



Effects of reduced impact logging on the forest regeneration in the central Amazonia



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ABSTRACT

Selective logging can alter the biota (presence of seed source) and distribution of resources (light and soil factors), modifying the performance of seedlings. To evaluate these effects on forest regeneration processes is of critical importance, since reduced impact logging (RIL) has been advocated as a potential tool for conservation. We describe the abiotic alterations caused by selective logging and examine the effect of disturbances on the abundance and performance of seedlings of seven tree species. To test long-term effects we evaluated the regeneration process in a chronosequence spanning 11-years after logging in which 144 plots were sampled, representing an area of 300,000 ha in the central Amazonia. Seedling performance was affected by habitat alterations caused by logging. Growth is enhanced in logged sites for up to three years after logging for all species. However, in five out of seven species, the mortality rates found in logged were higher than the ones in control sites up to 11 years after logging. For most species the presence of a seed source is the most important factor determining the number of regenerating individuals. This effect of dispersal limitation on seedlings can affect tree regeneration on logged areas, since no rules limit the number of individuals per species that can be harvested per hectare. Demographic responses to abiotic alterations resulting from selective logging affect tree species regeneration patterns, and in a long term can influence the structure of tropical forest communities. We concluded that over time the habitat becomes less suitable for species regeneration on logged areas. These results indicate that RIL can have more effects on tree regeneration than previously supposed. Methods to minimize these effects (mainly on survivorship rates) should be considered in future management plans.

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1. Introduction

Reduced Impact Logging (RIL) has been considered an important tool in reducing deforestation rates in many tropical forest areas (Putz et al., 2012; Schwartz et al., 2012). However, some authors argue that selective logging's techniques guarantee neither the maintenance of biodiversity (Burivalova et al., 2014) nor the sustainability of the logging activities themselves (Hawthorne et al., 2012; Phillips et al., 2004). RIL is a type of logging generally associated with sustainable practices, and therefore the main

challenge is in designing logging rules that are compatible with natural regeneration (Phillips et al., 2004; Schulze et al., 2008a). Characteristics such as recruitment, growth and survivorship of young individuals of tree species significantly affect forest composition (Poorter, 2005). Therefore, improve the knowledge about regeneration strategies of different tree species is important to evaluate the long-term effects of anthropogenic alterations on forest dynamics (Clark and Clark, 1999).

There are many theoretical approaches that model regeneration in tropical forests (Hubbell, 2001; Wright, 2002) and its effects on the forest diversity and dynamics. Two different views are the most prominent attempts to explain species presence and abundance: the niche model, which predicts the presence and abundance of individuals of tree species in response to abiotic conditions in combination with biotic interactions (Gravel et al., 2008); and neutral theory, which states that species presence is a function of dispersal limitations (Hubbell, 2001; Gravel et al., 2008). Environmental changes caused by logging can modify the

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regeneration trajectory by acting on several factors described in these classical models: increasing dispersal limitations through a reduction in adult abundance of harvested species, and alteration in abiotic factors such as light and soil nutrients (Nicotra et al., 1999). Furthermore, there is also a temporal factor in the effect of logging on regeneration. The distribution of early recruitment individuals should be related to the presence of the parent plant, while the presence of older saplings should be more influenced by environmental filters (Gravel et al., 2008). Thus, one would expect that removing adults in logged areas would affect early recruitment of individuals more than older saplings which would be more influenced by the effects of the environmental change.

Environmental changes resulting from selective logging must also modify the dynamics of the forest (Pinard, 2005 and references there in), especially through increased growth of individuals, because more light reaches the lower strata of the forest (Baraloto et al., 2005; Clark and Clark, 2001; Duah-Gyamfi et al., 2014; Makana and Thomas, 2004; Schwartz et al., 2012). The effects on mortality are less obvious and depend on the traits of living species (Makana and Thomas, 2004) but higher growth rates are usually associated with higher survivorship. Changes in such rates may modify the path of species regeneration in logged sites since the relationship between growth rate and mortality influences regeneration and may be crucial to both the establishment and long-term maintenance of the species (Wright et al., 2010).

Most studies of regeneration on logged sites have examined the variation in vital rates in sites created due to activities associated with logging, such as clearcutting, skidding, and log piling (Aoyagi et al., 2013; Duah-Gyamfi et al., 2014; Herault et al., 2010; Schwartz et al., 2012; Silva et al., 1995) and they provide valuable information for evaluating the mechanistic effects of logging on regeneration. However, RIL areas are a mosaic of sites directly affected by logging activities and non-touched areas. Plant populations are not split in these different new habitats, and thus it is important to verify the effect of the logging on tree regeneration considering both affected and non affected areas.

We first verify the effects of logging on the environmental conditions, especially with regard to light and soil. We also evaluate whether environmental variables (light and soil properties, the main environmental filters) and the presence of adults (an indirect measure of dispersal limits, Gravel et al., 2008) are modulating the species abundance. If the most important abiotic variables acting as environmental filters are heavily modified by selective logging, we can identify whether logging is either positively or negatively influencing regeneration. Additionally, we determined if the relationship between species abundance and the aforementioned factors varies as a function of the size of seedlings and saplings.

We also test the hypothesis that logging affects the regeneration of seedlings and saplings altering its growth and survivorship rates. We predict that the performance (quantified by the relationship between growth and survivorship rates) of the species will increase on the logged site. Furthermore, we evaluate changes in vital rates over time after logging through a chronological sequence. We studied commercial and non-commercial species, so we discuss the different pathways in regeneration between these both types of species.

2. Material and methods

2.1. Study area

This study was conducted in the central Amazonia, Brazil (between 2°43' and 3°04'S, and between 58°31' and 58°57'W). This forested area lies adjacent to the Amazon River, 250 km from Manaus. The regional climate is tropical humid, with 2200 annual

rainfall, and four months of dry season, between June and October (Laurance, 2001). Most of the study area belongs to Precious Woods Amazon (450,000 ha of forest, divided into approximately 35 management units), a selective logging company certified by the Forest Stewardship Council (FSC) since 1997. Logging activities began in 1995 using FSC guidelines and continues today. The studied forest operation units were logged in 2005, 2002 and 1996 and data collection occurred between 2007 and 2009, on sampling sites with effective regeneration ages of 2, 5, and 11 years at the beginning of this study. Wood was extracted at an intensity of roughly 17 m² ha⁻¹ (approximately 4 trees ha⁻¹), with a harvest cycle of 30 years and logging activities was restricted to plateau areas (PWA, 2015). Four replicates in different locations never logged were sampled as control (Fig. 1). Approximately 10% of the area was affected with logging activities like gaps, skid trails, etc.

2.2. Study species

We studied seven common species from several families: *Manilkara huberi*, *Manilkara bidentata*, *Pouteria anomala*, *Goupia glabra*, *Minuartia guianensis*, *Zygia racemosa*, *Protium hebetatum* (Table 1). With the exception of *G. glabra*, all species exhibit pluriannual reproduction. *M. huberi*, *M. bidentata*, *P. anomala*, and *M. guianensis* have fruits of similar size and are dispersed by vertebrates (birds, monkeys, etc) while *G. glabra*, the only species studied reproducing annually, is bird dispersed (Rankin-de-Merona and Ackerly, 1987). All of these species are among the 55 most abundant species in this community and all but *G. glabra* are shade tolerant. These species represent a broad set of traits including size, wood density and reproductive characteristics (Table 1).

2.3. Sample design

To verify the effect of logging and time since logging on species regeneration, we consider our treatment has four levels (2, 5 and 11 years of post-logging regeneration and the control). Within each of these four sites, a total 36 plots were installed (each plot measuring 20 × 20 m), grouped in 4 blocks of 9 plots per block (Fig. 1). For both the control and logged sites, a block consisted of nine plots arranged in three rows, three plots to each row (Fig. 1). In each block plots were spaced systematically 200 m apart. The spacing was assumed to be sufficient to consider the plots independent of one another with respect to the effects of source adults and light (Nicotra et al., 1999). The distance between the blocks in each treatment was around 2 km. Each logging treatment sampled an effective area of 1.44 ha. (Fig. 1). Control plots were installed in never logged areas adjacent to the sampled managed units (Fig. 1). The accumulated sampled area of the study (control plus all logged plots) was 5.76 ha. We focused our study to evaluate the abundance, growth and survivorship of all individuals smaller than 1 cm DBH. The minimum size of the sampled individuals varied between species, from 7 cm (*Z. racemosa*) to 10 cm (*P. hebetatum*) height.

The first census was conducted in 2007 and all plots were resampled in 2008 and in 2009, between the months of July and October. In each census height of all individuals was measured with a measuring tape (precision = 0.5 cm). Each individual was identified with a numbered metal tag to track growth and survivorship throughout the study.

2.4. Light availability

For an indirect measure of light availability, a hemispheric photo was taken with a Nikon Coolpix 4500 coupled with a fish-eye lens in the center of each plot to measure canopy openness. We analyzed the photos using the software Gap Light Analyzer

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