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Litterfall as an indicator of productivity and recovery of ecological functions in a rehabilitated riparian forest at Das Velhas River, southeast Brazil

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Abstract: Effectiveness of litterfall in restoration of Das Velhas River riparian forest in Brazil and the use of non-foliar fractions of litter as an indicator of recovery of ecological functions were evaluated from November 2011 to October 2012. One litterfall collector of 0.25 m^2 was placed in the center of each of the 15 noncontiguous 100 m^2 plots to sample litterfall monthly. Litter was sorted into leaves and non-foliar fractions, branches, reproductive organs and others; oven dried and weighed in precision scales. We calculated total annual litter production by fractions. Annual litterfall was high (8.4 Mg ha^{-1} yr^{-1}) and similar to that of primary and secondary riparian forests in studies conducted elsewhere. Non-foliar fractions represented 35.7 % of the litterfall and showed that not all planted species are reproducing yet. The results indicated that both avifauna and insects are contributing to functional diversity. The largest input of litterfall occurred in July and August, which are the driest months. Thus, litter production has been influenced by hydric seasonality, and also by edge effects, once the forest is narrow (< 50 m) and can be considered itself as an "edge". Litterfall was a useful indicator, showing that forest was productive and the litter fall was contributing to the nutrient cycle. Non-foliar fractions indicated the recovery of ecological functions in the forest, suggesting that litterfall can be used as indicator of restoration of ecological services.

Key words: Ecological restoration, litterfall non-foliar fractions, riparian zone.

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The number of ecological restoration programmes in degraded ecosystems has been increased around the world (Chazdon 2008). In riparian zones, many methodologies have been applied, mainly in response to land legalization issues or due to the growing need to solve water problems (Rodrigues & Nave 2004).

The success of restoration programs is often difficult to assess during the initial stages after implementation. Thus, it is important to select evaluation and monitoring indicators that can help determine whether the project needs adjustments or even redirection to accelerate the process of succession and recovery of riparian functions (Martins 2011). Monitoring is an essential component of many conservation plans, mainly the evaluation of progress (Cousins & Lindborg 2004).

In restored riparian zones, where the plant community has already been formed (four years or more after planting), the effectiveness of restoration can be assessed through analysis of physiognomic aspects such as vertical stratification of the plant community and nutrient cycling (Brancalion *et al.* 2012). In addition, litter fall is a good indi-

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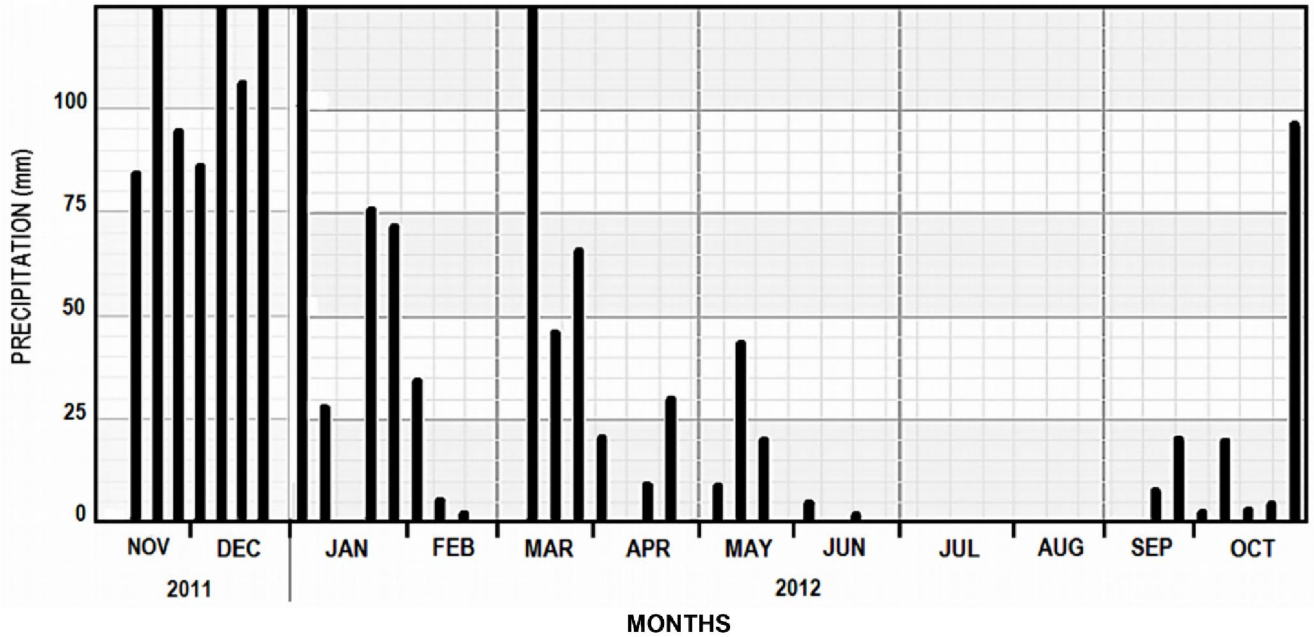

Fig. 1. Annual precipitation registered in an automatic station located at the region near the rehabilitated riparian zone at Das Velhas River, Minas Gerais State, Brazil. Source: National Institute of Meteorology (2013).

cator of productivity and nutrient cycling, enabling comparisons with other studies done in different forests (Martins 2011).

In riparian zones, litterfall indicates the ability of the ecosystem to capture soil nutrients and transform them into biomass to supply energy for food chains in terrestrial and aquatic systems (Poggiani 2012). Thus, to be considered restored, planted riparian zones should have productivity values similar to those observed in primary ones (SER 2004). Moreover, more detailed studies of litterfall fractions and litterfall spatial distribution at restored sites may provide additional information that help determine edge effects (Vidal *et al.* 2007) and other forest dynamics parameters such as the reproductive investment of trees.

This study used measured litterfall as an index of the effectiveness of restoration of a riparian forestat Das Velhas River, southeast Brazil. In addition, the use of non-foliar fractions as indicators of recovery of ecological functions was also investigated.

The Das Velhas River, whose drainage basin is located in the centre of Minas Gerais state, is the largest tributary of the São Francisco River extending for 761 km, and its area is highly urbanized with an estimated population of 4.5 million people distributed across 51 municipalities (Polignano *et al.* 2001).

The study site is located upstream to the highway bridge BR-381 (19° 50’ 22” S, 43° 51’ 59” W) between the municipalities of Belo Horizonte and Sabará. The study site is adjacent to a slaughter house and residential district. In 2007, a “flooded forest” of approximately 0.47 ha was established to stop soil erosion. Monthly precipitation was collected from an automatic weather station (Vaisala, model MAWS 301) located in Belo Horizonte, and the Fig. 1 shows the precipitation data from this weather station.

The restoration project consisted of ground leveling work at the site, external soil deposition, and planting of seedlings of 27 native tree species and two exotic fruit tree species using a planting model based on Schultz *et al.* (2004). A riparian buffer zone model with three zones was adopted: (1) an unmanaged zone adjacent to the water body for tree preservation; (2) a managed zone with woody species; and (3) a buffer zone for soil management (Schultz *et al.* 2004).

Fifteen (15) noncontiguous permanent plots (100 m^2 each) were randomly established along three parallels planting zones. All trees with any cbh (circumference at breast height > 10 cm) at 1.30 m

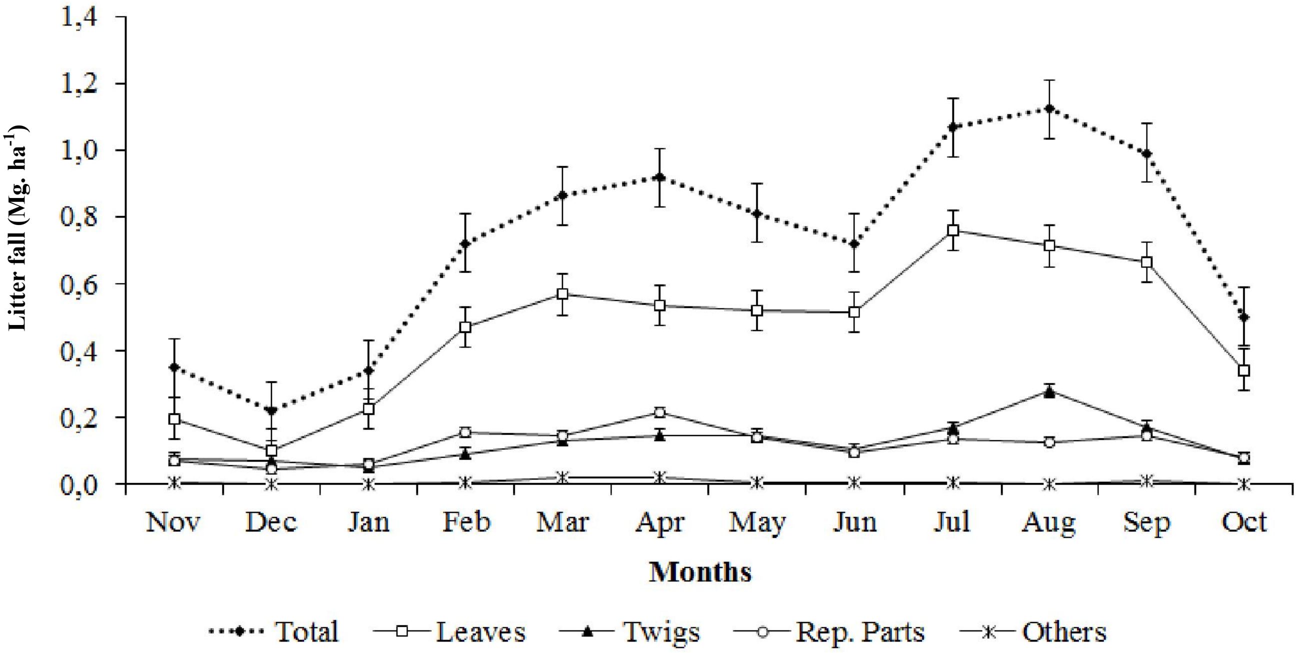

Fig. 2. Total litterfall and by fractions in each month during one year at the rehabilitated riparian zone at Das Velhas River, Minas Gerais state, Brazil.

from soil surface were counted. Tree height was measured using a graduated pole and tree circumference with a tape measure. The cbh was transformed into dbh (diameter at breast height) dividing the cbh value by π (i.e. 3.14).

In the centre of each plot, one 0.25 m^2 square-shaped collector made from iron bars and 3-mm nylon mesh was placed at 80 cm above ground for litterfall collection. Litterfall was sampled monthly, from November 2011 to October 2012, and was sorted into four different fractions: leaves, twigs, reproductive structures, and others (animal remains, excreta, etc.).

Litterfall fractions were oven dried at 65 °C until constant weight. Monthly litterfall production was estimated in kg ha^{-1} $month^{-1}$ based on the dry weight of each fraction, whereas annual litterfall was expressed in Mg ha^{-1} $year^{-1}$.

All data were checked for normality using the Anderson-Darling test and analysis of variance (one-way ANOVA) was carried out to check differences in production of litter fractions and production between planting zones. Pearson correlation was used to determine relationships between basal area and litterfall. All statistical analyses were run in the software MINITAB 16.0.

A total of 220 trees belonging to 27 species and 10 families, with an average height of 5.4 ± 1.8 m (mean ± SD), dbh of 7.4 cm ± 4.4 cm, density of 479 trees ha^{-1}, and total basal area of 12.547 m^2 ha^{-1} were sampled. Total annual litterfall, from November 2011 to October 2012, was 8.4 Mg ha^{-1} yr^{-1} and the non-foliar fraction was 3.0 Mg ha^{-1} yr^{-1} (36 %). Two peaks of productivity were observed: one at the end of the rainy season and the other that was more pronounced in the middle of the dry season (Fig. 2). Litterfall was significantly different between fractions (P = 0.0001). Overall, litterfall was composed by 65 % of leaves, 17 % twigs, 16 % reproductive structures and 2 % other components. Litterfall was not significantly different between planting zones (P = 0.26) and was not significantly correlated with basal area (r = -0.261, P = 0.348).

Total litterfall of 8.4 Mg ha^{-1} yr^{-1} observed in the rehabilitated forest was greater than values reported for some primary riparian zones of semi-evergreen forests in western São Paulo state: 6.4 kg ha^{-1} yr^{-1} at Assis farm, 8.8 kg ha^{-1} yr^{-1} at Marília I station, 9.7 kg ha^{-1} yr^{-1} at Tarumã farm, and 11.1 kg ha^{-1} yr^{-1} at Marília II station (Durigan *et al.* 1996). In addition, litterfall in our study was greater than in *cerrado*/savanna 622 kg ha^{-1} yr^{-1}, *cerradão*/tall savanna 1046 kg ha^{-1} yr^{-1}, and transition forest 6566 kg ha^{-1} yr^{-1} (Silva *et al.* 2007), but smaller than in a secondary forest (10.17 Mg ha^{-1} yr^{-1}) and close (8.98 Mg ha^{-1} yr^{-1}) to that reported in a recovered forest both in the state of Rio de Janeiro, Brazil (Machado *et al.* 2008).

High litterfall production in managed forests is evidence of normal nutrient cycling, because nutrient cycling begins with litter deposition, followed by its decomposition and nutrient release (Martins 2011). Thus, the high amount of litterfall observed in our study may be an indirect indicator of regular nutrient return to the soil or to the reserve of nutrients.

Litter productivity can be influenced by several factors. For instance, Portela & Santos (2007) studied six forest fragments in the state of São Paulo and found a positive relationship between fragment size and litterfall, with a tendency of greater litterfall in larger fragments. Conversely, Gomes *et al.* (2010) failed to find any relationship in four forest remnants ranging from 3.2 to 62 ha in Teresópolis, Rio de Janeiro. This correlation also seems unlikely in the studied fragment, because its productivity was high compared to the areas mentioned above.

Naiman *et al.* (2005) argued that litter production in riparian zones is greater at early successional stage than in mature forests because the young plant community actively invests in growth. In addition to successional stage, vegetation type is also a determinant of litter production. Chave *et al.* (2010) conducted a compilation of studies with litter-fall in several tropical forests in South America and found that partially flooded forests (8.89 Mg ha^{-1} yr^{-1}) and primary forests (8.61 Mg ha^{-1} yr^{-1}) had the highest litterfall, followed by secondary forests (8.01 Mg ha^{-1} yr^{-1}) and recently disturbed areas. When compared to Chave *et al.* (2010), the fragment in our study had intermediate litter production (8.4 Mg ha^{-1} yr^{-1}) between that of secondary and primary forests.

Litter productivity in the present study was influenced by precipitation. The first peak of production was observed in March, when precipitation was high which probably caused plant material to fall mainly due to storms, whereas the second peak occurred in July and August, which were the driest months (Figs. 1 & 2). The great accumulation of litter in the end of the dry season is a response of the tree community to water stress, mainly through leaf fall to reduce water loss by transpiration (Martins & Rodrigues 1999). Moreover, the seasonality in litterfall is also influenced by photoperiod and variations in temperature and relative humidity (Durigan *et al.* 1996). In fact, these latter factors may be caused by edge effects that modify the microclimatic conditions. For instance, Vidal *et al.* (2007) reported that litter deposition tends to increase from the edges to the centre of forest fragments because of the edge effect. No edge-interior difference was observed at the rehabilitated forest in our study, probably because edge effects are observed up to 35 m into the forest (Primack & Rodrigues 2001), and due to its small size, the studied fragment itself is an edge environment (a patch).

Litterfall can also be associated with plant community structure (Werneck *et al.* 2001). However, this relationship was not observed in the present study. Litterfall in this study seems to be more influenced by species composition and effect of leaf area. For instance, in zone 2, which was the most productive, there were several individuals of *Luehea grandiflora* Mart. & Zucc., a semi-evergreen species with broad and long leaves, which produces a large number of seeds per year (Lorenzi 2008). *Croton urucurana* Bail., a deciduous, helophytic, pioneer species typical of riparian zones (Lorenzi 2008) was abundant in zone 3. In this less productive zone with small leaves many individuals of *Mimosa bimucronata* (DC.) Kuntze, a deciduous species with pinnate compound leaves and small leaflets were also sampled (Lorenzi 1998).

In general, litterfall fractions have been used to evaluate site productivity, decomposition rate and to estimate nutrient return to the soil (Cuevas & Lugo 1998; Guendehou *et al.* 2014; Hansen *et al.* 2009; Odiwe & Muoghalu 2003). However, investigating non-foliar fractions can provide additional information and provide a more comprehensive analysis of litter production. For instance, the twigs fraction was the second greatest throughout the year, with peak production in August 2012 (Fig. 1), probably due to the occurrence of strong winds that broke tree branches, as also observed by Martins & Rodrigues (1999) in a semi-evergreen forest in Campinas, São Paulo. Moreover, the fall of twigs may be an indirect indicator of community maturity because young plants tend to lose smaller twigs, whereas in mature communities the fall of twigs may be greater, as observed in an *Acacia mearnsii* population at the state of Rio Grande do Sul (Shumacher *et al.* 2003).

Reproductive structures amounted to 16 % of total dry weight, with the exotic species *Melia azedarach* L. greatly contributing to this fraction due to its high fruit production observed in samples, and C. *urucurana*, which is an important high value species in the forest because it flowered and produced fruits for several months during the study period (Londe 2013). The analysis of reproductive structures also showed that not all trees are productive because material was found in only a few species, probably because they had not reached reproductive age.

The “others” fraction contributed little to total litterfall (2 %) and was composed of animal and insect feces. Despite its small contribution, this fraction indicates the presence of avifauna (e.g., feces and feathers) in the area, an essential mechanism for propagule dispersal in restored sites (Volpato *et al.* 2012). In addition, macro- and mega-fauna decomposers that are mainly responsible for the shredding of plant remains (Begon *et al.* 2007) such as the Diptera and Coleoptera species, and other associated organisms like carnivorous arachnids were also observed in the “others” fraction.

Litterfall is a useful indicator of productivity and the establishment of ecological functions showing that, in terms of productivity, riparian forest seems be sustainable. The early successional stage and vegetation type appear to be contributing to the high amount of litterfall, but other factors caused by edge effects may also be relevant. Thus, restoration of larger patches of riparian forests (or other ecosystems) is recommended to avoid these effects. Litterfall has been used as an indicator of site productivity and nutrient cycling. However, a more careful analysis of non-foliar fractions can reveal valuable additional information, such as the occurrence of ecological processes, and guide management actions in forests on process of restoration.

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