SELECTIVE LOGGING IMPACTS ON ABUNDANCE, BASAL AREA AND VOLUME IN TROPICAL FOREST UNDER SUSTAINABLE MANAGEMENT

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Introduction

The Amazonian forest is the largest source of tropical hardwood. "Terra-firme" (non-flooded) and "varzea" (periodically or annually flooded) forests dominate Amazonian landscape. High biodiversity, low human occupation, reduced number of merchantable tree species; soils poor in nutrients and acid are the main characteristic of the Amazonian region. According to INPE (2000), approximately 55,000 km^2 (11% of the total area) of primary forests have been deforested up to 1999 for the sake of agriculture and cattle ranching programs. Actually, selective logging followed by slash-and-burn agriculture is also playing an important role in keeping the very high rate of deforestation. Sustainable forest management has been advocated as the best way to combine production and ecosystem conservation. For this reason, the understanding of the forest dynamics is very important to define silvicultural systems (Carvalho 1999). Usually, studies on forest dynamics are very expensive and time-consuming. Continuous forest inventories are recommended to monitor changes over time in forests managed on sustainable yield basis, and to predict growth and yield of the remaining forests as well.

Materials and Methods

This study was carried out at MIL Madeireira area (80,000 ha), some 250 km East of Manaus (the Capital of Amazonas State), where a sustainable forest management (SFM) has been executed. The data were collected in one of annual allowable 2,250-ha logging compartment, logged in 1997. Before logging, fourteen 1-ha permanent plots were installed to monitor the remaining forest dynamics, based on Silva and Lopes (1984) methodology. In each plot, all trees with dbh ≥ 15 cm were recorded; before logging in December'1996 and after logging in June'1998. The stem volume over bark was estimated using the following equations: $V=e^{(7.6281 + 2.1809 \ln dbh)}$ for trees with dbh ≥ 45 cm, and $V=0.0094+9.1941*dbh^2*10^{-4}$ for trees with dbh < 45 cm (Silva et al. 1984).

Results and Discussion

Before logging, 154 different species (54 merchantable) were recorded. The contribution of merchantable species with dbh ≥ 45 cm for the total volume was 41%. Thirteen species (6 merchantable) contributed with 50% of the stand total abundance. The most abundant species were *Pouteria guianensis*, *Protium sagotianum* and *Lecythis prancei*. In relation to basal area, eighteen species (10 merchantable) contributed with 50% of the total, such as *Pouteria guianensis*, *Lecythis prancei* and *Iryanthera* sp. Seventeen species (11 merchantable) contributed with 50% of total volume.

In the permanent sample plots, 31 species were logged; from these, only 8 species contributed with 50% of total basal area removed by the operation. The most abundant logged species were *Minquartia guianensis* and *Manilkara huberi*, with 17% and 11%, respectively; and in terms of basal area, the most important logged species were *Manilkara huberi* and *Ocotea* *rubra* with 11.8% and 10.2%, respectively. Half of total logged volume was made by only 7 species, mainly *Manilkara huberi* (11.7%) and *Ocotea rubra* (11%).

During the second occasion, emphasis was also given on injured trees by logging and mortality rates. One year after logging, 80% of injured trees died. The injuries were classified as light and severe; based on remaining injured trees, 6 trees ha^{-1} suffered light injuries and 1.6 trees ha^{-1} were severely injured. In relation to merchantable species, these values were 3.0 and 0.9 trees ha^{-1}, respectively for light and severe injuries (Table 1).

In Paragominas, State of Pará, the evaluation of a traditional logging operation in three different sites, the following results were obtained (Verissimo et al. 1992): 148 trees ha^{-1} were injured, which correspond to 6.4 m^2 ha^{-1} in basal area and 62 m^3 ha^{-1} in volume. These values are 3-4 times as higher as the average obtained in our site.

Table 1. Forest dynamics in terms of abundance, basal area and volume

	Species	Abundance (trees ha^{-1})	Basal Area (m^2 ha^{-1})	Volume (m^3 ha^{-1})
Alive trees before logging	total	299.3	27.12	297.6
	merchantable	147.4	15.83	181.1
Logged trees	total	7.5	2.74	35.7
	merchantable	7.2	2.65	35.0
Natural mortality	total	0.9	0.85	0.23
	merchantable	0.6	0.57	0.17
Damage caused by logging	total	41.5	2.62	24.8
	merchantable	19.5	1.37	13.6
Mortality caused by logging	total	33.9	2.13	20.4
	merchantable	15.6	1.08	10.7
Recruitment	total	2.9	0.06	0.44
	merchantable	1.3	0.03	0.17
Alive trees after logging	total	255.6	22.65	246.0
	merchantable	123.4	12.38	138.7
Alive trees lightly injured	total	6.0	0.36	3.6
	merchantable	3.0	0.23	2.4
Alive trees severely injured	total	1.6	0.13	0.8
	merchantable	0.9	0.05	0.5

Eighteen months after the first evaluation, the remaining stock was equivalent to 85% of the original. The remaining volume of merchantable species with dbh $\geq$ 45 cm was 87 m^3 ha^{-1}. Means of all variables (abundance, basal area and volume) estimated for before and after logging have shown high significant ("t" test, $p<0.0001$) differences.

Between the first and the second occasion, the natural mortality was 0.85 trees ha^{-1}, which corresponds to a rate of 0.19% annually. For merchantable tree species this estimate drops to 0.57 trees ha^{-1}, which corresponds to a rate of 0.26% annually. The mortality caused by logging has reached 33.9 trees ha^{-1}, which corresponds to a rate of 11.3%. For merchantable species this estimate drops to 15.6 trees ha^{-1}, which corresponds to a rate of 10.6% annually.

On the other side, the recruitment rate was 0.63% for all species and 0.58% when only merchantable species were considered.

Each felled tree damaged other 5.5 trees in average (2.6 merchantable species); from those, 4.5 trees (2.08 merchantable) died less than one year after logging, and 1.03 trees have survived (0.52 merchantable). From those survived trees, 0.8 trees (0.4 merchantable) suffered light injuries, and 0.21 trees (0.12 merchantable) were severely injured. In terms of basal area, for each m^2 logged, other 0.964 m^2 (0.5 m^2 merchantable) were lost; from these, 0.78 m^2 (0.4 m^2 merchantable) died less than one year after logging, 0.355 m^2 (0.232 m^2 merchantable) suffered light injuries, and 0.127 m^2 (0.05 m^2 merchantable) were severely injured. Each felled tree damaged 0.349 m^2 (0.182 m^2 merchantable) of basal area; from these, 0.285 m^2 (0.144 m^2 merchantable) died less than one year after logging.

In terms of wood volume over bark, for each m^3 logged another 0.69 m^3 (0.38 m^3) were lost during the logging; from those, 0.57 m^3 (0.30 m^3 merchantable) died less one year after logging. From those survived trees, 0.1 m^3 (0.07 m^3 merchantable) suffered light injuries, and 0.02 m^3 (0.01 m^3 merchantable) were severely injured. Each felled tree damaged 3.3 m^3 (1.81 m^3 merchantable) of volume; from these, 2.71 m^3 (50% merchantable) died less than one year after logging.

The final results for all variables are smaller than those obtained in Paragominas, where a conventional logging was carried out (Verissimo et al. 1992). In Paragominas, each felled tree caused injuries to other 27 trees, and for each m^3 logged, other 1.9 m^3 were injured. In addition, logging without planning can cause damage to 25% of the original stand, in contrast to 9.6% obtained in the site analyzed for this study. In Manaus region, where an experimental logging was carried out, each felled tree damaged other 8 trees (Higuchi and Vieira 1990). In Flona Tapajós, in another experimental logging, the damage rates averaged 20% of trees (12% merchantable) with dbh greater than 5 cm, and the volume damaged during the logging averaged 28 m^3ha^{-1} (Silva *et al.* 1999).

A planned logging for an effective forest management can reduce significantly the impact of extraction on the remaining stand, when it is compared with the conventional logging practiced in the Brazilian Amazon. Conventional logging causes damages three to six times more than a planned logging. The reduction of abundance, basal area and volume in relation to the original stand was 17%, except for basal area and volume of merchantable species, which was 23%. Eighteen months after logging is not long enough to remove all bias due to the immediate effects of harvesting operations, therefore, it is expected that the stabilization of the remaining stand over time will be reached, and diameter and volume increment will respond positively to the canopy opening.

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