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Fast natural regeneration in abandoned pastures in southern Amazonia

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ABSTRACT

Abandoned pastureland provides a prime opportunity for forest recovery of these degraded areas in the Amazon. Many factors impact forest regeneration, including time and intensity of pasture use before abandonment, and proximity of a source of propagules. Given these conditions, it is necessary to better investigate the effect of such factors on the natural regeneration of abandoned pastureland. Here we employed chronosequences to study secondary forest succession in abandoned pastures along the Madeira River, Rondônia, Brazil. We installed 314 m^2 plots in 36 abandoned pastures previously subjected to long-term use (average of 9 years), but now at different stages of natural regeneration. All tree species stems $\geqslant$30 cm in height were identified, and their diameter was measured at ground level. Using a historical series of Landsat satellite images, time of pasture encroachment ("*encapoeiramento*"), time of pasture use, and time since last use were all calculated. The percentage of forest cover adjacent to each plot was calculated using a circular buffer (120 m radius) overlaid on a land-cover classification. Model selection procedure was used to access the importance of four predictors on natural regeneration variables (species density, basal area, stem density). We sampled 6380 stems belonging to 202 morphospecies grouped into 138 genera and 51 families. The two most important species were *Vismia guianensis* and *Vismia gracilis* that together represented 40% of abundance, 70% of frequency, and 101% of IVI (Importance Value Index) of the plants sampled. Most species (164) were recorded in a maximum of four out of 36 plots sampled. Species density increased by ca. five species per year after pasture encroachment. Occurrence of rare species increased with time following encroachment, while relative abundance and basal area of the main pioneer species decreased with the advance of forest succession. Time of pasture encroachment, time of pasture use, and time since last use had significant effect on natural regeneration, whereas cover of surrounding forest had limited influence. Although constrained by long-term use, natural regeneration in abandoned pastures occurred relatively rapidly based on the high occurrence of resprouting pioneer species, which formed secondary sites during the first years of succession. Afterwards, regeneration was incremented by the establishment of a number of late succession species. We conclude that forest restoration of abandoned pastures in the Amazon should use the natural potential of forest regeneration, considering both the speed and intensity of the process.

1. Introduction

Despite the global role played by the Amazon as a biodiversity repository and major source of ecosystem services, increasing economic activities in the region over the last five decades have caused profound changes in land cover (Fearnside, 1999; Malhi and Timmons, 2008). Most land use changes in the region are related to the expansion of livestock. For example, the Brazilian Amazon has around 12% of its territory already converted into pastures (Embrapa and INPE, 2014). However, a large proportion of areas cleared for pastures are typically abandoned after a few years of use for a number of reasons, including loss of productivity, soil impoverishment, and poor management practices, leading to an increasing fraction of degraded pastures or early successional forests. Abandoned pastures in the Amazon form a mosaic of secondary forests in the landscape with different ages and stages of natural regeneration (Ferraz et al., 2005), and they account for around 36% of the total deforested area in Brazil (Embrapa and INPE, 2014), if including both degraded pastures and secondary growth forests.

Amazonian forests are known for their quick forest recovery after pasture abandonment. Resprouting from shoots and roots,

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soil seed bank, and seed dispersal are the main mechanisms responsible for the reestablishment of the forest in abandoned pastures (Uhl et al., 1988; Guariguata and Ostertag, 2001; Wieland et al., 2011). Pioneer species gradually eliminate exotic grasses by shading and attracting seed dispersers, thus favoring the arrival and establishment of other tree species, most often shade-tolerant (Nepstad et al., 1996; Letcher and Chazdon, 2009). Despite the high potential of recovery, the speed of conversion of abandoned pastures into secondary forest will depend on local variables, landscape integrity, age, and intensity of pasture management.

Natural regeneration in intensively managed pastures is hampered by the reduced density of tree resprouters and depletion of soil seed bank (Holl, 1999). Therefore, recolonization of abandoned pastures by forest species depends on the arrival of propagules from external sources such as surrounding old-growth forests (Florentine and Westbrooke, 2004). It is expected that an increase in the extent of primary forests (source of propagules) adjacent to abandoned pastures would lead to an increase in forest regeneration (e.g. Jakovac et al., 2015). Seed rain in extensive pastureland is mainly restricted to areas bounded by adjacent forest, thus limiting the arrival of propagules (Cubiña and Aide, 2001). However, the arrival of seeds in regenerating areas can be boosted by dispersal agents (Guariguata and Ostertag, 2001; Hooper et al., 2005; Wieland et al., 2011). In particular, seed dispersal by bats plays an important role in natural regeneration in fragmented landscapes in the Amazon. These mammals are able to fly long distances across fragmented areas and disperse seeds of a number of forest species during flight (Uieda and Vasconcellos-Neto, 1985; Bernard and Fenton, 2003). On the other hand, birds are less effective as seed dispersal agents in large pasture areas by the lack of perches for landing (Uhl et al., 1988).

The time and intensity of pasture use before abandonment have an inverse relationship with the potential of forest regeneration (Nepstad et al., 1990, 1996; Pascarella et al., 2000). Management practices, such as mechanical or chemical elimination of trees, shrubs and liana resprouts, burning, and cattle trampling are known to reduce forest regeneration (e.g. Uhl et al., 1988). Differences in the rate of forest recovery, measured as changes in species composition and vegetation structure, have been associated with land use history (Aide et al., 2000; Guariguata and Ostertag, 2001; Longworth et al., 2014). For example, a study from Paragominas (eastern Amazon) showed that species richness (measured in 100 m^2 plots) in abandoned pastures after heavy use ranged from 1–5 species, compared to 13–26 species in light use sites (Uhl et al., 1988).

Studies based on chronosequences have been widely used to understand the succession process in secondary forests. Such studies can approximate the dynamics of natural regeneration by sampling areas at different stages of regeneration (Finegan, 1984; Chazdon et al., 2007; Letcher and Chazdon, 2009). To date, natural regeneration of intensively managed pastures in rainforest areas has been mostly investigated by long-term chronosequences, with many studies reporting forest succession with graudal accumulation of species and biomass (Uhl et al., 1988; Aide et al., 1995, 2000; Chazdon et al., 2007; Letcher and Chazdon, 2009; Williamson et al., 2012). In this study we focus on the early years (0–15 years) of natural regeneration in pastures abandoned after prolonged use in southern Amazonia. In the course of this study, we addressed the speed of regeneration in the early years after pasture abandonment and how the rate of natural regeneration in abandoned pastures is influenced by time of use and distance from surrounding forest. Considering the history of colonization of the study area, with high levels of forest fragmentation followed by the introduction of intensively managed pastures, natural regeneration was hypothesized to be slow in abandoned pastures in the region. It was also hypothesized that the greater intensity and increased duration of land use before abandonment would slow down forest regeneration, whereas a larger proportion of forest cover adjacent to abandoned pastures would accelerate it.

2. Material and methods

2.1. Study area

Sampling was carried out in abandoned pastures on farms along the upper Madeira River Basin located approximately 100 km west of the city of Porto Velho, Rondônia, Brazil (Fig. 1). The climate in the study area is tropical humid hyperthermic (Cochrane and Cochrane, 2010), with average temperatures around 26 °C and rainfall from 1700 to 2200 mm yr^{-1}, with a dry season from June to October (INMET, 2013). Terrain in the study area is flat, and altitudes range from 83 to 144 m. The area has a history of colonization that started in the 1970s with deforestation of primary and secondary forests for the establishment of pastures, a process that was accelerated after the construction of the BR-364 Highway (Ferraz et al., 2005). More recently, the region has been affected by the construction of the Jirau Hydroelectric Dam (Moser et al., 2014).

The right bank of the Madeira River is characterized by a recent geological formation, with large alluvial deposits and vegetation types comprising terra firme forests, várzea forests and *campinaranas,* the last two types being associated with seasonal flooding. The region has been the target of plant inventories in areas of terra firme forest where high species richness (900 species) was found. Most species were observed to occur in low densities, but a few species, such as *Attalea speciosa* Mart. ex Spreng, *Euterpe precatoria* Mart., and *Eschweilera coriacea* (DC.) S.A. Mori, dominated (Moser et al., 2014).

Most abandoned pastures sampled in this study are included in a buffer zone of 100 m designed to protect the area around the Jirau Reservoir (Fig. 1). Latosol is the predominant soil type in the study area (Cochrane and Cochrane, 2010), which was originally covered by terra firme forests, but is now dominated by livestock activities. Pastures in the region are generally intensively managed with the use of herbicides, mowing, and fire for pasture renovation and weed control. These areas are typically abandoned after a few years and then renewed, and the process can be repeated multiple times.

2.2. Sampling plots for structure and composition of vegetation

We installed 36 circular plots with 10 m radius in areas of abandoned pastures that were originally covered by terra firme forest (Fig. 1). The areas were selected based on a mosaic of high-resolution aerial photographs (0.5 m pixel) and field surveys that cover a representative sample in terms of geographic distribution and successional stages, ranging from homogeneous clean pastures to early secondary forests (0–15 years since encroachment). In each plot, all stems of tree species with height $\geqslant$30 cm were identified and measured in order to obtain conventional phytosociological parameters, including species density, frequency, stem density, basal area, and Importance Value Index (IVI; Kent and Coker, 1992). Diameter of stems free from swollen parts or deformations was measured with a digital calliper to ground level. For stemless juveniles of the palm *A. speciosa*, individuals were assumed to have a ground level diameter of 20 cm (Gehring et al., 2011). Species identification was performed by a parataxonomist in the field with the aid of identification guides (Ribeiro et al., 1999). Herbarium vouchers were collected whenever possible and were compared to the collection of the herbarium of Embrapa Genetic Resources and Biotechnology (CEN), which houses a large number of collec-