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Strategies for Achieving Sustainable Logging Rate in the Brazilian Amazon Forest

Evaldo Muñoz Braz[1], Patricia Povoa de Mattos[1*], Mariana Ferraz Oliveira[2], Renato Olivir Basso[3]
[1]Embrapa Forestry, Colombo, Brazil
[2]Universidade Federal do Paraná, Curitiba, Brazil
[3]Elabore Projetos e Consultoria Florestal, Sinop, Brazil
Email: *evaldo.braz@embrapa.br

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Data of increment of the remnant trees after logging, ingrowth and mortality was obtained by assessment before logging and after 6 years, two sites of 50 ha, in Amazon forest. Logging scenarios were simulated to identify the logging rate potential for each studying sites, by diameter class projection method. The cycle of 35 years and the logging rate of 30 $m^3 \cdot ha^{-1}$ exceed the time required for recovery in the primary forest, in the studied site. The simulation showed that in the studying area, a well-planned logging, with minimum logging damage would be possible to implement an initial cycle of 25 years to the forest to recover 30 $m^3 \cdot ha^{-1}$, if 50% of the timber stock were reserved. The forest increment, beyond important factors such as the increase of individual species, is quite dependent on the remnant trees.

Keywords: Diametric Structure; Forest Regeneration; Cut Cycle; Forest Growth

Introduction

The timber sector is of great importance to the state of Mato Grosso, Brazil, as timber production is the main source of employment in the region. Although regulatory agencies define minimum standards of forest management, these proposals lack details, suggestions or technical procedures to guide the sustainable forest management in Brazilian Amazon region. There are relevant gaps in the management of tropical natural forests.

As an example, the cut cycle of 35 years and a logging rate of 30 $m^3 \cdot ha^{-1}$ is defined by the Ministry of Environment as the standard for all over the Brazilian Amazon forest (Substitute Ministerio do Meio Ambiente by Brazil, 2006), but it does not specify different patterns according to sites characteristics. However, if for some regions this may be above the logging potential, for others it can be a low value, harming the timber producers. The use of fixed standards result in impossible sustainable management of natural forests in the Amazon, eliminating the possibility of managing the forest structure and definition of specific treatments, based on growth and stock differences, among other factors. The desirable would be the region fragmentation by similarities, and enabling the definition of differentiated management standards to Amazon.

On the other hand, usually the papers that apply simulation to evaluate the regeneration potential of a forest after logging consider exclusively the logging pattern following the company procedure or the current law standards. Thus, it is important to evaluate alternatives and variations of cut cycle, to obtain in a second cycle the timber volume logged in the first cycle, applying other logging rates (Braz et al., 2011).

Ek and Monserud (1979), when comparing a deterministic model in a stand with a stochastic spatial model of isolated trees proved that they were compatible with reality for short-term period prediction (approximately 26 years) and they showed similar results to predictions of long-term (120 years). Clutter (1980) considered that it might be fallacious to select stochastic models in advance rather than deterministic models. The comparison of probabilistic transition matrix, diameter movement rate and Wahlemberg, conducted by Pultz et al. (1999) showed that the three methods were efficient in the prognosis of the total number of trees.

This paper discusses the potential of native forest management sustainability, considering the cut cycle and logging rate allowed by law, suggesting alternatives that guarantee near 100% of timber volume recovery.

Material and Methods

The data were obtained in two sample areas of 50 ha each, located in Santa Carmen, micro region of Sinop, Mato Grosso State, Brazil, on a natural forest stand logged for six years (2007). The sampled areas are surrounded by forest and represent typical Open Rainforest from Sinop micro region.

The region is flat, presenting latosol soils and equatorial climate, with average annual rainfall of 2500 mm.

Before logging a census of all trees with diameter at breast

*Corresponding author.

height (DBH) equal or higher 30 cm was conducted. After 6 years, the total sampled area (100 ha) was surveyed to obtain the current forest structure (year 2013) by implementing a new census using 20 transect lines of 1000 m, every 50 m (**Figure 1**), when 1016 trees were re-measured, and calculate the PAI_{dbh} (periodic annual increment, in DBH) as presented in Equation (1).

$$PAI_{dbh} = \left(DBH_{final} - DBH_{initial}\right)/t \quad (1)$$

where DBH_{final} is the diameter at 1.30 m above soil level measured at the end of the evaluate period; $DBH_{initial}$ is the diameter at 1.30 m above soil level measured in the beginning of the evaluate period; and t is the time period in years, between the two measurements.

The regeneration (saplings and poles with DBH below 30 cm) was surveyed in 10 sampled areas of 10 m × 25 m.

The logging scenarios were simulated by diameter class projection method, fragmented into periods of five years, using the growth increment of remnant timber trees, ingrowth and mortality estimated by the post-logging survey. The proposition was to define a sustainable cut rate that forest recover would make possible a similar volume logging after the cutting cycle established.

The simulate scenarios evaluate were:

1) Heavy logging: refers to logging of 90% of trees with commercial potential in the area (the 10% of remnant trees would correspond to mother trees reserved). In this case, 53 $m^3 \cdot ha^{-1}$ would be logged.

2) Logging standard established by current law: The normative guide 05 (Substitute Ministerio do Meio Ambiente by Brazil, 2006) establish a 35 years cut cycle, with a cut rate of 30 $m^3 \cdot ha^{-1}$. The simulation was calculated with logging 50% of the commercial timber stock, considering trees equal or above 50 cm of DBH. To restrict to 30 $m^3 \cdot ha^{-1}$, the trees considered as logged were from higher DBHs, reserving trees from DBH classes of 55 cm, 65 cm and 46% of all trees from 75 cm.

3) Smaller cut cycle but maintenance of current law cut rate: the simulation was calculate for a 25-year cycle, with a cut rate of 30 $m^3 \cdot ha^{-1}$. In this case it was also considered the logging of 50% of the commercial timber stock, similar to that described in item 2).

Adherences of the simulate forest structures were evaluate using qui-square test.

Results

It was surveyed 1016 trees in 58 $m^3 \cdot ha^{-1}$ of commercial timber volume in the sampled area. The mortality measured was 1% per year. The average periodic increment of the tree species was 0.434 $cm \cdot ano^{-1}$, ranging from a minimum of 0.049 $cm \cdot ano^{-1}$ to a maximum of 1.89 $cm \cdot ano^{-1}$ (standard deviation = 0.29 cm).

Approximately 77% of the trees are concentrated in 5 species: "cupiúba" (*Goupia glabra* Aubl), "cambará" (*Qualea albiflora* Warn), "cedrinho" (*Erisma uncinatum* Warn), "itaúba" (*Mezilaurus itauba* (Meissn.) Taub.) and "amescla" (*Trattinickia burserifolia* Willd). The other 23% are distributed in 20 species, where 18 present commercial value or potential to be used in timber industry.

The annual mortality rate, medium, minimum and maximum average annual increment in DBH class center equal or above 35 cm is presented in **Table 1**. It was also obtained the limit of higher diameter for the five species, but this information was

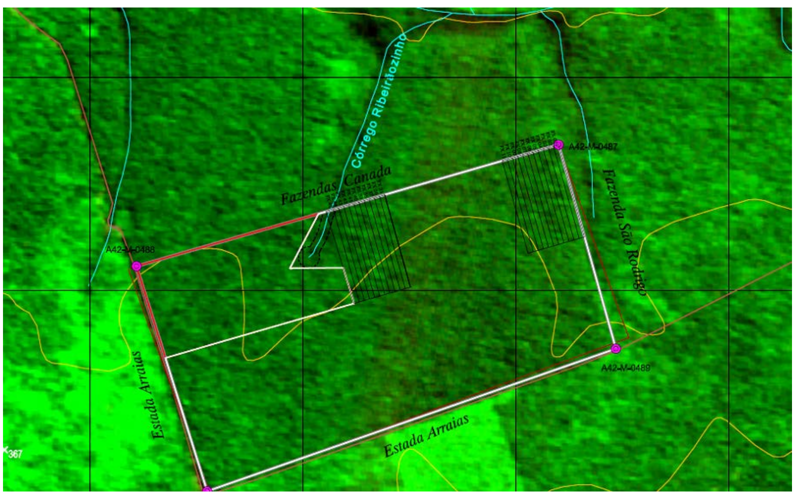

Figure 1.
Sampled areas location and the transect lines (Scale: 1:75,000).

Table 1.
Number of trees re-measured, mortality rate and diameter information in 100 ha sample area.

Species	Number of trees	Mortality rate ($\%\cdot yr^{-1}$)	Medium annual increment ($cm\cdot yr^{-1}$)	Minimum annual increment ($cm\cdot yr^{-1}$)	Maximum annual increment ($cm\cdot yr^{-1}$)	Standard deviation (cm)	Higher diameter (cm)
cupiúba	219	0.33	0.31	0.05	1.22	0.19	170
cambará	71	2.29	0.54	0.10	1.17	0.23	100
cedrinho	70	0.50	0.50	0.05	1.17	0.26	140
itaúba	120	0.36	0.26	0.05	0.68	0.15	120
amescla	80	0.50	0.58	0.10	1.57	0.38	140

assessed in the whole management stand, and not only in the sampled areas. It the higher diameter classes it was observed no more than two individuals.

In pre-logging structure, it was observed that 87% of these tree s were found between DBH class center of 45 cm and 85 cm (representing 5 DBH classes) and only 13% were found above these classes (considering 9 DBH classes), indicating high mortality in these classes. Comparing the number of trees in DBH class center of 85 cm with the higher DBH class center (175 cm), the survival rate is only 0.36%.

The number of trees in each DBH class does not present the classic J-shape (**Figure 2**), common in natural forests (Daniel et al., 1979). However, the distribution found in the field, before the operation, showed a situation of "full production" (Braz, 2010), where the trees of the upper strata present more than 50% of the stand basal area (**Figure 3**), what is probably compromising the forest regeneration and growth of trees in the lower strata.

There are large timber volumes available in DBH classes center above 65 cm (**Figure 4**).

The dynamic between DBH class centers of the five species is shown in **Figure 5**. The DBH class centers 35 cm and 45 cm presented reduction of number of trees due to mortality and transition to higher DBH class centers. However, it can be observed that the DBH class centers of 55 cm, 75 cm and 95 cm presented increase.

Considering all the tree species in the sampled area, regeneration below 20 cm of DBH resulted in 116 saplings per hectare, with 42% concentrated in the five main species. It was observed 1 sapling per hectare of cupiuba and 28 of amescla. The species cedrinho, cambará and itaúba presented 4 saplings per hectare.

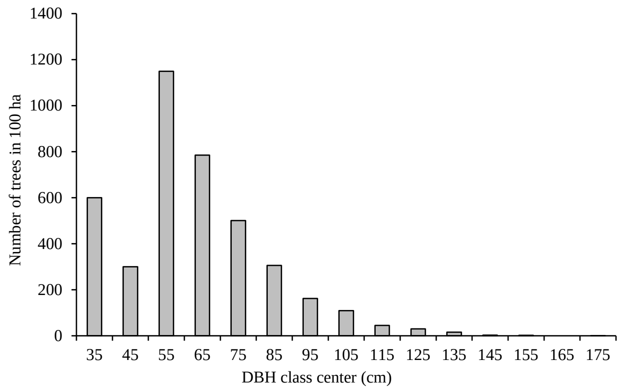

Figure 2.
Number of trees in each DBH class center, pre-logging.

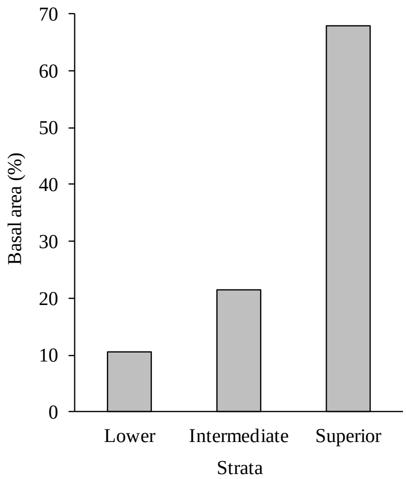

Figure 3.
Percentage of basal area in the superior, intermediate and lower strata pre-logging.

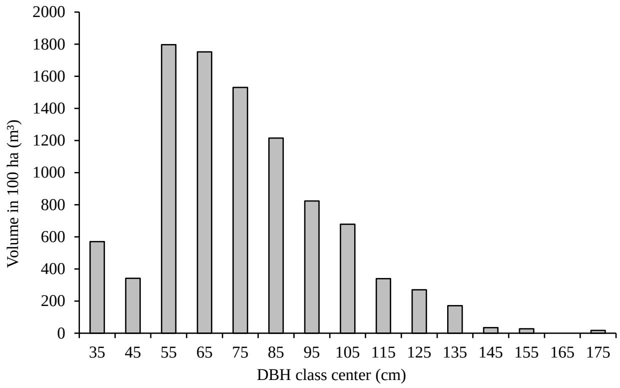

Figure 4.
Timber volumes surveyed to each DBH class center pre-logging.

Heavy Logging

The volume increment calculated for commercial timber DBH class centers (considered above 50 cm) was 0.66 $m^3 \cdot ha^{-1} \cdot yr^{-1}$. After six years, the ingrowths in DBH classes above 45 cm that come from smaller classes was 0.36 $m^3 \cdot ha^{-1}$. The simulation of timber volume recovery after a heavy logging is presented in **Figure 6(a)**. The volume recover is very slow, and at the end of the 35 years cycle, only 43% of the logged timber volume is recovered.

The qui-square test was not adherent to the forest structure obtained by simulation at the end of the 35 years cut cycle.

Logging Standard Established by Current Law

The volume increment calculated for commercial timber DBH class centers (considered above 50 cm) was 1.11 $m^3 \cdot ha^{-1} \cdot yr^{-1}$. The simulate scenario indicate that in the first cut cycle of 35 years (**Figure 6(b)**), under these cut restriction, considering that the forest did not reach yet the climax potential, there would be a volume recover of 39.00 m^3, representing 30% above the logged volume in the first occasion.

The qui-square test was adherent to the forest structure obtained by simulation at the end of the 35-year cut cycle.

Smaller Cut Cycle but Maintenance of Current Law Cut Rate

The volume increment calculated for commercial timber DBH class centers (considered above 50 cm) was 1.19 $m^3 \cdot ha^{-1} \cdot yr^{-1}$. The simulate scenario for a 25-year cut cycle shows that the logged timber volume may be 100% recovered. It is also possible to observe that although it was submitted to the same logging rate in a smaller cut cycle, it presents higher volume increment (**Figure 6(c)**). However, in this case the qui-square test did not present adherence to the forest structure simulated at the end of 25-year cut cycle.

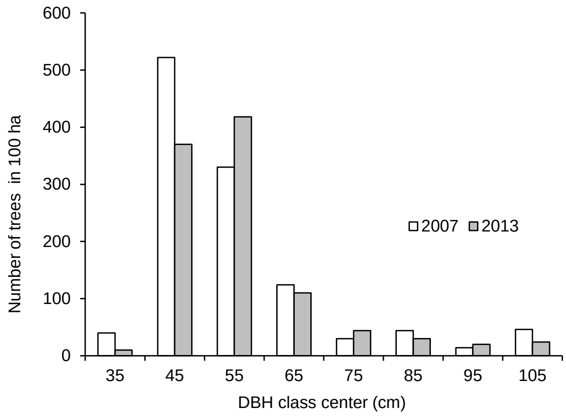

Figure 5.
Diametric distribution before management of the timber commercial species and, six years later, in the evaluated sampled areas.

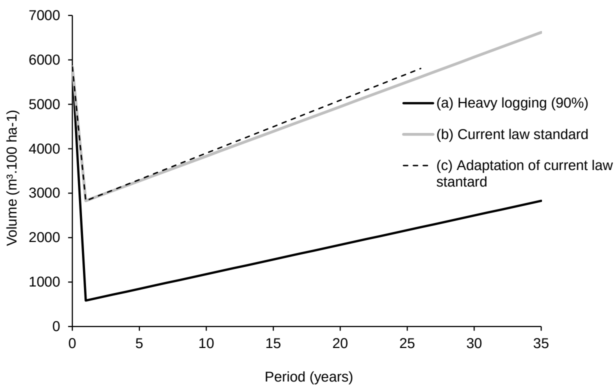

Figure 6.
Timber volumes recover considering different approaches of logging simulation.

Discussion

According to Passos and Mason (2005) forests of Mato Grosso State present a commercial timber stock of 65.66 $m^3 \cdot ha^{-1}$, considering the commercial tree species of DBH class center equal or above 45 cm. Nowadays the sawing diameter has increased to 50 cm of DBH. It was mentioned that this value was estimate to near 25 commercial species. However, there are other potential species that was not considered, showing that there is still extra volume that may be occasionally inserted into timber market.

The growth increment observed for the five species considered more important in the studying area are similar to those mentioned in other work (Silva et al., 2001; Azevedo, 2006). Observing the maximum and minimum growth values (Table 1) it is considered that proper studies to identify the maximum increment potential of different species are still a gap for future research.

The DBH limit and the drastic reduction of number of trees above the DBH class center of 85 cm corroborate Braz et al. (2012b) statement about the low production of the higher diameter class trees. So, it is probably too price to manage trees that present low survival rate and low increment, as observed in these higher diameter classes.

The forest regeneration below 30 cm of DBH shows that there is a large sapling growth after logging. However, there is reduced number of trees in 35 and 45 cm of DBH classes, probably due mainly to competition of the upper strata during the pre-cut primary forest phase. For O'Hara (1998), high number of small trees in the smaller classes, are usually justified due to the expectation of high mortality. Small gaps in later classes, do not mean, necessarily, a definitive irregularity in the final forest structure in next cycles. This regeneration, considering the potential of the main species, may also indicate the demand of silvicultural treatments to conduct the production to certain species of main interest and with enough tree individual that may complement the other classes in future loggings.

The results of heavy logging obtained are in agreement with the results of several other researchers (Alder & Silva, 2001; Oliveira et al., 2006; Braz et al., 2012a), that emphasize that the forest management are not sustainable when logging high values, considering all commercial tree species. In this simulation, the diametric increment of commercial species occurs satisfactory. The recovery of the commercial forest species also occurs satisfactory, but it is dependent of the structure reserved during the first logging cycle. This means that it increases proportionally to the remnant forest structure, as it is a result of a heavy logging.

This heavy logging, when there is no concern to reserve strategic structure for a future logging, implies in a cycle of at least 80 years to obtain the same timber volume logged at first. These long cycles due to heavy loggings are causing misunderstanding when analyzing sustainability of tropical forests management. Frequently the no controlled logging is confounded with the lack of management sustainability as a whole, leaving aside that cut rates should be evaluate and adjusted to the cycle that is objected.

If logging was conducted as defined by law (cycle of 35 years and a limit of 30 $m^3 \cdot ha^{-1}$), the recovered volume would be 39 $m^3 \cdot ha^{-1}$, which indicates that the cut rate should be reevaluate when considering a cycle of 35 years. However, increasing the extraction involves modifying the remnant forest structure, so it is necessary a new simulation. In this example, the maintenance of DBH classes 55, 65 and part of the 75 strengthened the remnant forest structure, favoring the increment. The logging resulted in the removal of classes with smaller increment that were the larger trees, and maintenance of the most productive DBH classes for some species. Classes such as DBH classes of 65 and 75 cm are the most productive for species such as *Erisma uncinatum* Warn, *Qualea albiflora* Warn and *Trattinickia burserifolia* Willd. Thus, the strategy to maintain total or part of these classes, may contribute to the forest increase increment, as already pointed out by Braz et al. (2012b). The values of what should be maintained per class cannot be fixed, as the forest structures are usually different. So, the volume increment is not also a fixed amount, and it can be different according to the remnant forest structure.

In the latter case, the volume increment was larger, even with the same remnant forest structure as the second simulation. This happens because in longer cycles (the previous case), when trees reach close to their larger diameters, the volume increase tends to decline (Braz et al., 2011). Thus, this 25-year cut cycle would be more productive and would result in higher economic income than the 35-year cycle. Furthermore, the possibility to apply this shorter cycle allowed by law until 2006 and the indicative of productive sustainability may be a strong argument to convince the farmer to implement in his forest a better monitoring program and management with silvicultural treatments.

The last two simulations suggest that near 50% of the commercial timber volume may be an indicative of a sustainable cut rate to Sinop region, considering all commercial tree species together. However, fixing rates is not recommended for forest management, as there are several variables to be considered, and each situation must be evaluate individually, considering the specificities of each stand or region.

This rate refers to the group of species, but the recovery potential of individual species should be evaluated. Sist et al. (2007) emphasize that even when applying low impact management only 50% of the commercial timber volume would be recovered. Van Gardingen et al. (2006) estimated in 33% the threshold as cut rate of timber species of commercial DBH classes for a 30-year cycle. In Amazon forest, Braz et al. (2012a) identified that to ensure 100% volume recover, considering the logged volume, three different cut rates in the commercial DBH classes: 24.4%, 35.4% and 42.4% for a group of 7, 13 and 6 species, respectively, defined by their different growth rhythms.

Sebben et al. (2007) considering the species growth individually obtained by the software Eco-gene, analyzed *Hymenaea courbaril* under strong logging pressure (logging above 45 cm of DBH class and maintaining only 10% of the commercial DBH classes, obtained basal area recover of only 30%. Gourlet-Fleury et al. (2005), also focusing on an important timber species from French Guiana (*Dicorynia guianensis*), through simulations by matrix models, consider that the logging activities that follow the logging pattern regularly used, recover no more than 60% of the stock.

On the other hand, the no adherences by the forest structure simulations were expected as observed in the heavy logging and the modification of the law standards. It was also expected the adherence observed in the patterns of a cycle of 35 years with limit logging of 30 $m^3 \cdot ha^{-1}$. This confirms the time and lower cut rates to the new forest structure to achieve a stable structure. This shows that the logging rate and the recover interval influence the recover to the original forest structure. However, it is important to highlight that it is a production forest, and it is not aiming at the original structure, but what is into consideration is the recovery of sustainable timber volume. As it was mentioned, the original forest structure before logging presented trees in lower productive DBH classes, which had higher mortality rates. To reach the exact original structure would not be economic or possible. But the aim of this work was to demonstrate the possibility to recover 100% of the logged volume. Durrieu de Madron and Forni (1997) considered that the recover individually by species when achieving over 60% of the original commercial trees, would be acceptable as a sustainable production system.

Conclusion

The level of forest production sustainability will vary according to the logging rate and the remnant forest structure.

The analyzes showed that the removal of 90% of timber stock, considering trees with DBH class center equal or above 55 cm, jeopardy the forest increment.

On the other hand, the cut cycle of 35 years for a logging rate of 30 $m^3 \cdot ha^{-1}$ may exceed the time required for volume recovery, considering the forest structure of this studying case. So, with a well-planned forest management, with attention to techniques and procedures to avoid forest damage, an initial cycle of 25 years would be sufficient to recover the logging volume of 30 m^3. However, it must be emphasize that it would be necessary to reserve 50% of the timber stock during the first logging occasion. Even though, it would be necessary to evaluate volume recover of timber species individually and estimate the structure that would be more adequate to achieve the planned volume recovery.

The increment of the forest is quite dependent on the remnant timber stock, beyond important factors as increment of individual species. On the other hand, very long cycles may result in reducing the average increase, because the trees as they approach their points of maximum mean annual increment tend to reduce their growth potential.

Thus, it is suggested that the 25-year cycle and a logging rate of 30 $m^3 \cdot ha^{-1}$ is the most suitable for primary forests of Sinop region that present commercial timber potential equal or above 58 $m^3 \cdot ha^{-1}$. This represents logging in the first occasion only 50% of the regional timber stock per hectare.

So, the bias of the simplistic point of view that considers volume or increment individually is not enough to guarantee the productive sustainability. It is also important to consider the number of trees and in what structure they will be reserved to achieve productive sustainability.

In addition, trees DBH adequate for logging by species or group of species should be determined in addition to silvicultural treatments, aiming at the maximum timber production in shorter cut cycles.

It should be emphasized that fixed volume logging rates and fixed cut cycles should be avoided by legal standards, as they are not consistent with the forest diversity that can be found in Amazon region.

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