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Medium-term dynamics of tree species composition in response to silvicultural intervention intensities in a tropical rain forest

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ABSTRACT

Managed forests are important landscape components in tropical regions and may contribute to biodiversity conservation. Yet, managing tropical forests sustainably requires an understanding of ecosystem responses to silvicultural interventions. We investigated how silvicultural intervention intensity affects tree species composition and diversity over 30 years in the Brazilian Amazon by comparing them to pre-logging conditions and to an unlogged control. The interventions comprised logging in 1982 and thinning in 1993–1994 and ranged in intensity from 19 to 53% reduction in the original basal area (BA). Trees with a diameter at breast height (DBH) ≥5 cm were measured on eight occasions in 41 permanent sample plots of 0.25 ha each. Silvicultural intervention intensity influenced both tree species composition and its trajectory within 30 years. In contrast, tree species diversity was not impaired. High intervention intensities (with BA reduction > 6.6 m^2 ha^{-1}) had a substantial influence on the community of trees (DBH ≥ 10 cm), which did not show signs of return to pre-logging species composition. The reduction of BA through harvesting damage and thinning had a stronger effect on species composition than logging of mature trees itself. Thus, damage should be kept to a minimal level and strong thinning interventions should be avoided. This may enhance ecosystem recovery and maintenance of biodiversity at other trophic levels. Since current permitted harvesting intensities in the Brazilian Amazon are lower than the lowest intensity examined in our study, legal harvesting practices are unlikely to cause substantial, long-term changes in tree species composition.

1. Introduction

Tropical forests are a source of many goods and services, presenting the most complex structures and the highest biological diversity among terrestrial ecosystems (Whitmore, 1998; Ghazoul and Sheil, 2010). The Brazilian Amazon harbors around 20% of the world's species of fauna and flora (Azevedo-Ramos, 2008), and it is estimated that it houses more than 12,000 tree species (ter Steege et al., 2013). Moreover, this region accounts for the largest-continuous area of tropical forest in the world (FAO, 2011). Many anthropogenic processes such as unregulated exploitation and land-use change threaten tropical forest ecosystems and only a small proportion of the biodiversity is contained within protected areas (ITTO, 2009). Thus, conservation strategies will also have to consider forest areas not designated for conservation. Given that logged and secondary forests still harbor a considerable amount of tropical biodiversity (Chazdon et al., 2009; Dent and Wright, 2009; Putz et al., 2012; Burivalova et al., 2014), these anthropogenically disturbed ecosystems are important landscape components for biodiversity maintenance and conservation.

The proportion and identity of species retained in managed forests depend on the applied practices and the ecosystem's resistance and resilience in relation to the disturbance. Considering that managing forests implies manipulating their structures and composition to favor some species and life forms over others, shifts are inevitable (Whitmore, 1998) as well as subsequent impacts on biodiversity (Putz, 2011). Consequently, the intensity and caution employed in silvicultural practices shape the compatibility of timber production and

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conservation (Putz, 2011). The long-term response of forest biodiversity will depend in particular on the question whether anthropogenic disturbances are compatible with the ecological stability of the system (Swanson et al., 1994). Finally, the maintenance of species diversity and composition will support the continuity of provision of goods and services (Thompson, 2010), and the ecosystem's ability to cope with changing environmental conditions (ITTO, 2009).

Therefore, when managing tropical forests, the challenge is to reduce harmful effects while maintaining productivity (Sheil and van Heist, 2000) and provision of other goods and services. To keep biodiversity, resilience and productivity in managed forests, it is essential to have a detailed understanding of these ecosystems, identifying at which level of use and manipulation thresholds might exist, beyond which the system may lose the capacity to recover from interventions (Thompson, 2011). Furthermore, it is crucial to understand the long-term response to management, since the effects may vary according to the time scale that is being considered.

Tree species diversity, measured either as species richness or as a diversity index, is a common response variable used to assess the impact of forest management interventions. In tropical forests, Clark and Covey (2012) reported that logging impaired tree species diversity, whereas many studies found no negative effect (e.g. Yosi et al., 2011; Baraloto et al., 2012; Carreño-Rocabado et al., 2012) or only a slight influence (e.g. Gourlet-Fleury et al., 2013; Duah-Gyamfi et al., 2014a). However, response variables related to species numbers do not represent species identities per se and therefore may not be suitable to identify relevant impacts of forest interventions (Sheil and van Heist, 2000; Putz, 2011; Putz et al., 2012). Although species diversity in general may be little affected, changes in species composition are likely to occur. If compositional changes through management favor post-disturbance dominance of few widespread species at the expense of rare and specialist species, this may lead to a local biotic homogenization (McKinney and Lockwood, 1999). Such a process will probably lead to lower species richness and higher similarity among formerly distinct communities (Olden et al., 2004).

The evaluation of management impacts on species composition and recovery is challenging (van Kuijk et al., 2009), since the effects may greatly vary among and within tropical forests (Ghazoul and Sheil, 2010). Given our limited understanding of forest ecosystems, it is necessary to make use of all available knowledge to support management decisions (Kimmins, 1997). This can contribute to improve techniques and to sustain tropical biodiversity in managed forests (Meijaard et al., 2005). To make management compatible with conservation of original biodiversity, interventions should not lead to substantial or long-lasting changes in plant species composition and dependent diversity at other trophic levels. So far, there is only scant information on possible thresholds of intervention intensity at which such compositional changes might happen in tropical forests.

In this study, we assessed the effects of different silvicultural intervention intensities on tree species composition and diversity over a period of 30 years. The experiment analyzed here is one of the few long-term studies on forest dynamics following logging and thinning in the Brazilian Amazon or any other lowland tropical rainforest. Specifically, we investigated the medium-term dynamics of tree species composition and diversity compared with the pre-logging condition and to an unlogged control treatment to address the following hypotheses:

(i) Logging, damage and thinning affect tree species composition in comparison to the natural forest;
(ii) Recovery of pre-logging species composition is negatively related to intervention intensity, measured as reduction in basal area;
(iii) Within the range of applied intervention intensities, tree species diversity is not impaired;
(iv) If changes in species composition over time are characterized by higher spatial similarity among managed treatments associated with lower species richness, we expected that a local biotic homogenization will occur.

2. Materials and methods

2.1. Study site

The study was conducted in the Tapajós National Forest, municipality of Belterra, State of Pará, Brazil (3°18′S to 3°19′S, 54°56′W to 54°57′ W). The area was originally chosen for the long-term experiment because it represents a typical forest of the region with a low degree of human impacts (Carvalho, 2002). The topography of the region is flat to slightly undulating and the altitude is around 175 m above sea level. The climate is tropical with one dry season and annual rainfall averages 2100 mm. The annual average temperature is approximately 25 °C and the relative humidity is around 86%. The predominant soil type is yellow latosol, which is characterized by a heavy clay texture, deep profile and low fertility and base saturation (Vieira, 1975). The vegetation of the region is classified as ombrophilous dense forest (IBGE, 2012).

2.2. Experimental design and sampling

The experiment is a randomized block design with four replicates (36 ha each). Each silvicultural intensity treatment has 12 permanent sample plots (0.25 ha each) distributed within the four blocks. An area of 36 ha of unlogged forest served as a control. In the logged area, the first assessment of the permanent sample plots occurred in 1981 following liana cutting. Logging was carried out in 1982 and the treatments differed mainly by the minimum felling diameter (Table 1). Directional felling and bucking of trees were performed with chainsaws and the logs were extracted using skidders.

Thinning through poison-girdling was applied between 1993 and 1994 to reduce the basal area to the planned level of the experiment by eliminating non-commercial trees to favor growth and regeneration of commercial species (Oliveira et al., 2006). Thus, intervention intensities comprised logging, damage to trees not harvested (i.e. trees that died as an indirect result of logging) and thinning, together ranging from 19 to 53% of basal area reduction in relation to the original value in 1981 (Table 1).

An accidental fire occurred in the experimental area in 1997, which affected 19 permanent sample plots (Table 1). Although these plots are still being monitored, they were not included in this study. The remaining 41 plots resulted in a coverage of 5.7% of the total experimental area (180 ha). Our design is in accordance with suggestions to capture the heterogeneity among sampling units through many small plots rather than few large plots in tropical forests, with a recommended minimum number of five plots (Bonar et al., 2011). Additionally, the species richness estimation for rarefied and extrapolated samples in the initial census, constructed by using iNEXT (iNterpolation and EXTrapolation) (Chao et al., 2014), indicated a trend towards an asymptote in species richness, and hence a good sampling size to represent the tree species community (see Fig. A1 in Supplementary data).

All trees with a diameter at breast height (DBH) ≥5 cm were sampled in the 41 permanent sample plots and permanently labeled with aluminum tags. Species were identified by their vernacular names by parataxonomists and for the least common species, plant material was collected for identification in the herbarium of Embrapa Amazônia Oriental. The permanent sample plots were inventoried in 1981, 1983, 1987, 1989, 1995, 2003, 2008 and 2012, except for the control area that was not measured in 1981. To permit comparisons with published results and to enable a more detailed analysis, the sampled trees were grouped into two size classes: poles (5 ≤ DBH < 10 cm) and trees (DBH ≥ 10 cm).