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Efficiency of different planted forests in recovering biodiversity and ecological interactions in Brazilian Amazon

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ABSTRACT

In tropical forests, several reforestation programs have been created to recover biological diversity in deforested environments. However, most of these studies have focused on the loss of species and ignored the loss of ecological interactions and ecosystem services that these species provide in their natural environment. Here, we assess how reforestation (including both native and exotic species) and the distance from the forest matrix could recover the following parameters: richness, composition, and ant–plant interactions in the southern Brazilian Amazon. For this, we collected data in five different agroforestry landscapes: primary and secondary forests, reforestations of teak and fig, and pasture. In general, we observed that the distance from the forest matrix was not an important factor for the recovery of ant–plant interactions at the scale of this study. Ant–plant interactions were more specialized in the pasture, possibly due to the low richness and high dominance in pastures, which generates a high ant–plant dependency. Moreover, none of the strategies employed for the recovery of diversity (teak and fig reforestation) increased the recovery rate of the studied parameters: richness, composition, and the patterns of ant–plant interactions, when compared to primary forests. These results indicate that regardless of species richness and composition, secondary forests and reforestation lands are functionally different from pastures. In conclusion, our results represent a valuable tool to conservation planners, mainly because we show that secondary forests created by natural regeneration can be an efficient and economical method for restoring the disruption of ant–plant interactions in tropical forests.

1. Introduction

One of the main causes of tropical deforestation is the conversion of forest to pasture for cattle ranching (Fearnside, 2006). This type of habitat modification not only decreases the diversity of plant and animal species (Mitja et al., 2008; Leal et al., 2012) but also reduces ecological interactions. This, in turn, affects all ecosystem services provided by such interactions (*e.g.*, pollination and seed dispersal) (Murcia, 1996; Cramer et al., 2007). Thus, there is an urgent need to implement conservation actions that aim to reduce the effects of deforestation on biodiversity as a whole (Melo et al., 2013).

One strategy frequently used to restore biodiversity is the reforestation of large areas or riversides. In this strategy, native and/or exotic species are planted to create microenvironments that can facilitate the establishment of other organisms and promote the recovery of biodiversity (Massad et al., 2011; Milder and Clark, 2011). However, the choice of pioneer species is a keystone factor in such reforestation programs, mainly due to the differences in local environmental conditions provided by the chosen species (*e.g.*, microclimatic conditions, habitat diversity and leaf litter accumulation) (Bellingham et al., 2010; Castillo-Núñez et al., 2011; Sansevero et al., 2011).

Among the plant species commonly used in reforestation programs in the tropics, we can highlight *Eucalyptus* spp. (Myrtaceae) and teak *Tectona grandis* Linn. f. (Verbenaceae) (Evans, 1999). Both plant species have a sub-product of great economic value. *T. grandis* is a species primarily planted for timber purposes but has damaging effects on plant succession processes; it has been shown to affect allelopathic properties (Healey and Gara, 2003) and decrease the attraction of seed dispersers (Tewari, 1992). Consequently, it is possible that the planting of native species may be a better alternative because these species have been reported to provide better

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habitats for native animals (Evans and Turnbull, 2004; Assumpção, 2008). However, in addition to the taxonomic identity of the species used in reforestation programs, the distance of the forest matrix (provider of propagules) can also exert a large influence on the richness and composition of species in these environments (Tabarelli and Gascon, 2005). This is primarily due to the dispersal ability limits of both seeds and animals (Wunderle, 1997; Wagner et al., 2004). Thus, it is expected that both the identity of the pioneer species and the distance from the forest matrix may be the main mechanisms responsible for the recovery of biodiversity in such reforestation programs.

Although the importance of ecological interactions in maintaining biodiversity has been reported since the 70s (Janzen, 1974), most studies have evaluated biodiversity restoration by focusing only on the recovery of the richness, and eventually, the species composition (Mullah et al., 2011; Azcárate and Peco, 2012; Reid et al., 2012). In fact, studies have often ignored the loss of ecological interaction diversity (Tylianakis et al., 2010). However, ecological interactions affect all ecosystem attributes, from primary productivity to population dynamics (Tylianakis et al., 2007; Del-Claro and Torezan-Silingardi, 2009), and play an important role in the structure and stability of biological communities (Janzen, 1974; Del-Claro and Torezan-Silingardi, 2009; Dyer et al., 2010). Thus, instead of using only the species approach to understand restoration processes, we should consider the interactions that these species are involved to understand the process as a whole and improve the reforestation programs.

Due to the high abundance of ants and plants in tropical forests (Longino et al., 2002; Feeley and Silman, 2012), the diversity of ecological interactions involving both organisms is extremely remarkable in these environments (Rico-Gray and Oliveira, 2007). One of these interactions occurs between ants and plants with extrafloral nectaries (EFN-bearing plants). In exchange for the energy-rich food provided, ants protect their host plant against potential herbivores (Rico-Gray and Oliveira, 2007). The frequency of EFN-bearing plants in some Brazilian Amazon landscapes can reach up to 53% of the total plant species (Rico-Gray and Oliveira, 2007); moreover, ant diversity can be extremely high, reaching approximately 270 species at local scales (Miranda et al., 2012). Thus, because of the abundance and importance of the ant–plant interactions in Amazon landscapes, this can be a useful model for understanding the efficiency of reforestation projects in the recovery of ecological interactions.

In this study, we evaluated the recovery of ecological interactions involving ants and EFN-bearing plants in five different agroforestry landscapes in the southern Brazilian Amazon: primary forest, secondary forest, teak reforestation, fig reforestation, and pasture. For this, we sampled the ecological interactions involving ants and EFN-bearing plants in different agroforestry landscapes in the southern Brazilian Amazon and compared then with primary forest and active pastures. To achieve this we answered the following questions: (1) Does the reforestation of pastures help in recovering the richness and composition of ants and plants species? (2) Are the network patterns that describe the interactions involving these organisms different between planted forests? (3) Does the distance between the primary forest and the others landscapes affect the velocity of recovery? We predict that the native reforestation (*Ficus maxima*) will be the landscape with better recovery of both the species and network properties. We also predicted that the sites that are closer to the forest matrix would be more restored than the other ones. Overall, our goal was to propose a new, empirical and effective recommendation to evaluate the restoration of ecological interactions in tropical forests using several metrics derived from network theory.

2. Materials and methods

2.1. Study area and sampled environments

We conducted fieldwork in December 2010 and December 2011 at the São Nicolau farm (9°48′S and 58°15′W, elev. 254 m), located in the municipality of Cotriguaçu in the north of Mato Grosso State, Brazil. The farm has 10,000 ha, of which 7000 ha are primary forest, 500 ha are riparian and secondary forests, 1700 ha are reforestation of several species, and 300 ha are pastures used by cattle. Reforestations and secondary forests were both previously pastures before the planting of vegetation and the abandonment of the pastures, respectively, which occurred between 1999 and 2000 (Rodrigues et al., 2011). The regional climate is AW type, according to the Köppen classification (warm and humid), with an average annual temperature of 24 °C, 85% humidity, and 2300 mm of precipitation (Rodrigues et al., 2011).

In this study, we collected data on five different landscapes: (1) Primary forest: defined as a "terra-firme" and closed-canopy forest without the influence of seasonal flooding of larger rivers. The understory is relatively open and very biodiverse, and the canopy varies between 30 and 40 m tall with some trees reaching up to 50 m; (2) Secondary forest: natural restoration of nearly 13 years without the presence of cattle or anthropogenic interference. This landscape is used in our design as the control of the experimental plantation of trees. The understory of secondary forests is extremely dense, with vegetation higher than three meters; there is a low leaf litter accumulation and light incidence; (3) Teak reforestation: reforestation of *T. grandis* (Verbenaceae) of nearly 10 years, an exotic tree that loses its leaves annually. During the collection period in this landscape, leaves were green, allowing little light penetration in the understory. Moreover, the understory is open and has an abundant leaf litter accumulation; (4) Fig reforestation: reforestation of *Ficus maxima* (Moraceae) of nearly 10 years and performed with seedlings obtained from native seeds in our study area. This landscape presents some gaps formed by dead individuals, which are characterized by grasses and shrubs. The understory has plants of varying sizes and low leaf litter accumulation; (5) Pasture: landscape with a great predominance of planted grasses (not more than 50 cm tall) used as food for cattle. In addition, this landscape is characterized by a very high incidence of light and the absence of leaf litter accumulation. This landscape is used in our design as a "starting point" of forest succession under different reforestations.

2.2. Experimental design and data collection

We performed the survey of ant–plant interactions in 62 plots: primary forest ($n = 12$ plots), secondary forest ($n = 10$ plots), teak reforestation ($n = 14$ plots), fig reforestation ($n = 14$ plots), and pasture ($n = 10$ plots) (Fig. 1). With the exception of the primary forest, we divided the landscapes into two classes of distance from the primary forest (forest matrix), in which half of the plots were located immediately close the forest edge and the other half were 250 m from the edge. In these landscapes, plots consisted of rectangles of 57.5 m × 52 m and totaled 3000 m^2; all plots were at least 200 m apart. The data collection in the primary forest was conducted in a module of the Brazilian Program for Biodiversity Research (PPBio) at the São Nicolau farm. This module consists of six parallel trails running north/south and two parallel trails running east/west. Each stretch of 1 km on the trails was considered an independent sample unit of 250 m × 12 m, totaling 12 plots of 3000 m^2. At each of the 62 plots, we searched for EFN-bearing plants that were accessible to the collector (height between 0.5 and 3 m), and tried to reach the total of 40 individuals of plants