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Can forest management be sustainable in a bamboo dominated forest? A 12-year study of forest dynamics in western Amazon

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ABSTRACT

The western Amazon supports the largest formation of neotropical bamboo forests. This forest ecosystem is neglected due to its low commercial timber volume and fragile forest structure that amplifies the damage caused by logging operations. This study was conducted in a lightly logged bamboo-dominated forest in Brazilian western Amazon, with the objective to evaluate the sustainability of the applied forest management regime in terms of tree density, above-ground dried biomass and tree bole volume stocks recovery rates and species groups. The forest dynamics were monitored over a period of 12 years in 10 permanent sample plots of 1 ha. Two main results of this study are important to the establishment of cycle lengths, logging intensities and silvicultural treatments for tropical forest management in bamboo-dominated forest: the rapid increment of the above-ground biomass (AGB) observed in the area after logging, and the slow growth of commercial and logged species. In addition, although no climate data was collected in this study, the reported 2005 and 2010 atypical climate events strongly affected forest dynamics and productivity.

These results indicate that short cutting cycles and light logging intensities, and the rotation of logged species, should produce the appropriate combination in terms of the disturbance frequency and scale to promote sustainable timber production in bamboo-dominated forests.

1. Introduction

The Bambusoideae subfamily (Poaceae) grows naturally from slightly above sea level up to 4500 m and are present in all continents, except Europe and Antarctica. The main centers of diversity are in Asia (eastern and southern) and the Atlantic side of South America (Judziewicz et al., 1999; Ohrnberger, 1999). Due to a large amount of documented uses (over than 1500; Bystriakova et al., 2003), bamboo species are one of the most important non-timber forest products over the World. However, despite their importance, very little is known about bamboo distribution and resources, especially in natural forests (Bystriakova et al., 2003).

The western Amazon supports the largest formation of neotropical bamboo-dominated forest, with an area of about 180,000 km^2 (Nelson, 1994; Griscom and Ashton, 2006). This neglected forest ecosystem (Rockwell et al., 2007) generally has a lower timber volume and forest structure amplifies the damage caused by the felling of trees and the passage of heavy machines for road opening as well as log skidding (D'Oliveira et al., 2004; Veldman et al., 2009). In such forests, succession is arrested (*sensu* Griscom and Ashton, 2003) in a self-perpetuating cycle in which bamboo (*Guadua* spp.) loads and crushes small (DBH < 30 cm) trees (Griscom and Ashton, 2006), resulting in poor timber species establishment and bamboo-dominated regeneration. In southeastern Amazon, especially in the Acre State (Brazil) the establishment of forest management plans in these areas is not rare, although the environmental sustainability of timber production in these areas appears to be questionable (D'Oliveira et al., 2004; Rockwell et al., 2007).

Despite that, the Brazilian forest laws does not provide specific rules to the management of bamboo-dominated forests. Regardless of forest type, the Brazilian law indicates the same silvicultural system, differentiating only cycle length and logging intensity according to log extraction method (CONAMA, 2009), divided in not mechanized (i.e. animal traction), 10-year cycle length and maximum logging intensity of 10 m^3 ha^{-1} and mechanized 25–35 year cycle length and maximum logging intensity of 30 m^3 ha^{-1}.

There is no consensus regarding the sustainability of tropical forest management for timber production among scientists. It is generally accepted that tropical forest management can be considered sustainable when practiced under reduced-impact logging rules (e.g., Nebel et al., 2001; Macpherson et al., 2010; Miller et al., 2011), but to recover the initial harvested volume during the length of a cycle, in addition to considering the impacts of logging operations, silvicultural treatments are required to guarantee the establishment and growth of timber species (e.g., Fredericksen

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and Mostacedo, 2000; Fredericksen and Putz, 2003; Dauber et al., 2005; Wadsworth and Zweed, 2006; Sist and Ferreira, 2007; Villegas et al., 2008). However, some scientists claim that tropical forest management produces irreversible damage in forests, which leads to degradation and conversion to agricultural uses and is only expected to be sustainable in very particular situations, such as under community forest management (e.g., Zimmerman and Kormos, 2012).

The effects of logging operations on tropical forests during the length of a cycle and, hence, on the sustainability of timber production, are difficult to assess due to the complexity of tropical forest ecosystems and the long term over which logging influences forest dynamics (e.g., Huth and Ditzer, 2001). Forest recovery is usually assessed in terms of basal area (e.g., Bonnell et al., 2011), volume (e.g., Silva et al., 1996) or above-ground biomass (AGB – Mazzei et al., 2010) and species composition (e.g. Carreño-Rocabado et al., 2012; Menger et al., 2013). The parameters that affect AGB accumulation and loss are tree growth, in growth and mortality. These parameters are used to estimate forest production and to define logging cycles and logging intensities in tropical forest management (e.g., Macpherson et al., 2010).

Changes in plant communities are evaluated by classifying species into different successional groups based on their ability to establish, survive and growth in different shade conditions and the dichotomy between pioneer and climax species could be defined, in a coarse level, as function of species light demanding throughout their existence (Ghazoul and Sheil, 2010). Due to the increase in light in the forest floor, natural gaps are the main driver of opportunities to new recruitment and growth in undisturbed tropical forests (Brokaw, 1985; Denslow, 1987). The fall of trees and skid of logs during forest operations produce gaps which alter the species composition of the managed forests, increasing the proportion of pioneer species in the plant community (e.g. Felton et al., 2006). Thus, pioneer species have been used as an indicator of forest disturbance (e.g. D'Oliveira and Ribas, 2011).

The most common way to obtain consistent results to support the sustainability of timber production in tropical forests is through long-term studies. These studies are expensive and difficult to conduct, but forest dynamics have been studied through permanent sample plots (PSP) for decades (e.g., Sheil, 1998; Malhi et al., 2002; Lewis et al., 2004; Laurance et al., 2009). Despite the limitations of this method, PSP are currently recognized as the best way to conduct monitoring of managed and non-managed tropical forests. In this study, we followed the development of a 70 ha bamboo (*Guadua* spp.) dominated forest in Antimary State Forest in Acre State in the Brazilian western Amazon, from one year before logging (1999) until eleven years after logging. Our objective was to evaluate the sustainability of the applied forest management regime considering the above-ground dried biomass accumulation, tree bole volume recovery and changes on commercial and pioneer species population composition.

2. Methodology

2.1. The studied areas

Antimary State Forest is located between Rio Branco and Sena Madureira in Acre State in the Brazilian western Amazon (68°01′ to 68°23′W; 9°13′ to 9°31′S). Antimary State Forest covers an area of 768.3 km^2 and has approximately 380 inhabitants, or 109 families, who make their living through extractivism (rubber tapping and Brazil nut collection) and shifting cultivation (Fig. 1). The climate falls within Awi (Köppen), with annual precipitation of approximately 2000 mm and an average temperature of 25 °C. Wet and dry seasons can be recognized. The dry season occurs between the months of June and September. Within Antimary State Forest, there are three types of forest: dense tropical forests (forests with a uniform canopy and emergent trees), open tropical forest (with a high occurrence of lianas and palm trees) and *tabocal*, which is an open type of forest dominated by bamboo species locally referred to as "tabocas" (*Guadua* spp.). The area has a topography dominated by gently sloping hills and a maximum altitudinal range of approximately 300 m, and the predominant soils are dystrophic yellow latosols with high clay content (Funtac, 1989).

The forest area studied in this work was the Tabocal annual production unit, an originally bamboo dominated forest with a relatively low timber volume of 157 $m^3\ ha^{-1}$ which was mechanically logged in 2000. Although a light logging intensity of 6.9 $m^3\ ha^{-1}$ (0.29 $m^2\ ha^{-1}$) was applied to fourteen species in the Tabocal annual production unit, the forest damage produced by the logging operations in the area was high (1.91 $m^2\ ha^{-1}$) (D'Oliveira et al., 2004). Considering the entire group of species selected for logging, only 47.2% of the commercial volume was extracted from the area (Table 1). Ten PSP were established and measured one year prior to logging (1999). The PSP were subsequently re-measured one (2001), four (2004), seven (2007) and eleven years after logging (2011).

2.2. Permanent sample plots (PSP)

The PSP are square plots of 1 ha (100 × 100 m), sub-divided into 100 sub-plots of 100 m^2 each (10 × 10 m). In these plots, all trees with a DBH ⩾ 20 cm were tagged, identified and measured. In 20 randomly selected sub-plots in each PSP, all trees with a DBH ⩾ 5 cm were also tagged, identified and measured.

2.3. Tree density, volume and above-ground biomass estimates

Tree density was taken as the number of standing trees per hectare. Stem diameter measurements were used to estimate the above-ground biomass (AGB) value for each measured tree using an allometric equation developed for a similar forest in the Southern Amazon (Nogueira et al., 2008 – Eq. (1)). Stem diameters were employed to calculate the volume (FUNTAC, 1989 – Eq. (2)) of each tree.

$$AGB = \exp(-1.716 + 2.413^{*} \ln(D))/1000 \tag{1}$$

$$V = 0.000308^{*}(D) \wedge 2.1988 \tag{2}$$

where AGB is the above-ground oven-dried biomass expressed in $Mg\ ha^{-1}$; D is the DBH expressed in cm, V is the bole volume expressed in $m^3\ ha^{-1}$

2.4. Mean annual above-ground biomass increment

The above-ground biomass (AGB) at any sample time was taken as the sum of the AGB for all trees at that time. Increments in any interval between two sample times (1 and 2) were taken as AGB at time 1 and then subtracting the AGB of trees that had died (death) in the interval and adding the AGB of trees that had been recruited (ingrowth) in the same interval (Eq. (3))

$$AGB = (AGB\_St_{t1} - AGB\_Ing_{t1}) - (AGB\_St_{t0} + AGB\_Mort_{t1}) \tag{3}$$

where AGB_ST_{t1} is the above-ground biomass of the standing trees in a census, AGB_Ing_{t1} is the above-ground biomass of the in growth during the census interval, AGB_ST_{t0} is the above-ground biomass of the standing trees in the previous census, AGB_Mort_{t1} is the above-ground biomass of the trees that died during the census interval.