Forest Ecology and Management 392 (2017) 36–44

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Natural regeneration of trees in selectively logged forest in western Amazonia

Anelena Lima de Carvalho[a,*], Marcus Vinício Neves d'Oliveira[b], Francis E. Putz[c], Luís Claudio de Oliveira[b]

[a] Tropical Forest Science, National Institute for Amazon Research, Amazonas, Brazil
[b] EMBRAPA – CPAF-ACRE, Caixa Postal 392, CEP 69900-180 Rio Branco, Brazil
[c] Department of Biology, University of Florida, Gainesville, FL 32611-8526, USA

A R T I C L E I N F O

Article history:
Received 30 November 2016
Accepted 27 February 2017

Keywords:
Amazon
Reduced-impact logging
Tropical forestry
Natural forest management
Forest dynamics
Soil compaction
Forest degradation

A B S T R A C T

We evaluated the impacts of selective logging on tree regeneration one, four, and eight years after harvests in Antimary State Forest in the State of Acre, Brazil. We inventoried tree seedlings, saplings, and poles (>50 cm tall to <10 cm DBH) on secondary roads, log landing, and skid trails, as well as in the bole and crown zones of canopy gaps created by felling; for comparison we also sampled areas not affected directly by logging. We compared these habitats on the basis soil (physical) characteristics, canopy cover, and floristic composition. For areas one and four years after logging, we supplemented the ground-based information with aerial LiDAR data. By eight years post-logging the size class distributions of tree regeneration in all habitat types resembled those in unlogged areas, and densities were only lower in crown gaps. Eight years after logging, relative densities of pioneer trees were highest on secondary roads and log landings; no among habitat differences were observed in the relative densities of non-pioneer species at any time along the chronosequence. Tree species diversity (Fisher's alpha) converged on unlogged values on skid trails, bole gaps, and crown gaps at 8-years post-logging, but values remained lower on secondary roads and log landings. Canopy openness was greatest one year after logging, especially in log landings (mean 45.4 ± SE 4.5%) whereas four and eight years post-logging it did not exceed 10% and no differences were found among habitats. Soil bulk density was elevated relative to un-logged areas only on log landings one and four years after logging, and this difference disappeared by eight years post-logging. The total area disturbed by logging varied from 7.0% to 8.6% with nearly half of the totals in felling gaps (3.0–3.7%).

1. Introduction

A challenge for sustainable tropical forest management (SFM) is to secure sufficient regeneration of commercial timber species after selective logging, especially those that are light-demanding (e.g., Fredericksen and Pariona, 2002). Most felling gaps opened by the harvest of single trees are too small for the establishment and growth of many shade-intolerant species (Yamamoto, 2000; Fredericksen and Mostacedo, 2000), which sometimes regenerate more abundantly on log landings and skid trails (e.g., Soriano et al., 2012). Unfortunately, for forest managers, seedlings that do get established in areas previously traversed by heavy equipment can later be inhibited by soil compaction and soil surface displacement (Pinard et al., 1995). Logging may also favor the colonization and growth of non-commercial species that suppress the regeneration of timber trees (e.g., Vieira, 1995; Mostacedo and Fredericksen, 1999). To understand the impacts of selective logging, it is important to know the extent and degree of canopy opening and soil damage, how these disturbances affect tree regeneration, and for how long their impacts persist.

Logging disturbances vary in spatial scale and intensity, from extensive and heavy, such as roads and log landings, to those that are restricted and relatively light, such as skid trails and felling gaps (Karsten et al., 2014). The amounts of soil disturbance and residual tree damage also vary with harvest intensity, log extraction machinery employed, and the extent to which reduced-impact logging (RIL) techniques are employed (Putz et al., 2001). Selective logging also causes other short and long-term effects including changes in forest understory micro-climates, nutrient cycle disruption, and changes in species composition (e.g., Mostacedo et al., 2009; TerSteege et al., 1995; Elliott and Knoepp, 2005; McNabb et al., 1997; Fredericksen and Mostacedo, 2000;

* Corresponding author at: EMBRAPA – CPAF-ACRE, Caixa Postal 392, CEP 69900-180 Rio Branco, Brazil.
E-mail address: anelenacarvalho@gmail.com (A.L. de Carvalho).

http://dx.doi.org/10.1016/j.foreco.2017.02.049
0378-1127/

Pinard et al., 1995). Wide variation in logging intensities (<1 m^3/ha to >100 m^3/ha), timber extraction methods, and post-logging silvicultural treatments limit generalizations about the effects of logging over time (Putz et al., 2001).

Concepts of SFM vary (e.g., Wang, 2004; Zimmerman and Kormos, 2012; d'Oliveira et al., 2012) as do the silvicultural practices that are appropriate for different forests and management goals. Despite this diversity of conditions and expectations, Brazilian forest law prescribes the same silvicultural system for all its Amazonian forests. This system sets the minimum harvest cycle length at 10 years for low intensity logging (<10 $m^3\,ha^{-1}$) and 25–35 years for higher intensity logging (10–30 $m^3\,ha^{-1}$; CONAMA, 2009). It seems likely that these rules are not equally appropriate across even the small State of Acre in the western Amazon where the 18 described forest types range from open palm forest to dense forest (Salimon et al., 2011). Locally tailored silvicultural guidelines are especially critical for the hard-to-manage bamboo-dominated forests that cover approximately 161,500 km^2 in the departments of Madre de Dios - Peru, Acre - Brazil, and Pando - Bolivia (Nelson, 1994; de Carvalho et al., 2013). Design of these guidelines is hampered by the paucity of research on this forest type, especially about natural regeneration of commercial tree species after logging (but see Rockwell et al., 2014; d'Oliveira et al., 2012; d'Oliveira et al., 2006).

We studied tree regeneration dynamics in response to canopy and soil disturbances caused by selective logging in Antimary State Forest in Acre, Brazil. To explore the impacts of logging over time we used a chronosequence of stands logged one, four, and eight years prior to measurement. We compare soil conditions and tree regeneration on abandoned secondary roads, log landings, skid trails, and felling gaps with adjacent areas that were unlogged.

2. Material and methods

2.1. Study site

Antimary State Forest (ASF) is located between the cities of Rio Branco and Sena Madureira in the State of Acre in the southwestern Brazilian Amazon (Fig. 1). ASF covers an area of 768 km^2 and has approximately 380 inhabitants (109 families) who make their living through rubber tapping, Brazil-nut collecting, and shifting cultivation. The three dominant vegetation types are dense forests with a uniformly closed canopy and emergent trees, open forest with abundant lianas and palms, and bamboo-dominated forest (tabocal). The climate is classified as Awi (Köppen), with annual precipitation of approximately 2000 $mm\,yr^{-1}$ and a June-September dry season during which monthly precipitation is <100 mm; the average temperature is 25 °C. The topography is gently sloping, with an altitudinal range of approximately 300 m; the predominant soils are dystrophic yellow latosols with high clay content (Funtac, 1989).

Formal forest management in the area started in 1985 with establishment of a large research program coordinated by FUNTAC (Acre State Technological Foundation). Between 1999 and 2003, timber was harvested by FUNTAC but in 2004, a forest concession system was adopted through which ASF inhabitants receive social and financial benefits (d'Oliveira et al., 2013).

Two of the Annual Production Units (APUs) we studied were selectively logged following the Modeflora methodology (Figueiredo, 2007) one year (in 2013) and four years (in 2010) prior to our study; the 8-year APU (logged in 2007) was selectively logged following a detailed harvest plan. With the Modeflora approach to selective logging, trees >35 cm DBH of commercial species with boles suitable for harvest are tagged, mapped with a high-sensitivity GPS, identified to species, and measured during the forest inventory. Permanent preservation areas and restricted access areas (slopes > 15%) are demarcated in the field. Mapped trees are classified as loggable (commercial species > 50 cm DBH), future crop trees (35–50 cm DBH), seed trees (10% of trees of commercial species > 50 cm DBH), and protected species (*Bertholetia excelsa* and *Hevea braziliensis*). This information is included on digital forest exploitation plans that are available to all logging crews (Figueiredo, 2007). Adherence to the logging guidelines reportedly reduces the area affected directly by logging from 22.2% to 14.8% (EMBRAPA, 2008). The numbers of species harvested and logging intensities in the three APUs in our chronosequence were all similar (Table 1).

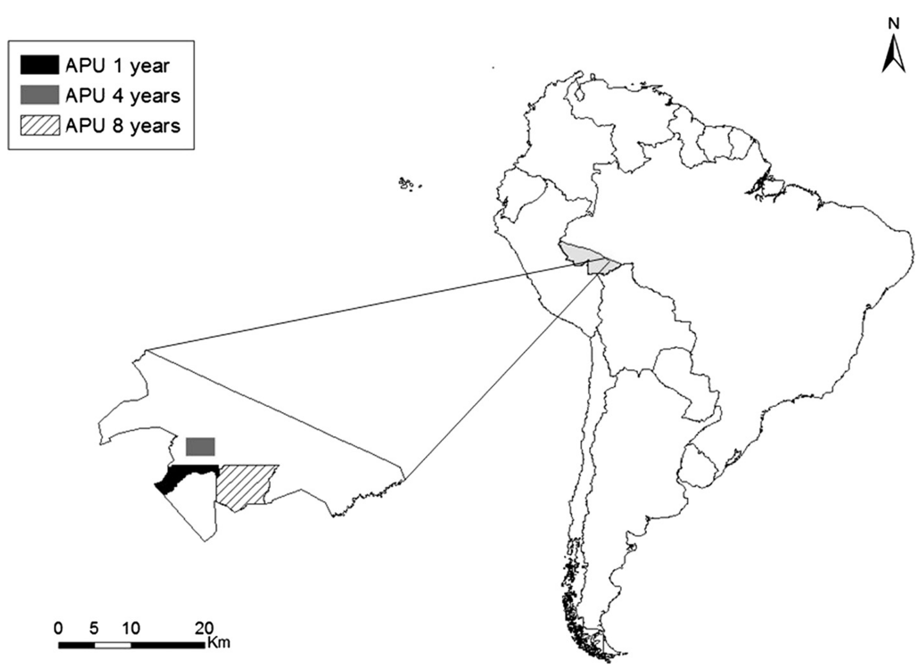

Fig. 1. Antimary State Forest in Acre State, Brazil.