streams have high density and richness of shredders (Cheshire *et al.*, 2005; Allan *et al.*, 2009), most studies report low numbers (Boyero *et al.*, 2011, 2012; Rezende *et al.*, 2015) compared scrapers, which function in leaf fragmentation by consuming periphyton in these systems (Wantzen and Wagner, 2006; Gonçalves *et al.*, 2012a).

In South American savanna streams, litterfall occurs mainly in the dry season due to hydrological stress (Gonçalves and Callisto, 2013; Gonçalves *et al.*, 2014a). Leaf litter breakdown may vary throughout the year, stimulated by increases in temperature (higher metabolism in the system), density of decomposer communities (microorganisms and invertebrates), nutrient concentrations (manly nitrogen and phosphorus), and water flow (fiscal abrasion) (Gonçalves *et al.*, 2014b; Graça *et al.*, 2016). However, the majority of tropical studies evaluate only i) specific species of litter; ii) specific sample periods (60 to 90 days, manly in dry season); and iii) leaves collected outside of the riparian vegetation of the study stream. This methodological approach may negligence the high species number in tropical riparian zones and the mixing effects on the leaf litter input and breakdown in this system (Gessner *et al.*, 2010).

Only two studies have been carried out in tropical streams, which measure aggregate leaf litter breakdown and litter fall input over the course of one year (Sales *et al.*, 2015; Rezende *et al.*, 2016). According to Rezende *et al.* (2016), this approach produces results that are more realistic in terms of measurement of litter breakdown, as they reflect seasonal variation in litter quality throughout the year. Another interesting aspect that has not been previously investigated is riparian zone litter dynamics in transition biomes (*e.g.* savannah and rainforest). Our hypotheses were constructed based on tropical studies of leaf litter breakdown and litter fall(Sales *et al.*, 2015; Rezende *et al.*, 2016), and in the transition characteristic of studied riparian zone, as follows: i) the total CPOM input will be higher than savanna riparian zones (less productive by lower rainfall), but lower than Atlantic rainforest (more productive due to higher rainfall); ii) the CPOM will peak during the transition from dry to rainy season (due to hydric stress and mechanical removal by rain); and iii) seasonal changes will accelerate leaf breakdown in rainy season due to increase in physical abrasion and decomposer community activity (higher metabolisms). This study aims to describe the litter input and leaf breakdown of allochthonous CPOM over one year in a savanna stream.

METHODS

Study area

The study was conducted in the Boleiras stream (first order) in the Rio Preto State Park, Minas Gerais, Brazil (18°07’04” S - 43°20’42” W). The stream is located in the upper region of Jequitinhonha Valley in the Espinhaço Mountain complex, which has an average altitude of 800 meters. The climate regime is a tropical AW (with a dry winter), with a rainy season from November to March (average rainfall 223 mm) and a dry season from June to August (average rainfall 8 mm; http://hidroweb.ana.gov.br/).

Input of organic matter

Litterfall was measured monthly from January to December 2012. We selected 5 sampling points spaced 20 meters apart, for a total length of 100 meters along the stream (for details, see Sales *et al.*, 2015; Rezende *et al.*, 2016). The litter directly entering the stream (vertical input, VI) was measured at each sampling point using 3 rows of 6 buckets each ($0.53\ m^2$) (*i.e.*, a total of 18 buckets per point at 5 points = 90 replicates) suspended 2 m above the stream with ropes, which were transversely displayed in 5 rows (points were used as replicates: 5 points x 11 months = 55 replicates). The bucket bottoms were perforated to allow rainwater to evacuate. At monthly intervals, accumulated litter in the buckets was retrieved and weighed *in situ* (wet weight), and the contents of the bucket with the highest leaf litter mass in each row was used for the leaf litter breakdown experiments (see below). The contents of the remaining buckets (5 buckets in each row, which were not used in the leaf litter breakdown experiment) were oven dried to a constant mass (60ºC, 72 h), and the resulting weight was used as a correction factor to estimate the moisture of the litter used in the leaf litter breakdown experiment. The dry material was separated into the following categories: leaves, branches, reproductive material (flowers and fruits), and ‘miscellaneous’ (unidentified particulate organic matter).

Leaf litter breakdown and aquatic invertebrates

For this analysis, we used the leaves from the vertical input that were collected in 15 buckets above the stream; the leaves were weighed and placed in 15 litter bags (30 × 30-cm, with a 10-mm mesh), and submerged (leaf litter from one bucket for one litter bag) in the stream for 30 days (until the next sampling period). The amount of material placed in the bags ranged from 1 to 3 g (litter bags having different sample weight due to monthly changes in litterfall throughout the year), and after one month, the leaf litter samples were removed and replaced with new ones (for additional information, see Sales *et al.*, 2015; Rezende *et al.*, 2016). The collected litter bags were transported to the laboratory in a cooler. According to Rezende *et al.* (2016), the use of bulk litter instead of leaves from known species better reflects decomposition at a site, representing a more realistic measurement of litter breakdown by accounting for seasonal variation in litter quality.

The remains of the leaf litter were washed with distilled water over a 250 µm sieve in the laboratory, and the collected invertebrates were fixed in 70% ethanol. Invertebrates were later identified to family and genus, and classified into functional trophic groups as follows: gathering-collectors, filtering-collectors, shredders, scrapers, and predators, according to Hamada *et al.* (2014), Pérez (1988), Merritt and Cummins (1996), and (Cummins *et al.*, 2005). Leaf discs (12 mm diam.) were removed with a cork borer from five randomly selected leaves, and the 5 discs were used to determine ash-free dry mass (AFDM; for correction of inorganic compounds). We calculated the AFDM by subtracting the ash weight (muffle in 750°C for 4h) from dry weight. The remaining leaf litter was placed in aluminum trays and dried in an oven at 60°C for 72 h to determine dry weight. Due to the high water flow and safety concerns during litterbag installation, the leaf breakdown experiment could not be performed from January to March.

Physical and chemical parameters of water and leaf litter

A multianalyzer (model 85, YSI Inc., Yellow Springs, OH, USA) was used to measure *in situ* temperature (°C), electrical conductivity (µS cm^{-1}), pH (measured using YSI's EcoSense pH100A), and dissolved oxygen (mg L^{-1}). On each sampling occasion, we measured current velocity (m s^{-1}) using a flow meter (Sigma Sports model FP101, Global Water Instrumentation, Inc., Gold River, CA, USA), and the depth and width of the stream with measuring tape. Rainfall and air temperature data (mean values for the entire month) were obtained from a meteorological station (number 1843015) of the National Water Agency of Brazil (http://hidroweb.ana.gov.br/).

Total polyphenol and tannin concentrations were estimated per 100 mg of leaf litter as proposed by Bärlocher and Graça (2005) and Graça and Bärlocher (2005), respectively. Phenolic concentrations were estimated per leaf after 30 days of incubation. The initial concentration per leaf was not measured for the breakdown experiment.

Statistical analyses

We are describing a case study (in a single stream) and therefore, the results and inference only relate to this stream. All analyses were performed in R version 3.3.0. Data normality was assessed with a Kolmogorov-Smirnov test, and homogeneity of variance was assessed with Levene's test; values were ln (+1) transformed if necessary. Differences in litterfall between the vertical inputs (points as replicates) and the inputs (response variables) over time (explanatory variable) were analyzed by repeated-measures ANOVA (RM-ANOVA; Crawley, 2007), and a contrast analysis was used to assess differences among months (Crawley, 2007). In this contrast analysis (orthogonal), the months were ordered by increasing input values and tested in a pairwise fashion (with the months with the closest values). Stepwise model simplification was performed by sequentially adding monthly values that did not affect the model, and testing against the next month in the sequence (for more details, see chapter 9 in Crawley, 2007).

Monthly leaf litter breakdown rates (*k*) were obtained from a model assuming negative exponential mass loss during the 30 days of incubation ($W_t = W_0 e^{-kt}$: Wt = remaining weight; W_0 = initial weight; -*k* = decay rate; t = time). RM-ANOVAs and contrast analyses were used to test for significant differences among months (explanatory variable) in the remaining mass in the litter bags, and the abundances of scrapers and shredders (response variables). The average values of 5 points along the stream were used as repeated measures (over the months). A one-way ANOVA was used to test phenol and tannin concentrations (dependent variable) over the months (explanatory variables) (Crawley, 2007), and associations between variables were assessed using a Spearman's correlation test (Crawley, 2007). A multiple linear regression was used to evaluate relationships between remaining mass and climate variables (air temperature and precipitation), physical and chemical water properties (dissolved oxygen, conductivity, pH, current speed, and water flow), the decomposer community (scrapers and shredders), and chemical characteristics of leaves (initial tannins, and initial and final phenols) (Crawley, 2007). In multiple linear regression, the beta coefficients represent the independent contributions of each independent variable to the prediction of the dependent variable. This type of correlation is also referred to as a partial correlation.

RESULTS

Water and leaf litter physical and chemical parameters

Rainfall during the study period was low (mean of 10±37 mm; Fig. 1) with peaks in January and November. The average annual flow rate was 0.25 m^3 s (±0.1), and water temperature ranged from 18 to 22°C, with air temperature ranging from 16 to 23°C. The water stream was circumneutral, with low electrical conductivity but high levels of dissolved oxygen (Tab. 1). The average concentrations of secondary compounds were 5% tannins and 11% phenols for total litter mass throughout the year. Higher leaf litter tannin concentrations (12%) were observed in August (ANOVA; $F_{(8,\ 85)}$= 3.56; P=0.001), but the concentration of phenols did not change over time (ANOVA; $F_{(8,\ 85)}$= 1.85, P=0.078).

Organic matter input

Total OM input (litterfall) over the 11-month study period was 335 g.m^{-2} year $^{-1}$ or 30±5 SE g.m^{-2} month^{-1}, indicating an annual average of 360±5 g.m^{-2} year^{-1}. Leaf litter was the OM category with the highest annual contribution (50%) and two input peaks, one in April and another in September and October (Tab. 2; Fig. 2). The lowest values occurred in the dry season from June to August. Branches had the second largest contribution (31±3%), with an input peak in November that coincided with higher rainfall (Tab. 2; Fig. 2). Flowers and fruits contributed 18% (±1) of the total OM, with an input peak in May (Tab. 2; Fig. 2). Miscellaneous OM made the smallest contribution with 2% (±1), which did not change throughout the year. Branches positively correlated with rainfall (r=0.63, P=0.03), but there were no significant correlations among any other categories of OM input with either rainfall or air temperature (P>0.05).

Leaf litter breakdown rates

The average remaining mass was 65% (±3) over the year, with lower values in May (49%) and higher values in August (79%). The mean decomposition coefficient ("*k*") was -0.016, ranging from -0.008 (August) to -0.029 (May). Similar to that observed for vertical input litterfall, the remaining leaf mass showed a bimodal distribution with two peaks, the first in August and the second in November and December (Tab. 2; Fig. 3). The remaining mass (adjusted R^2 = 0.76, $F_{(3,5)}$= 7.44; P=0.03) showed a positive relationship with water flow (Beta= 0.70) and water temperature (Beta= 0.38), but a negative relationship with scraper abundance (Beta= -0.42). The remaining mass was not affected by the other variables tested.

Aquatic invertebrate communities

The density of invertebrates that colonized the leaf litter ranged from 260 (October) to 9 individuals g^{-1} (November),

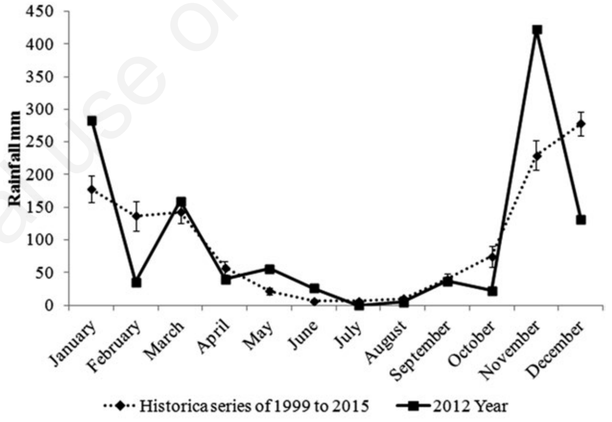

Fig. 1. Monthly values (total ± SE) for historical rainfall from 1999 to 2015, and in 2012.

Tab. 1. Dissolved oxygen (DO), electrical conductivity (cond.), water temperature (WT), pH, current velocity (WV), water flow, air temperature (AT) and total precipitation (rainfall) in the Boleiras stream (January to December 2012).

Month	DO (mg L^{-1})	Cond (µS cm^{-1})	WT (°C)	pH	WV (m $^{-1}$)	Flow (m^3 s^{-1})	AT (°C)	Rainfall (mm)
January	—	—	—	—	—	—	20.35	346.90
February	—	—	—	—	—	—	20.80	44.60
March	—	—	—	—	—	—	20.55	127.90
April	8.03	3.72	21.68	5.10	0.22	0.08	20.65	41.70
May	8.27	3.38	19.26	6.01	0.19	0.11	18.15	66.30
June	9.82	3.18	18.08	6.14	0.25	0.12	18.10	19.80
July	9.12	3.02	15.96	6.01	0.26	0.13	17.10	2.70
August	13.84	3.16	19.44	6.16	0.16	0.09	16.00	12.10
September	10.03	3.91	21.19	6.65	0.17	0.10	19.60	17.40
October	6.22	4.66	22.92	6.51	0.09	0.06	20.65	52.70
November	5.14	16.08	22.62	6.23	0.76	1.48	20.10	362.20
December	5.60	11.65	22.81	6.22	0.18	0.10	22.80	112.30
Mean	8.45	5.86	20.43	6.11	0.25	0.25	19.57	100.55

averaging 117 (±9 SE) ind g^{-1}. The average richness over the year was 10, and was lowest in November (2 *taxa*) and highest in October (15 *taxa*). During the study period, 10,038 invertebrates were collected that were associated with leaf litter, with the most abundant *taxa* being Tanypodinae (25%), Chironominae (19%), and Orthocladiinae (16%) in the family Chironomidae (Diptera), which represented 60% of the collected individuals.

Only 6% of all invertebrates were classified as shredders, with the highest values observed in August (12%) and November (13%) (Tab. 2; Fig 3). The shredder trophic functional group was represented by *Triplectides* sp., *Notalina* sp., *Marilia* sp., *Phylloicus* sp. (Trichoptera), *Paragripopteryx* sp. (Plecoptera) and *Hyalella* sp. (Crustacea; Tab. 3). The total relative abundance of scrapers was twice more (12%) than that of shredders, with significantly higher values in July (18%) compared to other months (Tab. 2; Fig. 3). The 'scraper' trophic functional group was represented by *Oxyethira* sp., *Neotrichia* sp., *Metrichia* sp., *Helichopsyche* sp. (Trichoptera), *Miroculis* sp., *Hagenulopsis* sp., *Farrodes* sp. and *Askola* sp. (Ephemeroptera) (Tab. 3).

DISCUSSION

Organic matter input

The total litter fall input in this transition system (360 to 365 g m^{-2} $year^{-1}$) was higher than other savanna sys-

Tab. 2. Results from RM-ANOVA and contrast analyses (P<0.05) for organic matter categories (total OM, leaves, branches, flowers and fruits (Fl + Fr), and miscellaneous), percentage of remaining mass, and relative abundances of shredders and scrapers individually and summed (Sh + Sc) in the Boleiras stream.

	DF	SS%	F	P	Contrast analysis
Total organic matter					
Error	1	0.2			
Month	10	21.6	4.161	<0.01	M < September = October = November
Residual	43	78.3			
Leaves					
Error	1	0.1			
Month	10	37.2	8.996	<0.01	M < April = September = October
Residual	43	62.7			
Branches					
Error	1	0.1			
Month	10	19.4	3.667	<0.01	M < November
Residual	43	80.5			
Fl + Fr					
Error	1	2.2			
Month	10	18.0	3.405	<0.01	M < May
Residual	43	79.8			
Miscellaneous					
Error	1	0.1			
Month	10	7.8	1.304	0.233	
Residual	43	92.0			
Remaining mass					
Error	1	5.6			
Month	8	21.4	3.412	<0.01	May < M < November = December = August
Residual	35	73.0			
Shredders					
Error	2	0.9			
Month	8	18.0	3.019	<0.01	M < August = November
Residual	34	81.1			
Scrapers					
Error	2	7.8			
Month	8	13.7	2.376	0.02	M < July
Residual	34	78.5			
Sh + Sc					
Error	2	8.1			
Month	8	11.9	2.03	0.04	M < November
Residual	34	80.0			

DF, degrees of freedom; SS%, sums of squares; M, other months.

tems (288 to 336 g m^{-2} year^{-1} in Gonçalves *et al.*, 2006a; França *et al.*, 2009; Gonçalves and Callisto, 2013; Rezende *et al.*, 2016), but lower than typically found in tropical rainforests (113 to 2812 g m^{-2} year^{-1} in Abelho, 2001; Chara *et al.*, 2007; Gregório *et al.*, 2007; Zhou *et al.*, 2007; Alvarez *et al.*, 2009; Cogo and Santos, 2013; Lisboa *et al.*, 2014). Savanna systems (*e.g.*, the Cerrado) and tropical rainforests (*e.g.*, Atlantic forest and the Amazon forest) have a different precipitation range, which explains the differences in productivity (Gonçalves and Callisto, 2013; Gonçalves *et al.*, 2014a). Therefore, the transition zone between Cerrado and Atlantic forest, as in this study area, may have intermediate patterns in plant productivity in riparian zones.

Total CPOM in the litterfall was seasonal, with peaks in dry and rainy season. Leaves were the highest fraction in of CPOM, as shown in other tropical studies (Wantzen *et al.*, 2008; Alvarez *et al.*, 2009; Chave *et al.*, 2010; Tank *et al.*, 2010; Zhang *et al.*, 2014; Rezende *et al.*, 2016). The higher leaf biomass and total CPOM in the transition period is also consistent with other studies of savanna (Gonçalves *et al.*, 2006a; Gonçalves and Callisto, 2013; Rezende *et al.*, 2016) and other Brazilian tropical systems (Gregório *et al.*, 2007; França *et al.*, 2009; Gonçalves *et al.*, 2014a). This leaf senescence is triggered by desiccation due to water stress, and explains the higher CPOM input from August to November (Campanella and Bertiller, 2008). Leaf renewal can also be stimulated by mechanical removal by the first rains (Larned, 2000; Rezende *et al.*, 2016). Input of branches (the second highest CPOM) in November also indicates greater mechanical removal by rainfall and associated winds (Vanschaik *et al.*, 1993; Gonçalves *et al.*, 2014a).

The novelty in litterfall refers to high leaf litter input also in April, which has not observed in other savanna systems (Gonçalves *et al.*, 2006a; Gonçalves and Callisto, 2013; Rezende *et al.*, 2016) or other Brazilian biomes (Gregório *et al.*, 2007; França *et al.*, 2009; Gonçalves *et al.*, 2014a). Riparian vegetation is an ecotone that serves as an ecological corridor among biomes, and the species composition includes that of the adjacent systems (Wantzen *et al.*, 2008; Gonçalves and Callisto, 2013). Thus, the ecotone characteristics of the riparian zones are highlighted due to geographical proximity (transition system) of this savanna stream to the Atlantic forest biome. The input peak in April may also be a phenological response of one specific species that was not observed in previous studies (Gonçalves and Callisto, 2013). This phenological response may also explain the increase in flower and fruit biomass in May, due to lower rainfall and less physical damage to plant parts associated with germination. We can also conclude that phenological and seasonal factors drive CPOM input from transition riparian vegetation.

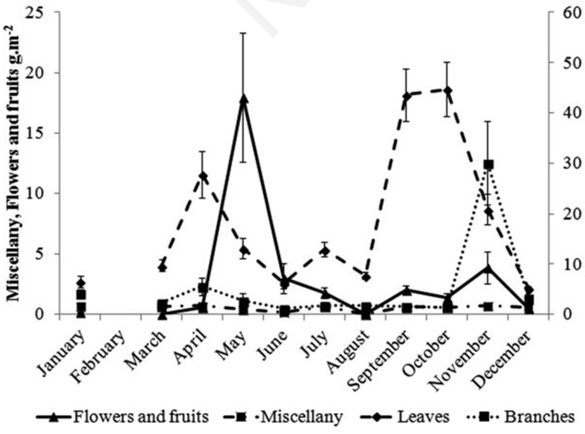

Fig. 2. Monthly values (mean ± SE) for flowers and fruits, miscellaneous organic matter, leaves, and branches in vertical input from the riparian vegetation into the Boleiras stream (January through December 2012).

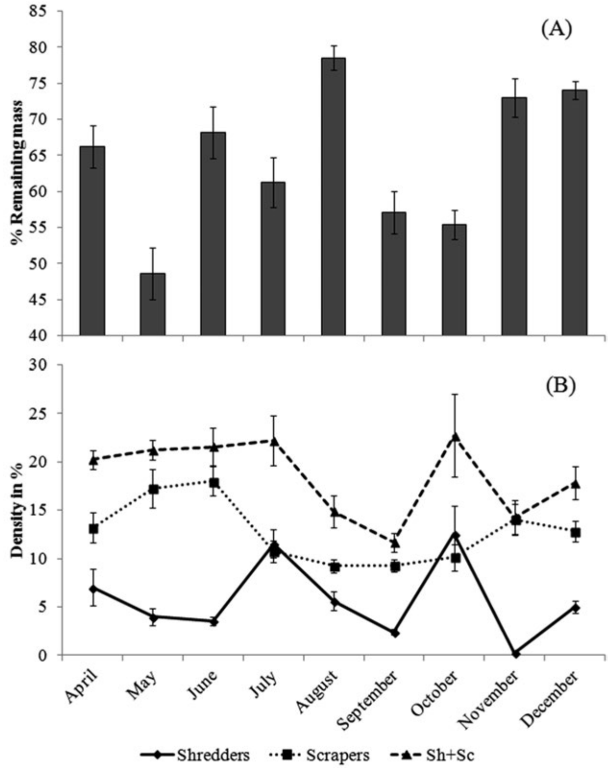

Fig. 3. Monthly values (mean ± SE) for the remaining mass percentage (A), as well as the density of shredders and scrapers individually and summed (Sh + Sc; B) colonizing the leaf litter in the Boleiras stream (April to December 2012).

Tab. 3. List of the relative abundance (RA), functional trophic group (FTG), order, family, and genus of the benthic invertebrate community associated with leaf litter in the Boleiras stream (April to December 2012).

Order	Family	Family / Genus	FTG	RA
Coleoptera	Psephenidae	*Psephenus* sp. (L)	Sc	0.081
	Staphylinidae	*Bledius* sp. (L)	Pr	0.027
Crustacean	Amphipod	Dogielinotidae/*Hyalella* sp. (L)	Sh	0.054
	Cladocera	Bosminidae/*Bosmina* sp. (L)	Fc	0.243
Diptera	Ceratopogonidae	*Atrichopogon* sp. (L)	Pr	0.269
		Bezzia sp. (L)	Pr	0.647
		Probezzia sp. (L)	Pr	0.296
		Sphaeromias sp. (L)	Pr	0.350
	Chironomidae	Chironominae (L)	Gc	0.052
		Orthocladiinae (L)	Gc / Sc	0.044
		Stenochironomus sp. (L)	Sh	3.530
		Tanypodinae (L)	Pr	0.066
	Empididae	*Hemerodromia* sp. (L)	Pr	0.620
	Simullidae	*Chirostilbia* sp. (L)	Fc	6.818
Ephemeroptera	Baetidae	*Cloeodes* sp. (L)	Sc	5.039
		Paracloeodes sp. (L)	Gc	0.620
	Euthyplociidae	*Campylocia* sp. (L)	Gc	0.081
	Leptohyphidae	*Leptohyphes* sp. (L)	Gc	2.371
		Leptohyphidae sp1	Gc	5.335
		Traveryphes sp. (L)	Gc	19.671
		Tricorythodes sp. (L)	Gc	6.791
		Tricorythopsis sp. (L)	Gc	14.605
	Leptophlebiidae	*Askola* sp. (L)	Sc	0.135
		Farrodes sp. (L)	Sc	0.269
		Hagenulopsis sp. (L)	Sc	0.269
		Miroculis sp. (L)	Sc	0.189
Hemiptera	Naucoridae	*Limnocoris* sp. (L)	Pr	0.081
Megaloptera	Corydalidae	*Corydalus* sp. (L)	Pr	0.081
Odonata	Gomphidae	*Phyllogomphoides* sp (L)	Pr	0.054
	Libellulidae	*Elasmothemis* sp. (L)	Pr	0.027
	Calopterygidae	*Hetaerina* sp. (L)	Pr	0.377
	Coenagrionidae	*Acanthagrion* sp. (L)	Pr	0.323
	Gomphidae	*Phyllogomphoides* sp (L)	Pr	0.054
	Libellulidae	*Elasmothemis* sp. (L)	Pr	0.027
		Macrothemis sp. (L)	Pr	0.108
	Perilestidae	*Perilestes* sp. (L)	Pr	0.377
Plecoptera	Grypopterygidae	*Paragripopteryx* sp. (L)	Sh	6.117
		Tupiperla sp. (L)	Gc	3.880
	Perlidae	*Anacroneuria* sp. (L)	Pr	0.781
Trichoptera	Calamoceratidae	*Phylloicus* sp. (L)	Sh	1.240
	Helicopsychidae	*Helichopsyche* sp. (L)	Sc	0.189
	Hydrobiosidae	*Atopsyche* sp. (L)	Pr	0.027
	Hydropsychidae	*Leptonema* sp. (L)	Fc	3.099
		Smicridea sp. (L)	Fc	2.452
	Hydroptilidae	*Metrichia* sp. (L)	Sc	0.216
		Neotrichia sp. (L)	Sc	0.350
		Oxyethira sp. (L)	Sc	6.252
	Leptoceridae	*Nectopsyche* sp. (L)	Gc / Sh	0.108
		Notalina sp. (L)	Sh	0.808
		Oecetis sp. (L)	Pr	0.054
		Triplectides sp. (L)	Sh	0.189
	Odontoceridae	*Marilia* sp. (L)	Sh	0.835
	Philopotamidae	*Wormaldia* sp. (L)	Fc	0.620
	Polycentropodidae	*Cyrnellus* sp. (L)	Fc	0.512
		Polycentropus sp. (L)	Fc / Pr	0.728
		Polyplectropus sp. (L)	Fc	0.862

Gc, gathering-collectors; Fc, filtering-collectors; Sh, shredders; Sc, scrapers; Pr, predators.

Leaf litter breakdown rates

The peak in leaf litter breakdown in May (beginning of dry season) contrasts that observed in others savanna streams, which typically peak in summer season (December to February) (Sales *et al.*, 2015; Rezende *et al.*, 2016). This result may be explained by the peak in high energy resources such as flowers and fruits (Gonçalves *et al.*, 2006a; França *et al.*, 2009; Gonçalves and Callisto, 2013), as an increase in flower and fruit input can promote environmental enrichment and accelerate leaf litter breakdown (Gonçalves *et al.*, 2014b; Alvim *et al.*, 2015a, 2015b). The input of higher-quality organic matter (*e.g.*, flowers and fruits, leaf litter species with high concentrations of nutrients such as nitrogen and phosphorus) can increase the density of decomposers (Ferreira *et al.*, 2014; Cornut *et al.*, 2015; Graça *et al.*, 2015), which consequently consume the lower-quality organic matter (*e.g.*, leaf litter with high concentrations of secondary and structural compounds). These results are the first to indicate flowers and fruits as potential influence in nutrient dynamics tropical streams.

Leaf litter breakdown rates ($k \sim 0.016$ day^{-1}) show an upper range comparable to other savanna streams (0.007 to 0.016 day^{-1} in Gonçalves *et al.*, 2006b; Gonçalves *et al.*, 2007; Moretti *et al.*, 2007a; Gonçalves *et al.*, 2012b), and were classified as 'fast' for tropical systems according to Gonçalves *et al.* (2014b). However, shredders were not associated with leaf litter breakdown rates. On the other hand, the remaining mass showed a positive relationship with water flow (due to rainfall increase), possibly through physical abrasion (Rezende *et al.*, 2014). The lower abundance of shredders with increased water flow and litter breakdown can be explained by the washing force, which decreases colonization by invertebrates (Ferreira and Graça, 2006; Rezende *et al.*, 2014). Finally, the higher activity of scrapers compared to shredders in the current study generally agrees with results of other studies in savanna streams (Gonçalves *et al.*, 2006b; Moretti *et al.*, 2007a). Scrapers can promote the fragmentation of plant tissue by scraping the periphyton growing on the substrate (Gonçalves *et al.*, 2006b).

The density (2 to 780 individuals.g^{-1} in Moretti *et al.*, 2007a; Ligeiro *et al.*, 2010; Gonçalves *et al.*, 2012a; Gonçalves *et al.*, 2012b; Rezende *et al.*, 2016) and average richness of invertebrates (1 to 22 taxa in Moretti *et al.*, 2007b; Alvim *et al.*, 2015b; Rezende *et al.*, 2016) at our site was low compared to other savanna streams. The most abundant *taxa* were Tanypodinae, Chironominae, and Orthocladiinae, belonging to the family Chironomidae (Diptera). The dominance of Chironomidae is typical in tropical and temperate streams (Milošević *et al.*, 2012; Biasi *et al.*, 2013; Uieda and Carvalho, 2015) due to their high adaptive capacity for various environmental conditions (Anderson and Ferrington, 2012; Milošević *et al.*, 2012). The low abundance of shredders (higher in August and November) and scrapers is also typical of tropical streams (Boyero *et al.*, 2011, 2012).

CONCLUSIONS

The total CPOM (productivity) input in the transition riparian zone was higher than that of other savanna systems, but lower than typical for Atlantic forest; this supports our first hypothesis. The CPOM also shows peaks in the transition period (from dry to rainy season) in response to water stress, supporting our second hypothesis. The higher leaf litter breakdown in May can be explained by the peak in input of higher-quality organic matter (flowers and fruits). The positive relationship between the remaining mass and water flow corroborates our third hypothesis (by increase of physical abrasion). Therefore, assuming that climate factors (*e.g.*, rainfall) directly affect the input and quality of CPOM and leaf litter breakdown rates, changes in the climate can alter functioning of savanna streams. The transition riparian zone (*e.g.* savanna and rainforest) show intermediate patterns of plant productivity and leaf processing in tropical zones. Leaf litter breakdown was driven by environmental enrichment, indicating that changes in the savanna riparian composition may also alter ecosystem function.

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