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The effect of forest fragmentation on the soil seed bank of Central Amazonia

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ABSTRACT

Deforestation of tropical forests has contributed to the formation of fragmented landscapes, surrounded mainly by a matrix of secondary forests, pastures and agriculture. In this study we evaluated the fragment-area effects on the density, diversity and composition of the soil seed bank. Fragments of primary forest of different sizes (1, 10 and 100 ha) and continuous primary forests were sampled in a region of terra firme forest in Central Amazonia. We collected 180 soil samples (45 samples per treatment), and monitored seedling emergence from the soil seed bank in a greenhouse for seven months. Density of emerged seedlings, floristic composition, richness and diversity of species were compared among treatments with Kruskal-Wallis non-parametric test, Mann-Whitney test, Fisher's Alpha diversity index and Non-metric multidimensional scaling (NMDS). Seedling density was inversely proportional to the size of the fragment, being higher in fragments of 1 ha, 10 ha, and lower in the primary forest and fragments of 100 ha. Diversity was higher in the fragments when compared to the primary forests. Melastomataceae was the most abundant family in all treatments. Species composition changed along the disturbance gradient, and is dominated, in the smaller fragments by species that are indicators of degraded environments. Results suggested that the area of the forest fragments affects the size and composition of the soil seed bank, and can significantly influence the potential resilience and regeneration of these sites in the event of natural or anthropic disturbance.

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1. Introduction

Deforestation of tropical forests, especially with the objective of introducing pasture and agriculture, promotes a reduction of biodiversity and the formation of fragmented landscapes (Laurance et al., 2011; Sandor and Chazdon, 2014; Santo-Silva et al., 2016). Accumulated deforestation of the Brazilian Legal Amazon from 1988 to 2015 was 413,882 km^2. In the year 2014 deforestation was 5012 km^2, approximately 60% of the deforested areas corresponded to pastures, 23% secondary forests and 6% agriculture (INPE, 2016a, 2016b). Forest fragmentation has been shown to modify micro-climate and wind regime, cause physical and ecological changes in the vegetation, increasing tree isolation and mortality rates, and interfere in the dispersion pattern of some species (Bierregaard et al., 1992; Laurance et al., 2002; Lovejoy et al., 1986; Pizo and Vieira, 2004). Floristic composition and richness are also changed with an increase of the abundance of pioneer and secondary species, within fragments and especially near the edges (Laurance et al., 2006; Mesquita et al., 2015; Santo-Silva et al., 2013).

Ecological changes due to forest fragmentation may be directly related to the size of the fragment and these are known as area effects. Smaller fragments tend to be affected more severely than larger ones, suffering a higher tree mortality and loss of species, including plants, primates, birds, insects, among others (Benítez-Malvido and Martínez-Ramos, 2003; Boyle and Smith, 2010; Laurance and Vasconcelos, 2009; Stouffer et al., 2009). The degradation of environmental conditions of small fragments tends to be favorable for secondary and invasive species (Scariot, 2001).

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Laurance et al. (2006) showed that fast growing trees of the genera *Bellucia*, *Cecropia* and *Vismia* increased significantly in density and basal area in forest fragments in Central Amazonia. In addition, there is also evidence of an increase in the abundance of lianas in these disturbed forests (Benítez-Malvido and Martínez-Ramos, 2003).

All these ecological changes promoted by deforestation and forest fragmentation can affect the potential for regeneration of the forests through the seed bank (Martins and Engel, 2007; Wilson et al., 2016). Soil seed bank is an important source of regeneration of these environments, especially for the pioneer species, which mostly form persistent seed banks (Dalling, 2002; Plue and Cousins, 2013). The input of seeds to the soil seed bank is determined by seed rainfall. The losses may be the result of the physiological properties of the seeds, which will influence the germination, dormancy and viability. In addition, the death of the seed may also occur due to animal predation, pathogen attack, depth of burial or natural senescence. The balance between these inputs and outputs will control seed density, species composition and the genetic composition of soil seed stock (Baider et al., 1999; Dalling et al., 1998; Thompson, 2000).

To date, the impact of forest fragmentation has been mainly examined for plants starting at the seedling stage (Benítez-Malvido, 1998; Bernacci et al., 2006; Carmo et al., 2011), and mostly on established trees (e.g. Laurance et al., 1998; Santo-Silva et al., 2016). However, little is known about the effect of fragmentation on the seed bank of tropical forests and how the area of the fragments can influence its structure and dynamics, and none of the few studies to date (Alvarez-Aquino et al., 2005; Martins and Engel, 2007; Valenta et al., 2015) assessed this effect on Amazonian forests.

Most animal and plant taxa (including seedlings) studied so far were impoverished in fragments, proportionally to the fragment area (Benítez-Malvido and Martínez-Ramos, 2003; Ferraz et al., 2007; Scariot, 1999; Stratford and Stouffer, 1999). In this study we evaluated the fragment-area effect on the density, diversity and floristic composition of seedlings emerging from the seed banks of forest fragments (1, 10 and 100 ha) and old growth forest. Our hypothesis is that changes in these seed banks are dependent on fragment size, given the higher proportional border effect as fragment area decrease. A larger border effect implies lower humidity, higher light levels, and a shorter dispersal distance from the matrix around fragments, conditions that benefit pioneer species and increase the probability of invasion by non-forest species. Therefore, we predict that abundance of seeds in the soil seed bank will increase and species composition degrade, compared to old-growth forests, as fragment area decrease.

Understanding the role of the seed bank for the regeneration of tropical forests in the face of growing threats, mainly due to deforestation and changes in land-use, is essential not only to assess the vulnerability of forests, but especially to support strategies for the conservation and maintenance of biodiversity (Madawala et al., 2016; Williams-Linera et al., 2016).

2. Material and methods

2.1. Study area

This study was carried out in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), on *terra firme* in tropical moist forest (Veloso et al., 1991), about 80 km north of Manaus city in the state of Amazonas, Brazil (2°25″ S e 59°50″ W). The BDFFP studies the environmental consequences of deforestation and fragmentation on the Amazon forest and is the largest and longest experimental study of forest fragmentation in the world (Laurance et al., 2002; Lovejoy et al., 1986). Climate in the study area is *Af*, tropical humid, in the Köppen classification, with an average annual temperature of 27 °C and precipitation between 1900 and 3500 mm per year, with higher rainfall occurring from February to April (Alvares et al., 2013; Fisch et al., 1998). Soils are dystrophic yellow latosols, poor in nutrients (Chauvel et al., 1987; Ranzani, 1980).

The study area encompasses three experimental sites consisting of ranches (Dimona, Esteio and Porto Alegre) that were clear-cut of primary forest in the early 1980s and abandoned or converted to pastures, with remaining isolated forest fragments of 1, 10 and 100 ha (Fig. 1). The ranches have different land use histories and

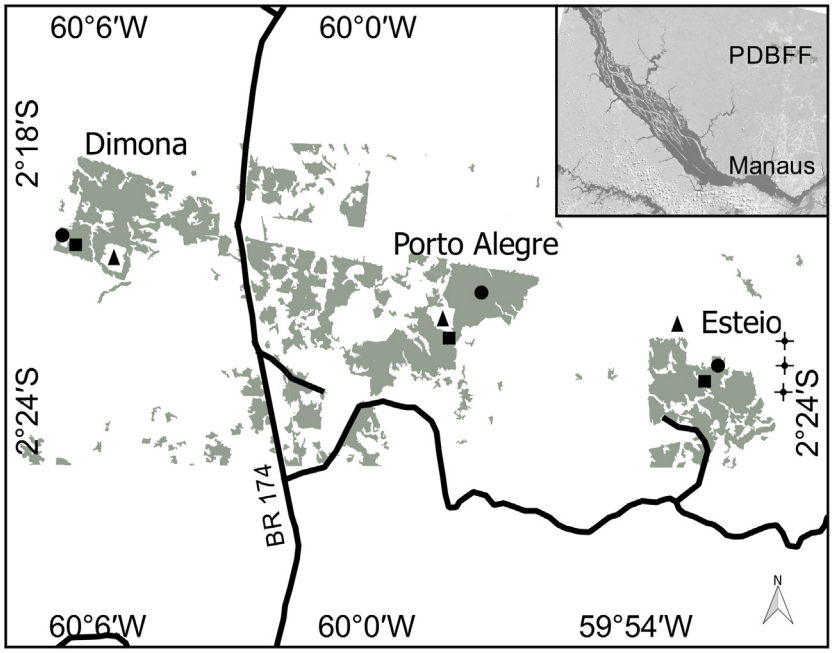

Fig. 1. Map of the experimental area of the Biological Dynamics of Forest Fragments Project (BDFFP), highlighted the ranches Dimona, Esteio, Porto Alegre and the collection areas of 1 ha fragments (black circles), 10 ha fragments (black square), 100 ha fragments (black triangle), and old growth forest (cross). White areas correspond to primary forests and gray to secondary forests.

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