



Forest biomass recovery after conventional and reduced-impact logging in Amazonian Brazil



Thales A.P. West^{a,b,*}, Edson Vidal^{b,c}, Francis E. Putz^{a,d}

^a Department of Biology, University of Florida, Gainesville, FL 32641, USA

^b Departamento de Ciências Florestais, ESALQ/Universidade de São Paulo, Piracicaba, SP 13418, Brazil

^c Instituto do Homem e Meio Ambiente da Amazonia (IMAIZON), R. Domingos Marreiros, no 2020, Bairro Fatima, Belem, Para 66060-160, Brazil

^d Center for International Forestry Research (CIFOR), Bogor, Indonesia

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ABSTRACT

Growing concerns about unnecessarily destructive selective logging of tropical forests and its impacts on greenhouse gas (GHG) emissions motivated this study on post-logging biomass dynamics over a 16-year period in a control plot and in plots subjected to conventional logging (CL) or reduced-impact logging (RIL) in Paragominas, Pará State, Brazil. All trees >25 cm were monitored in 25.4 ha plots of each treatment, each with a subplot of 5.25 ha for trees >10 cm dbh. The commercial timber volumes in felled trees were 38.9 and 37.4 m³ ha⁻¹ in the RIL and CL plots, respectively, but the extracted volumes were 38.6 and 29.7 m³ ha⁻¹, respectively. Immediately after logging, plots subjected to RIL and CL lost 17% and 26% of their above-ground biomass, respectively. Over the 16 years after logging, the average annual increments in above-ground biomass (recruitment plus residual tree growth minus mortality) were 2.8 Mg ha⁻¹ year⁻¹ in the RIL plot but only 0.5 Mg ha⁻¹ year⁻¹ in the CL plot. By 16 years post-logging, the RIL plot recovered 100% of its original above-ground biomass while the CL plot recovered only 77%; over the same period, biomass in the control plot maintained 96% of its initial stock. These findings reinforce the claim that conversion from CL to RIL would represent an efficient forest-based strategy to mitigate climate change under the REDD+ and would be an important step towards sustainable forest management.

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1. Introduction

Tropical forests play an important role in climate regulation as sinks for greenhouse gases (GHG), storing 471 ± 93 Pg C, which is equivalent to 55% of the carbon stored in Earth's forests (Pan et al., 2011). Due to their high species density and lack of markets for the wood of most species, the large volume of woody biomass in tropical forests does not necessarily imply substantial volumes of commercial timber (Wadsworth, 1997). Because so few tree species produce marketable wood, logging in tropical forest is selective and damage per unit area is low, but damage per cubic meter of harvested wood can be substantial (Dykstra, 2002). One option to reduce greenhouse gas (GHG) emissions from logging activities is to decrease the associated damage to residual forests by employing reduced-impact logging (RIL) techniques (Sasaki et al., 2012). Common RIL techniques include pre-harvest mapping of crop trees, pre-harvest planning of roads and skidtrails, pre-harvest liana cutting, and the use of appropriate felling techniques including directional felling and cutting stumps low to the ground

to avoid waste (Johns et al., 1996; Putz et al., 2008a). To improve forest management, a case can be made that RIL should be among the options of the United Nation REDD+ program (reduced emissions of atmospheric heat-trapping gases from deforestation and forest degradation, including the role of conservation, sustainable management of forests and enhancement of forest carbon stocks). The conversion from conventional logging (CL) to RIL should be eligible for compensation in both voluntary and regulated carbon-based payment schemes (Angelsen, 2008; Sasaki et al., 2012; UN-REDD, 2008).

The immediate impacts of logging on residual forest structure and biomass vary with logging intensity but also with logging methods. Reportedly, collateral damage can be reduced by up to 50% when RIL techniques are applied (Pinard and Cropper, 2000). If RIL techniques were used in the entire 350 million ha of tropical forests officially designated for logging in the tropics, global GHG emissions would be reduced by 0.16 Gt C year⁻¹ (Putz et al., 2008b). Unfortunately, due to the scarcity of long-term data on biomass recovery of tropical forests subjected to RIL and CL, this estimate is based mostly on short-term studies and computer simulations. The objective of this study is to estimate how RIL and CL influenced biomass recovery dynamics 16 years post-logging in Amazonian Brazil.

* Corresponding author at: Department of Biology, University of Florida, Gainesville, FL 32641, USA. Tel.: +1 352 392 1468.

E-mail address: thales.west@ufl.edu (T.A.P. West).

2. Methods

The study area is in the eastern Brazilian Amazon (3°17'S, 47°34'W) at an elevation of about 200 m on private land where the Amazon Institute of People and the Environment (IMAZON) conducts this logging experiment (Fig. 1). The forest is evergreen with canopy heights of 25–40 m. The terrain is level to undulating and the soils are predominately yellow latosols, rich in aluminum. Average annual rainfall is 1700 mm with a January–May wet season followed by a June–November period during which average monthly rainfall is <50 mm (Barreto et al., 1998; Johns et al., 1996).

In 1993 the forest was subjected to either conventional logging (CL, 75 ha) or reduced-impact logging (RIL, 105 ha); an additional 30 ha was reserved as an unlogged control. Although no direct indications of previous logging or fire were observed, the abundance of lianas may be evidence of logging many years before the experiment was implemented. Two years prior to logging, a 24.5 ha plot (350 × 700 m) was established at a random location in each area with a more intensively studied 5.25 ha (75 × 700 m) sub-plot in the center of each. All trees >10 cm DBH (stem diameter at 1.3 m from the ground or above buttresses) in the 5.25 ha sub-plots and all trees >25 cm DBH in the 24.5 ha plots were marked, mapped, and identified to species. Furthermore, trees were described in terms of the presence or absence of lianas, crown exposure (adapted from Dawkins, 1958), and trunk and crown quality. At the time of initial establishment of the RIL plot, all lianas >2 cm DBH on trees to be harvested were cut. About one year after logging, trees were remeasured, described as explained above, and recorded as having suffered trunk or crown damage during logging. During subsequent measurements, these same data were collected and new recruits were recorded (for further information related to sample design and data collection see Johns et al. 1996). Data collected in 2005 included substantial inconsistencies with previous and subsequent inventories and were therefore discarded. Felled volumes were similar in both treatments (39 m³ ha⁻¹ in RIL and 37 m³ ha⁻¹ in CL) but the extracted volumes from the CL plot were much lower Barreto et al. 1998; Table 1).

To estimate the above-ground biomass of each sampled tree and the forest as a whole, we used an allometric equation based on DBH and wood density (Chave et al., 2005) and then scaled up using the methods recommended by the UNFCCC (2011). Biomass was calculated from data from the 24.5 ha plots, with data for trees 10–25 cm DBH extrapolated from the 5.25 ha sub-plots. For trees larger than the maximum included in calculation of the allometrical equation (>156 cm DBH; 5 of the 26,846 trees sampled), biomass values were estimated by extrapolation. Species-specific wood densities were obtained from the literature following the procedures described by Medjibe et al. (2011). Biomass increments were assumed to proceed at the average rate between measurements (UNFCCC, 2011). Additionally, annual forest biomass was separated into diameter classes to evaluate changes in forest structure.

Given the lack of replication of the treatments in this study and the consequent possibility that any observed treatment effect is the result of pre-existing conditions, we compared median post-logging growth rates of residual trees of species represented by ≥5 individuals with 20–40 cm DBH in both the CL and the RIL plot. Additionally, we also used geoR package (Ribeiro and Diggle, 2001) available for R v.3.0.2 (R Core Team, 2013) to construct a semivariogram of the area that includes both CL and RIL plots to detect any spatial auto-correlation in the data.

3. Results

Residual trees with 20–40 cm DBH of species represented by ≥5 individuals in both RIL and CL plots grew faster in the latter. Concerns about the possibility of spatial auto-correlation in the aboveground biomass that might have confounded the results in this pseudoreplicated study were allayed by the lack of any apparent spatial trends in a semivariogram of the RIL and CL plots (see Supplementary materials for the detailed results).

Pre-logging (1993) above-ground biomass estimates for the RIL, CL, control plots were 260, 264, and 238 Mg ha⁻¹, respectively. Soon after logging (1994), plots subjected to RIL and CL had lost 17% and 26% of their above-ground biomass, respectively. Over

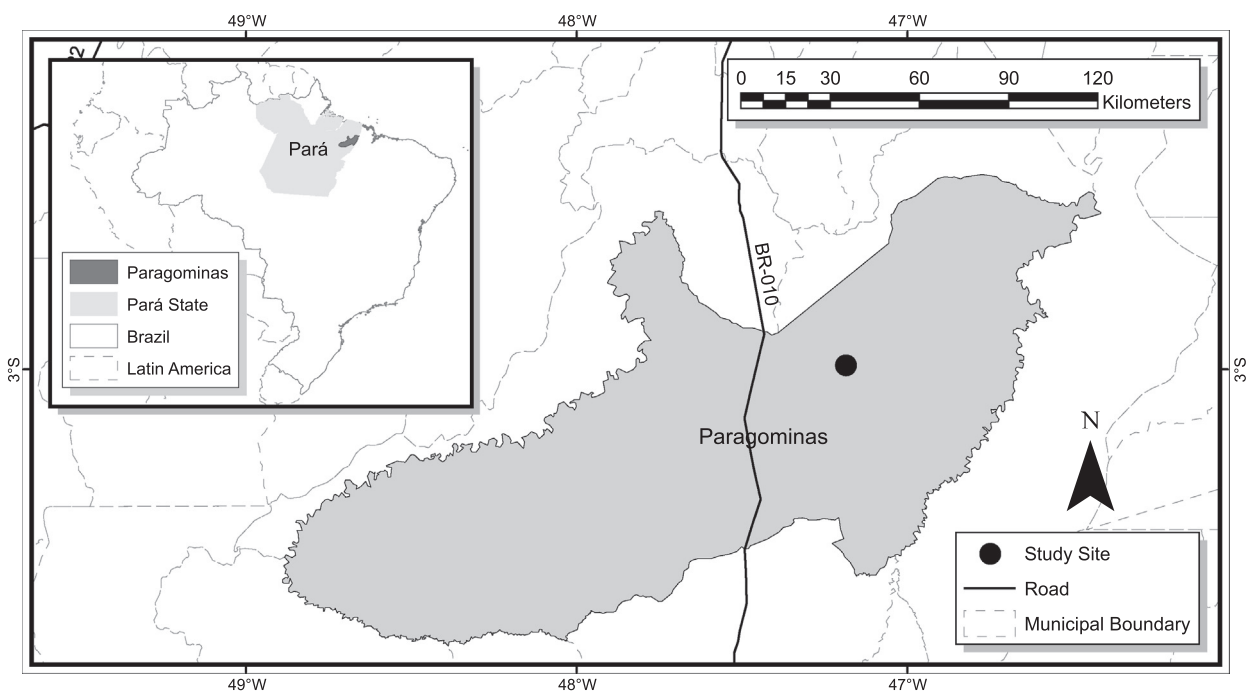


Fig. 1. Location of the study site.

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