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Are litterfall and litter decomposition processes indicators of forest regeneration in the neotropics? Insights from a case study in the Brazilian Amazon

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ABSTRACT

Litterfall plays an important role in nutrient cycling and maintenance of soil fertility in terrestrial ecosystems. We gauged the effects of anthropogenic impacts on the production, decomposition and seasonality of litterfall in primary and secondary forests within a tropical landscape of the Brazilian Amazon. We hypothesized that leaf litter quantity and quality would differ in line with forest disturbance and that these changes would translate into dissimilar decomposition rates. If proved, these processes could be used as surrogates for indentifying the ecological status of forest habitats. The obtained results have shown that, in the study area litterfall is reduced and litter decomposition is braked in disturbed habitats when compared with primary and recovered secondary forests. Also, within similar climatic conditions, the litter production and decomposition rates begin to stabilize in mature secondary forests. Our results represent a useful contribution to understand the dynamics of the litterfall and litter decomposition processes in the neotropics. Both processes were correlated and sensitive to disturbance gradients and should used as forest recovery indicators in ecological monitoring and ecological restoration studies.

1. Introduction

Litterfall in forest ecosystems are composed of organic material, including leaves, twigs, flowers, fruits, bark, and other plant parts that have fallen to the forest floor (Celentano et al., 2011; Scoriza et al., 2012; Camargo et al., 2015). This material functions primarily as a route for the transfer of nutrients from vegetation to the soil, maintaining soil fertility which is essential for the sustainability of forest systems (Silver et al., 2014; Camargo et al., 2015; Erfani et al., 2017). In the Amazon region, litter is essential for the ecosystem functioning because of the low soil fertility and litter decomposition that allows for nutrient release from the plant biomass to the ecosystem (Martius et al., 2004; Quesada et al., 2011; Almeida et al., 2015). Litter layer also acts as a thermal insulator (microclimatic soil control) and water retainer. It mitigates erosive effects and has a significant effect on the hydrologic cycle, acting mainly as a filter and storing water from the atmosphere in the soil (Caldeira et al., 2013). In addition to all the ecological services mentioned above, litter is also a shelter and habitat for oviposition and larval development for many invertebrate species in soil (Cajaiba et al., 2017a) as well as an important feeding area and breeding grounds for many other animals, including vertebrates (Paudel et al., 2015).

Several biotic and abiotic factors affect litter production, such as vegetation type, altitude, latitude, precipitation, temperature, luminosity, relief, deciduousness, successional stage, water availability, and soil characteristics (Scoriza and Rodrigues, 2014; Holanda et al., 2017). Depending on the characteristics of each ecosystem, one factor may prevail over the others (Figueiredo Filho et al., 2003). Therefore, each soil type supports different plant species which are adapted to specific nutritional conditions. The factors affecting decomposition include substrate chemical composition, particularly the amount of leachate and water-soluble substances, environmental conditions such as temperature, precipitation, real evapotranspiration, humidity, aeration,

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and soil structure, as well as anatomical characteristics and energy levels (Silva et al., 2014; Pinto et al., 2016). Another factor to be considered is the composition of the detritivore community and its affinity for the substrate.

Tropical forests play an important role in global nutrient cycling (Lanuza et al., 2018). Although a vast amount of tropical forests has been cleared (FAO, 2015) and their nutrient cycling services have been significantly disrupted (Lanuza et al., 2018), the cover of tropical secondary forests has increased in some regions as a result of changing land uses (Aide et al., 2013; Chazdon, 2014). Moreover, there has been a dramatic increase in large-scale forest restoration (Chazdon et al., 2017; Lanuza et al., 2018). Regenerating secondary forest is an increasingly common forest type in the tropics, creating a patchy distribution of disturbance histories and stand ages across the landscape (Schilling et al., 2016). In conserved tropical forest ecosystems, there is a continuous production of litter throughout the year (Werneck et al., 2001). The total amount of produced litter at different periods depends on the type and composition of the studied vegetation (Schumacher et al., 2011), the biotic and abiotic characteristics of the areas, and the degree of disturbance and connectivity of the areas (Nascimento et al., 2015). Therefore, the contribution of litter in disturbed areas can be used as an indicator to evaluate the vegetation recovery process (Nascimento et al., 2015). The vertical and horizontal structure of the plant community and the species composition and distribution may also interfere with the litter distribution and production (Vidal et al., 2007). Thus, the litter can be classified as an environmental indicator because it responds to changes in the ecosystems through changes in its deposition processes (Gessner et al., 2010; Nascimento et al., 2015).

Our study examined the patterns of litterfall and litter decomposition processes in primary and increasingly common disturbed secondary forests in a landscape of the Brazilian Amazon. The following specific hypotheses were tested: (1) leaf litter quantity and quality decrease in line with forest disturbance; (2) these trends are highly correlated with litter decomposition rates; (3) forest disturbance gradients could be identified using litterfall production and litter decomposition processes. If proved, these hypotheses could support our main objective that is the use of litterfall and litter decomposition processes to assess the recovery status of secondary forests in the neotropics.

2. Material and methods

2.1. Study area

The study was developed in the municipality of Uruará, southwestern Pará state, northern Brazil (−03°43′27″S; −53°44′8″W, Fig. S1). The region is located approximately 1000 km away from Belém, the capital of Pará state, and is crossed by the Transamazon Highway (official designation BR-230). Uruará was part of the Altamira PIC (Integrated Colonization Project), one of the first official settlements in the Amazon, created to resettle families from the south, southeast and northeast of Brazil (Perz and Walker, 2002).

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Land cover is characterized by large deforested areas radiating from the main road (TransAmazon) to the feeder roads (travessões), and spreading westward over time from the area of initial settlement in the east. The area has unevenly distributed patches of high-fertility soils known as "terra roxa". Extensive livestock production, exploitation of timber at a large scale (mostly illegal) and cacao production are the main agro-pastoral strategies, but are usually complemented by annual crops and horticulture. In some parts of the study area, sandy soils predominate and pasture and annual crop production are favoured (Cajaiba et al., 2017b).

The climate is characterized as hot-humid (Köppen's classification), with annual average temperature and precipitation of 26 °C and 2000 mm respectively (Peel et al., 2007). The studied areas make up representative habiats of the region, such as Primary Forest (PF); Secondary Forest with 25, 15 and 5 years of regeneration (denominated of SF-25, SF-15 and SF-5, respectively). In each of the studied habitats, four areas were selected, thus totaling sixteen sampling areas (see Table S1 supplementary material, for details of the sampling effort).

2.2. Environmental conditions monitoring

In order to evaluate the environmental complexity of each study site (four per habitat and sixteen in total), an area of 10 m × 10 m (100 m^2) was delimited around each collector. The following parameters were measured: density, given by the average number of arboreal individuals with diameter at breast height (DBH) > 5 cm, measured with a measuring tape directly on the stem (1.3 m); canopy cover (through the following scales: 0–5%, 6–25%, 26–50%, 51–75%, 76–95% and 96–100%) measured with a convex spherical densitometer; pH of the soil, according to the Manual of soil analysis methods proposed by Embrapa (1997).

The data of air temperature, pluvial precipitation, relative humidity (monthly average values) were provided by the Meteorological Station at Ceplac (Comissão Executiva do Plano da Lavoura Cacaueira). The meteorological data obtained for the study period confirm the classification of the climate of the region as being of Aw type of Köppen - tropical humid, presenting only two well defined seasons: rainy season, which starts in January until mid June; and dry season, starting in July through December. The total rainfall in the study period was 1912.65 mm. The highest values were recorded in the months of March (283.75 mm) and April (275.12 mm) and the lowest values, in the months of September (35.1 mm) and November (34.71 mm). The average value of the air temperature for the period was 25.09 °C. The highest average temperature occurred in September (28.5 °C) and the lowest in May (23.1 °C). Relative air humidity in the region remained above 57%, with November and December having the lowest values (57%) and April, the highest (98.01%) month (Fig. S2, Supplementary material).

2.3. Litterfall production

In each sampling area, 10 collectors made of 2 mm nylon mesh measuring 1.0 × 1.0 × 0.15 m, installed 30 cm above the soil surface were randomly distributed to avoid litter mass loss due to microbial activity. To avoid the edge effect, the collectors were installed at a minimum distance of 100 m from the edge. The litter was collected monthly, over a period of 12 months, from August 2016 to July 2017. Each sample collected was divided into fractions: leaves, thin branches (diameter ≤ 2 cm), reproductive material (flowers, fruits and seeds) and residues (unidentified plant material and parts of animals and/or waste). The latter was excluded from the analysis because this fraction is composed of material from different origins and that cannot be identified (Vidal et al., 2007). In the laboratory, the materials were packed in paper bags and submitted to forced circulation at 65 °C for 72 h. Each fraction was weighed separately on a 0.001 g high precision digital scale to determine its contribution to total litterfall. The total production was obtained through the sum of the four fractions, which represents the monthly production of litter per collector. The annual production of litterfall was obtained through the sum of the monthly production of the collectors and was recorded in mg ha^{-1} $year^{-1}$ to allow comparison with other studies (Almeida et al., 2015).

2.4. Litter decomposition

For estimating litter decomposition, portions of 10 g of leaves previously dried in an oven at 65 °C until constant weight, were packed in litter bags with 1 mm^2 mesh and measuring 20 × 20 cm and were randomly distributed on the surface of the forest floor, simulating the natural fall of the materials from which litter originates.