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The Use of Volume Yield and the Number of Trees to Control Forest Management Operations and Combat Illegal Harvesting

Dennys Chrystian Pinto Pereira[1,2], Ademir Roberto Ruschel[1,3], Rodrigo Antonio Pereira Junior[1,4] & Ulisses Sidnei da Conceição Silva[1,5]

[1] Graduate Program in Forest Sciences, Federal Rural University of the Amazon, Belém, Brazil

[2] Brazilian Institute for the Environment and Renewable Natural Resources, Brazil

[3] Brazilian Agricultural Research Corporation (Embrapa), Brazil

[4] Federal Institute of Education, Science and Technology of Pará, Ananindeua Campus, Brazil

[5] Biodiversity and Forests Institute, Federal University of Western Pará, Santarém, Brazil

Correspondence: Ulisses Sidnei da Conceição Silva, Biodiversity and Forests Institute, Federal University of Western Pará, Vera Paz, s/n, Salé, CEP 68040-255, Santarém, Pará, Brazil. E-mail: usc.silva@gmail.com

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Abstract

There is a lack of understanding on the relationship between the authorized volume of wood harvest in Sustainable Forest Management Plans (SFMP) in the Amazon, the volumes listed in the official systems of volume control, the actual harvested volumes, and the consequences these parameters have for the illegal wood market.The objective of this study was to evaluate the production and volume yield and the number of harvested trees as part of forest management plans in public and private forests through analysis of harvest data from 85 SFMP registered in the official electronic system of control of forest products in the state of Pará. The forest management plans were categorized into public (federal and state), and private, with these being further subdivided into having one or more than one annual production unit, and community-managed forest. This analysis was based on the hypothesis that production and volume yield from SFMP in public and private forests did not differ. Calculations were made to test this hypothesis, and these included forest harvest yield, the percentage of the number of trees harvested in the SFMP using the relationship between the authorized and harvested volumes as well as the numbers of authorized trees and those harvested.The results show that the yields based on numbers of trees and volumes were statistically lower for SFMP in public forests compared to private forests. These results suggest that a significant part of SFMP in private forests could systematically become a source of forest credits used to obtain fraudulent documents for forest products that are illegally harvested, which is referred to as “esquentamento” in Portuguese.

Keywords: forest harvesting, volumetric yield, number of trees harvested, official system of forest harvesting control

1. Introduction

During the last 30 years there has been considerable evolution in the techniques used in the elaboration and execution of Sustainable Forest Management Plans. This is a consequence of the large number of research studies that have been conducted in the Amazon in the areas of silviculture, forest harvesting, forest economy, and socio-environmental development, among others (Uhl & Vieira, 1989; Veríssimo et al., 1992; Putz & Pinard, 1993; Dykstra & Heinrich, 1996; Gretzinger, 1996; Uhl et al., 1997; Amaral et al., 1998; Barreto et al., 1998; Silva et al., 1999; Sabogal et al., 2000; Holmes et al., 2002; Sabogal et al., 2006). Currently, research on innovations in forest management are focused on geotechnologies (Figueredo et al., 2015, 2016; Ferreira da Silva et al., 2018; Silva et al., 2018a, 2018b), and species-specific management (Braz et al., 2014, 2018).

Concomitant with the developments of new techniques and practices of forest management, environmental oversight agencies have modified their monitoring and compliance activities (Embrapa & Ibama, 2006). However, even with this evolution in the monitoring and compliance capabilities of these agencies, illegal forest harvesting activities have significantly reduced the implementation and impact of sustainable forest management (Richardson & Peres, 2016). According to Lentini et al. (2005), this illegal activity represents one of the main

obstacles that discourage to greater adoption of sustainable forest management in the Brazilian Amazon. The international focus on issues related to forest management has changed from focusing on monitoring whether or not sustainable forest management principles are being complied with to the legality of use of forest resources (Gagarin et al., 2019). In the context of monitoring the legality of forest exploration, this change in focus can be considered acceptable since very little has changed over recent years with respect to aspects of compliance, monitoring, and control of wood production in SFMP. This situation has enabled a wide variety of frauds to be perpetrated which have been able to provide legal status to illegal wood, through PFMS that are legally licensed, and oftentimes very well-managed.

Despite the regulatory strategies that have been implemented to improve detection of certain forms of illegal wood harvesting that are able to subtly hide the true origin of the wood, the actual degree to which timber harvesting companies are in compliance with forest harvesting authorizations is poorly understood, and there is no alternative available for large-scale evaluations of these irregularities in wood harvesting permissions (Brancalion et al., 2018; Richardson & Peres, 2016). Forest products that are illegally obtained have been concealed as being legally licensed (Silgueiro et al., 2015). The most common forms of fraud are: *i*) the underreporting of harvested trees (Brancalion et al., 2018); *ii*) authorized total volumes are potentially attained through illegal extraction in neighboring forests (Richardson & Peres, 2016); a strong bias for overestimation of volume of high-value species (Brancalion et al., 2018) and, *iii*) manage and use the "surplus" of legal wood from more valuable species to provide legal status to illegally extracted wood (Brancalion et al., 2018).

These frauds are based on making false declarations in the official system of control of forest management, simulating the harvesting of trees through a forest management plan, when in reality the trees were illegally harvested from a different forest area, thus enabling their commercialization as if they were harvested through a legal management plan. This practice is known as "esquentamento" in Portuguese, which means that the wood was "laundered" or obtained using false documentation. The quantification of forest products obtained through illegal forest harvesting in the Amazon that is counted in electronic systems of forest control and that has forest production and transport documents that are apparently legal, but are illegal, is still unknown.

There is very little known about the relationship between volumes authorized in forest management plans in the Amazon, the volumes reported in official control systems, and the real harvested volumes, as well as the possible consequences of these relationships with illegal wood harvesting. Although these data are publicly available, they are not published in a way that is easily available to the general public.

Among other challenges and difficulties associated with elaboration of a high-quality management plan in the Amazon, such a plan must include methods and techniques that increase the monitoring capacity of state compliance agencies, as well as the accuracy of information from the field that can support projects that are better adapted to the reality of forest harvesting based on input from forest technicians and businessmen involved in the sector (Papa, 2019).

This study questions whether production and forest harvest yield, expressed as volumetric yield and the number of trees harvested, is equal comparing forest management plans from public and private forests. In this context, this study focused on the analysis of the consistency between volume and the number of trees, authorized and harvested, between forest management plans from public and private forests, based on data from official systems of control of forest management of the state of Pará, eastern Amazonia, Brazil.

2. Method

2.1 Selection of Sustainable Forest Management Plans (SFMP)

The SFMP were categorized according to the dominiality of the forest—federal and state public forests, and private forests—and also by the number of annual production units (APU). This categorization resulted in the following treatments: (a) public, with a federal forest concession; (b) public, with a state forest concession; (c) private, with a single APU; (d) private, with more than one APU; and (e) community-based dominion.

Using these treatments as a base, Forest Exploration Authorizations (AUTEF) were analyzed in the official electronic forest product control systems of the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) and the Secretary of the Environment and Sustainability of the State of Pará (SEMAS) were consulted. The objective of analysis of the AUTEFs was to quantify the authorized and harvested volumes and numbers of trees for AUTEFs issued between 2012 and 2017 and for which forest management activities were conducted during the officially authorized period and absent of legal or administrative impediments which would affect the complete execution of the chronogram of forest management activities.

Subsequently, AUTEFs that were part of Annual Operational Plans (AOPs) of APUs with a management area ≥ 500 ha and concomitantly with an authorized harvest volume ≥ 20 thousand m³. An exception was made for AUTEFs that were part of community-managed AOPs, wherein the minimum area of the APU was 390 ha and the minimum authorized harvest volume 11 thousand m³.

Through this process, 85 AUTEFs were selected, which were distributed across the different treatments analyzing authorized and harvested volumes. There were17 AUTEFs selected in each of the five treatments, with federal public forests having SFMP in the National Forests (FLONA) of Saracá-Taquera and Altamira. The state public forests with AUTEFs had SFMP in the Glebas Mamuru-Arapiuns forests and the Paru state forest. The treatments of private forests with more than one APU and private forests with a single APU each had 17 AUTEFs selected, as did the community-managed forests (Figure 1 and Table 1). However, for the analysis of the number of authorized and harvested trees this process resulted in the selection of just 40 AUTEFs because the counting of the number of harvested trees by the state system of forest control (SISFLORA) was only begun in 2016, which limited the number of available AUTEFs. In this context, only the public forest and private forest treatments could be included.

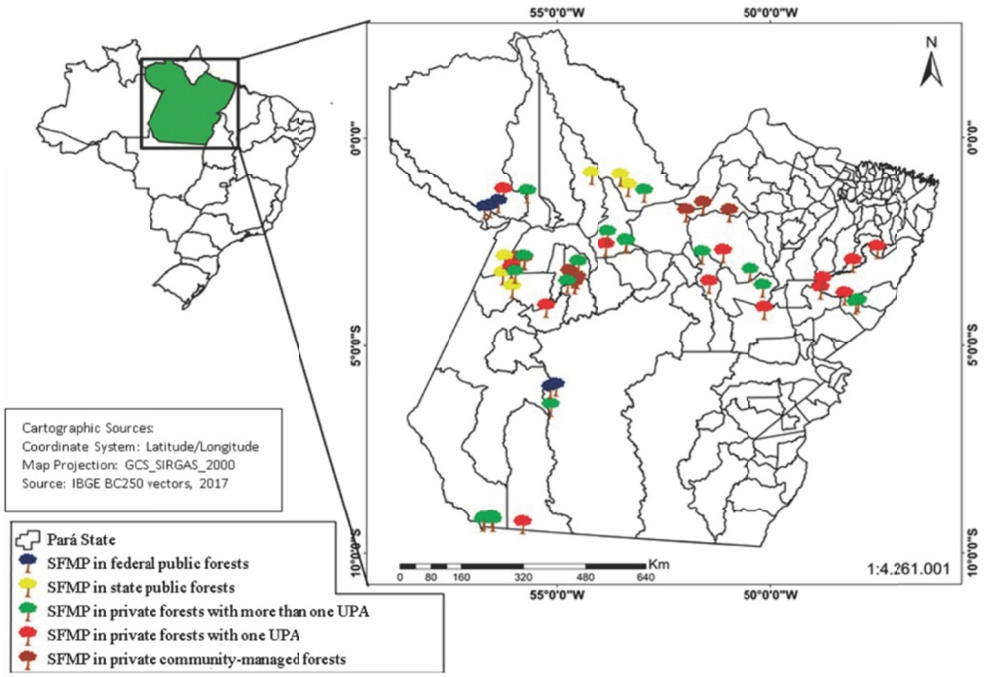

Figure 1.Map showing the locations of forest management plans selected in public and private forests in the state of Pará, Brazil

Table 1. Total and average areas, amplitude, volume, and harvest intensity, with sample standard deviation, for selected forest management plans in public and private forests in the state of Pará, Brazil

Forest Management Plan (SFMP) categories (Treatments)	Nº of AUTEFs	Size of APUs (ha)	Amplitude of APUs (ha)	Average area of APUs (ha)	Average approved volume (m³)	Average harvest intensity (m³/ha)
Public Federal	17	24,391.08	700.0-3,544.85	1,461.9 (±1,037.85)	29,922.3 (±17,302.44)	22.2 (±4.39)
State public	17	36,134.70	688.1-3,944.8	2,108.6 (±1,050.99)	50,002.4 (±25,405.27)	23.6 (±1.98)
Private (single APU)	17	15,264.02	617.6-1,349.4	915.6 (±264.68)	24,596.9 (±8,180.88)	26.6 (±3.22)
Private (multiple APUs)	17	29,665.41	584.3-2,990.3	1,673.8 (±969.04)	44,205.5 (±23,127.17)	25.7 (±5.34)
Community-managed	17	35,542.75	393.63-5,616.2	2,090.7 (±1,640.30)	114,405.70 (±38,872.56)	25.2 (±4.98)
Total	85	140,997.96				

2.2 Data Analysis

Volumetric yield of forest harvesting, or harvesting efficiency in terms of wood volume production, is a measure of how close the actual harvested volume is to the authorized volume. This was quantified through calculation of the ratio between authorized and actual harvested volumes, expressed as a percentage, and this yielded the Forest Harvest Yield Index in volume (IREFvol), calculated by Equation 1:

$$IREFvol = (VEE/VA) \times 100 \quad (1)$$

Where, IREFvol (volumetric Forest Harvest Yield Index); VEE (Actual Harvested Volume): volume measured during the activity report and by the movement of forest products as registered in official control systems, as established by the Normative Rule nº 05/2016 of the state environmental agency, and, VA (Authorized Volume): volume authorized by the AUTEF.

The number of harvested trees, or harvesting efficiency in terms of tree production, is a measure of how close the actual number of trees harvested is to the authorized number of trees. This was quantified through calculation of the ratio between authorized number of trees and the actual number harvested expressed as a percentage, and this yielded the Forest Harvest Yield Index for the number of trees (IREFna), calculated by Equation 2:

$$IREFna = (NAE/NAA) \times 100 \quad (2)$$

Where, IREFna (Forest Harvest Yield Index for the number of trees) = NAE (Number of Trees Harvested), and, NAA (Number of Trees Authorized).

For the statistical analysis of volumetric yield from forest harvesting, the following five treatments (17 AUTEFs in each) were considered, with the response variable being IREFvol:

T1: Volumetric Forest Harvest Yield Index for SFMP in public federal forests.

T2: Volumetric Forest Harvest Yield Index for SFMP in public state forests.

T3: Volumetric Forest Harvest Yield Index for SFMP in private forests with a single APU.

T4: Volumetric Forest Harvest Yield Index for SFMP in private forests with multiple APUs.

T5: Volumetric Forest Harvest Yield Index for SFMP in community-managed forests.

For the statistical analysis of the number of trees from forest harvesting, two treatments in 40 AUTEFs were considered, with the response variable being IREFna:

T1: Forest Harvest Yield Index for the number of trees for SFMP in public forests (20 AUTEFs).

T2: Forest Harvest Yield Index for the number of trees for SFMP in private forests (20 AUTEFs).

The treatments IREFvol and IREFna were submitted to the Kolmogorov-Smirnov and Levene tests to evaluate the assumptions of normality and homoscedasticity of the variances, respectively, which are requirements for parametric tests. To compare the IREFvol values between treatments the Kruskal-Wallis non-parametric test (H test) was used, and when necessary, post-hoc multiple comparisons were made using the Dunn test. Comparison of IREFna values between treatments was done using the Mann-Whitney (U test) (Siegel et al., 2006).

To compare IREFvol and IREFna, data from other studies conducted in the Amazon were used with these indices.

3. Results

The volumetric Forest Harvest Yield Index (IREFvol) for SFMP in private forests with single or multiple APUs, and for community-managed forest, and for state and federal public forests were evaluated using the Kruskal-Wallis test, and the results showed a statistically significant difference ($H = 53.937$ and $p = 0.001$). Subsequently, the Dunn post-hoc multiple comparison test showed that SFMP in public and private forests form two separate groups (Table 2 and Figure 2).

Table 2. Percentage of volumetric Forest Harvest Yield Index (IREFvol) of harvest authorizations for management plans in public and private forests in the state of Pará

AUTEF	Public		Private		Community-managed
	State	Federal	Multiple APUs	Single APU	
1	29.51	35.52	68.86	76.17	84.87
2	35.32	46.51	70.25	81.48	84.89
3	37.51	51.92	75.76	85.00	85.49
4	48.17	54.83	76.29	86.84	86.10
5	51.53	56.37	77.91	90.46	86.18
6	52.22	57.04	82.58	93.48	86.79
7	56.12	58.39	84.82	94.40	87.13
8	56.23	59.78	86.95	94.72	90.79
9	60.78	66.81	87.26	95.54	91.65
10	61.92	66.88	88.18	98.85	92.28
11	62.03	70.58	94.93	99.01	92.96
12	67.04	72.96	97.84	99.06	93.48
13	71.85	74.31	98.23	99.23	94.57
14	72.14	79.17	98.43	99.32	95.54
15	75.87	80.67	98.46	99.63	98.00
16	78.40	84.70	99.24	99.79	99.57
17	79.04	87.96	99.68	99.84	99.99
Average±sd	58.57a±15.02	64.96a±14.24	87.39b±10.71	93.69b±7.29	91.19b±5.20
Standard error	3.643	3.453	2.597	1.768	1.262

Note. * Averages followed by the same letter are not statistically different for IREFvol according to the Kruskal-Wallis non-parametric test.

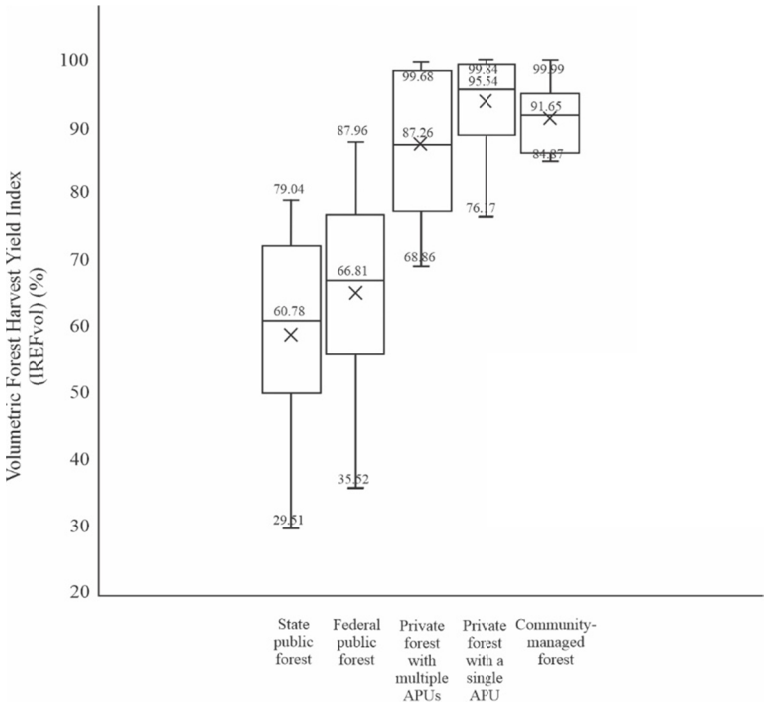

Figure 2. Boxplots of the volumetric Forest Harvest Yield Index (IREFvol) for federal public, state public, private with a single APU, private with multiple APUs, and community-managed forest management plans, state of Pará, Brazil

The total volumes harvested in all forest management plans did not exceed those authorized by the AUTEFs (Tables 2 and 3). For the public forest management plans, a total of 47.06% of the AUTEFs had values of IREFvol below 60% and none of these harvested more than 90% of the authorized volume (Table 3 and Figure 3). It is important to emphasize that the state public forest management plans were those that had the lowest values of IREFvol, with no AUTEF passing 80%, while values of IREFvol above 80% only occurred in federal public forests (Table 2).

Table 3. Number of SFMP in public and private forests according to the volumetric Forest Harvest Yield Index (IREFvol) by class, state of Pará, Brazil

	$IREF_{VOL}$ CLASS								
Type of SFMP	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	**Total**
Public forest	1	3	2	10	6	9	3		**34**
Private forest					1	5	15	30	**51**

SFMP: Sustainable Forest Management Plan.

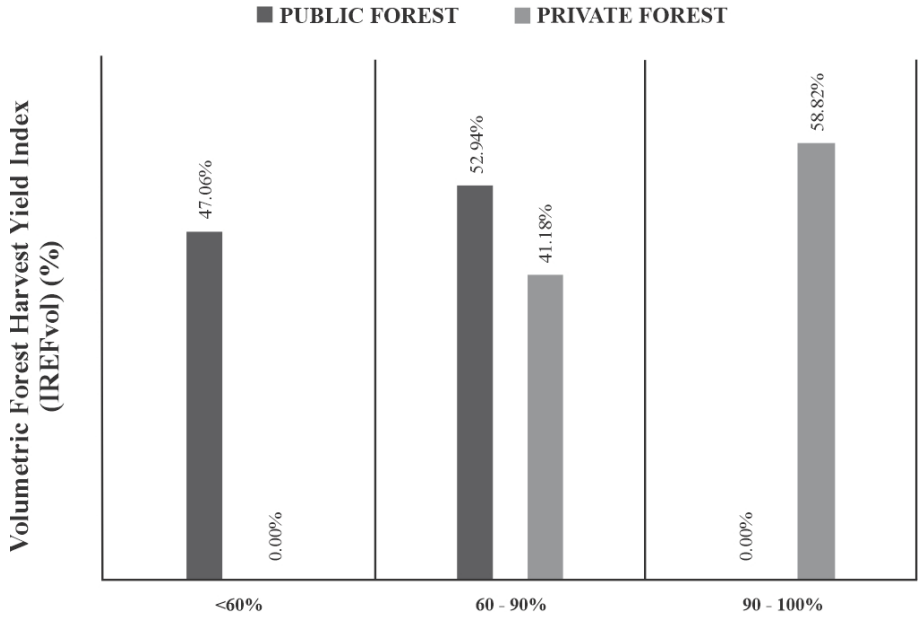

Figure 3. Distribution of the Volumetric Forest Harvest Yield Indices (IREFvol) by class for public and private forest management plans, state of Pará, Brazil

All the private forest management plans had values of IREFvol above 60%, with 41.18% of the AUTEFs having values of IREFvol between 60% and 90% of the authorized volume, and 58.82% harvesting more than 90% of the authorized volume (Table 3 and Figure 3). The private forest management plans with a single APU had larger average (93.69%) and median (95.54%) values of IREFvol, with the SFMP of the community-managed forests being similar, with average (91.19%) and median (91.65%) values (Table 2 and Figure 3). In contrast, management plans in private forests with multiple APUs had the lowest average (87.64%) and median (87.26%) values, and also the lowest value of IREFvol (68.86%), with the only one below 70% among all SFMP in private forests (Table 2).

The greater dispersion around the median of the values of IREFvol occurred in public forests (Figure 4). The lower variation of IREFvol values for SFMP in private forests is because these had values of IREFvol between 60% and 100% (Table 3 and Figure 3), while for SFMP in public forests the IREFvol values were distributed between 20% and 90%, thus having a larger rate of variation (Table 3 and Figure 3). The lower rate of variation for SFMP in private forests demonstrates that there is a common tendency, with respect to IREFvol, to harvest a minimum of around 70% of the authorized volume, but in most cases the harvested volume equals nearly the entire authorized volume (Table 3).

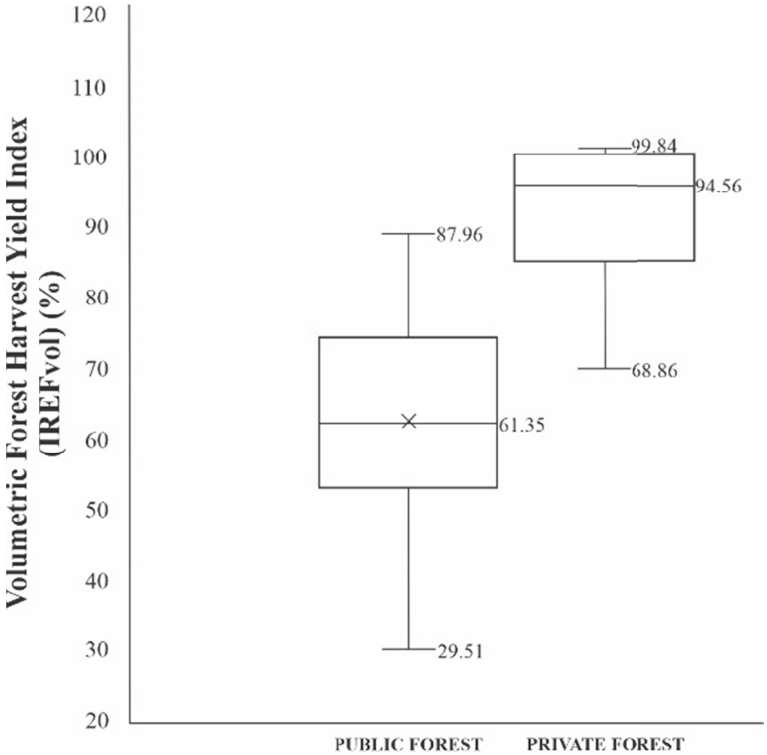

Figure 4. Boxplot of the volumetric Forest Harvest Yield Index (IREFvol) from forest management plans for public and private forests, state of Pará, Brazil

The Forest Harvest Yield Index in terms of number of harvested trees (IREFna) analyzed using the Mann-Whitney U test (U = 53.937 and p = 0.001) revealed significant differences in IREFna among SFMP in public and private forests (Table 4 and Figure 5).

Table 4. Forest Harvest Yield Index in terms of number of harvested trees (IREFna) for 15 AUTEFs in public and private forests in the state of Pará, Brazil

AUTEFs	IREFna (%) Public forest	IREFna (%) Private forest
1	39.04	94.04
2	40.36	94.75
3	46.58	94.75
4	47.65	97.19
5	51.35	97.73
6	56.06	98.4
7	70.35	98.96
8	70.83	99.95
9	79.01	100.66
10	79.03	100.97
11	80.78	114.24
12	82.25	124.3
13	84.4	174.25
14	99.1	214.41
15	123.24	224.59
Average±sd	70.002a±23.52	121.946b±44.56
Standard error	6.07	11.50

Note. * Averages followed by the same letter are not statistically different for IREFna according to the Mann-Whitney non-parametric test.

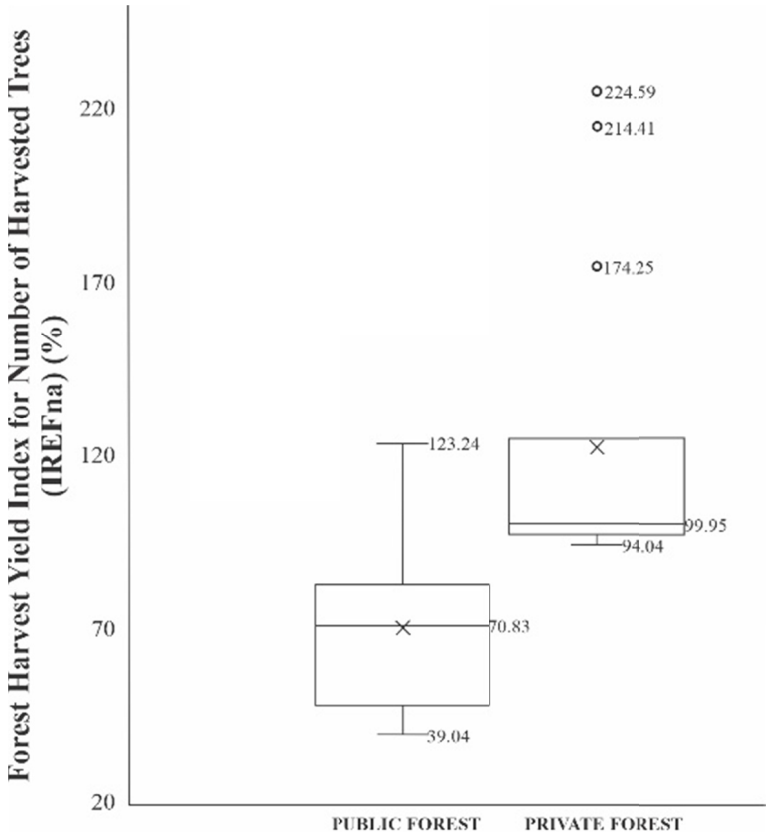

Figure 5. Boxplot of the Forest Harvest Yield Index (IREFna) from forest management plans for public and private forests, state of Pará, Brazil

The IREFna from forest management plans for public forests had lower variation around the median (23.52%) compared to that from SFMP in private forests (44.56%). In SFMP of public forests the IREFna varied between 39.04% and 123.24% (Table 4), with 93.33% of the AOPs having explored less than the number of trees authorized in the AUTEFs, and just one (6.67%) harvested more trees than the number of trees authorized in the AUTEF (Tables 4 and 5 and Figure 6). The SFMP in private forests had values of IREFna between 94.04% and 224.59% (Table 4), of which 53.33% of the AOPs harvested between 94.04% and 99.95% of the number of trees authorized by the AUTEFs, and 46.67% of the AUTEFs harvested between 100.66% and 224.59% more trees than the number authorized by the AUTEFs (Tables 4 and 5 and Figure 6).

Table 5. Number of SFMP in public and private forests according to the Forest Harvest Yield Index (IREFna) in the state of Pará, Brazil

	$IREF_{NA}$ CLASS								
Type of SFMP	30-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%	> 100%	**Total**
Public forest	1	3	2		4	3	1	1	**15**
Private forest							8	7	**15**

SFMP: Sustainable Forest Management Plan.

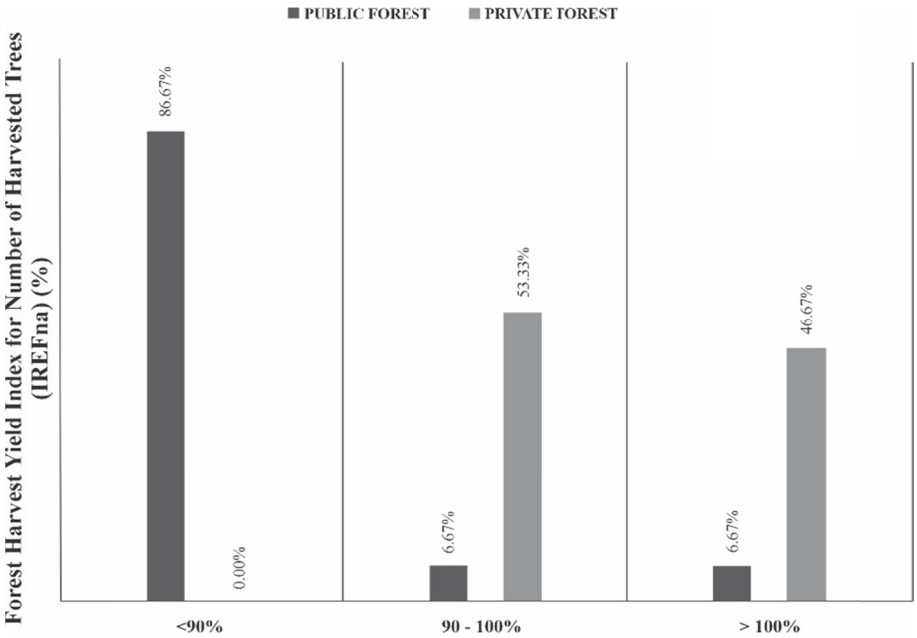

Figure 6. Distribution of the Forest Harvest Yield Index for number of harvested trees (IREFna) by class for public and private forest management plans, state of Pará, Brazil

The application of the indices IREFvol and IREFna to data from other studies done in the Amazon are shown in Table 6.

Table 6. Number of SFMP in public and private forests according to the Forest Harvest Yield Index (IREFna) in the state of Pará, Brazil

Author	Study location	Calculated value	
		IREFvol	IREFna
Emmert (2014)	Management plans in public and private forests in Rondônia.	81.20% (public forest) 88.10% (private forest)	-
Buchmann (2016)	Management Units (UT) in the Flona Tapajós, Pará (public forest).	-	73.8-71.73%
Almeida (2018)	Public forest of Saracá-Taquera, Pará.	80.67%	95.53%
Gomes et al. (2018)	Community-managed public forest in the Flona Tapajós, Pará.	84.04%	-
Biazatti et al. (2019)	Forest management units in federal public forests, western Amazonia.	65%	61%

4. Discussion

Management plans in private forests had high values of IREFvol and IREFna, which initially may suggest greater efficiency associated with these plans related to those from public forests (Tables 2 and 4). However, acceptance of this hypothesis means accepting that in private forests there is practically no occurrence of hollows in trees that are selected, authorized, and harvested, and that the set of trees that were substitutes and were harvested presents an almost equal volume of trees that were pre-selected for harvest but that were discarded. Additionally, this hypothesis implies that there is precision between the estimated volume of a tree obtained during the forest inventory and the volumes of logs that are registered in the timber packing list and harvesting declarations. However, this hypothesis is completely rejected, principally because these factors equally affect management plans in public as well as private forests. In this way, yields of volume and the number of harvested trees between the categories of management plans in public and private forests should be statistically identical.

The results for IREFvol and IREFna for management plans in public and private forests (Tables 2 and 4) are similar to those reported by other studies done in the Brazilian Amazon (Table 6). Specifically, the values of IREFvol calculated in the studies by Almeida (2018), and Gomes et al. (2018) are near those calculated for SFMP in private forest with several APUs (Table 2). It is possible that this similarity is because the SFMP

studied by Gomes et al. (2018), despite being from a public community-managed forest, is classified in the category of a 'high-intensity' SFMP with more than one APU, and the characteristics of harvesting and management operations are similar to those of a private forest with several APUs.

Tables 2 and 3 show that no AUTEF from any management plan surpassed the total authorized volume and all of them were in compliance with the legal limit imposed by current forest management regulations that maintain harvest intensity at 30 m^3 ha^{-1} (CONAMA, 2009). This baseline for the legal limit on volume provides the environmental licensing agencies with authority to control and monitor authorized volumes and apply fines resulting from infractions of the volume limit. However, compliance of the SFMP with this law is an automatic mechanism imposed by official systems of control and does not guarantee that frauds will not occur in the execution of SFMP.

The fact that many SFMP in public as well as private forests did not surpass the total volume as listed in the AUTEFs (Tables 2 and 3) demonstrated the existence of a difference between the authorized and harvested volumes. As shown by Almeida (2018), and Souza and Soares (2013), among others, this difference between the planned and harvested volumes is, minimally, a function of i) discard of authorized trees due to the presence of hollows in the trunk, a tortuous stem that cannot be processed by the timber company, use of the tree as shelter by fauna, protection of remaining trees, and restrictions in Environmental Protection Areas (APP); ii) substitution of authorized trees by trees that with different dimensions and therefore different volumes; iii) the level of precision in the volume calculation varies between that used in the packing list, which is oftentimes more precise than the standing volume because the stem length is precisely measured while during the census this parameter is only estimated.

In management plans in private forests the harvested volume is apparently little influenced by the occurrence of hollows, discard or substitution of trees, or by the estimation of commercial height in the forest inventory for volume calculation using a generic equation. This could be an initial explanation for the 58.82% of AUTEFs that, theoretically, harvested and transported more than 90% of the authorized volume (Figure 3). Volumes for these AUTEFs were remarkably close to the total authorized volume, and this may therefore indicate a high level of precision between the authorized and harvested volumes, which directly influences the median of IREFvol of 94.56% for these management plans (Figure 2).

In management plans in public forests, 100% of the AUTEFs theoretically harvested and transported less than 90% of the authorized volume (Table 2), and of these 52.94% theoretically harvested and transported between 60% and 90% of the AUTEF volume (Figure 3), which resulted in a median IREFvol value of 61.35%. This indicates the occurrence of tree hollows, discards, and substitutions, among other exploratory variables that influenced the harvest of the total authorized volume and consequently the use of lower volumes than the total volume of the Autefs.

With respect to yield in relation to the number of harvested trees, the median value for IREFna was 70.83% for SFMP in public forests. In comparison with value calculated in other studies (Table 6), the IREFna in the current study is similar to the values of 73.8% and 71.73% from Buchmann (2016), below the value of 95.53% from Almeida (2018), e and above the 61% median value from Biazatti et al. (2019). In these management plans, about 30.00% of the number of authorized trees were not harvested, a value similar to that from Buchmann (2016), who worked in two work units (UT) in an experimental area in the FLONA Tapajós and found that about 24% of the trees selected for harvest were not harvested. In contrast, the median IREFna of 99.95% for management plans in private forests is near the 95.53% calculated by Almeida (2018) and much higher than the 61% calculated in the studies by Buchmann (2016) and Biazatti et al. (2019) (Table 6).

A total of 46.67% of the AUTEFs for management plans in private forests harvested more than the volume authorized by the AUTEF, the highest value for which was 224.59% of the authorized volume, (Tables 4 and 5). Explanations for this excess harvesting include, i) besides harvesting all authorized trees, unauthorized trees were also harvested, and ii) authorized trees were substituted, and the number of these harvested was greater than the number authorized in the AUTEFs. Furthermore, 53.33% of the AUTEFs in these management plans harvested a lower number of trees than the authorized number, and the values for IREFna for these were between 94.04% and 99.5%. Nonetheless, the IREFna of the SFMP in private forests demonstrates that while these management plans do not harvest above the limit authorized in the AUTEF, they harvest a number of trees very near this limit. It can be affirmed that this fact, among others, is a consequence of a lack of control of the number of trees harvested on the part of environmental compliance agencies. This could possibly be due to a lack of a legal framework, which contrasts with controls on volume wherein a limit of 30m^3/ha is imposed by the Brazilian system of forest control (Brasil, 2009) which is automatically used by the forest control system.

Management plans in public forests had lower yield in volume (IREFvol) and in the number of harvested trees (IREFna) compared to management plans in private forests The values of IREFvol and IREFna for management plans in public forests (Tables 2 and 4; Figures 4 and 5), indicate that: i) many selected and authorized trees were not harvested (about 30%), probably as a function of presence of hollows or stem defects which prevented the use of these trees; ii) there was little substitution of authorized and discarded trees, and even with substitution the number of harvested trees was much lower than that authorized in the AUTEF, and, iii) the real harvested volume was less than the individual volume estimated in the inventory for each authorized tree. These factors caused the median harvested volume (IREFvol = 61.35%) to be considerably lower than the authorized volume from the AUTEF. The difference between the authorized and harvested volumes, about 40% of the authorized volume, enables it to be used to obtain fraudulent documents for forest products that are illegally harvested. This practice generally does not occur in these cases due to increased rigor in control of timber harvesting by environmental compliance agencies that are responsible for monitoring of harvesting activities and for conducting frequent field inspections. This induces the owner of the SFMP to return this unused volume, and principally, of the monetary payment of the registered harvested volume as listed in official control systems.

In SFMP in private forests, the values of IREFvol and IREFna (Tables 2 and 4; Figures 4 and 5) indicate that: i) there was little to no discard of trees selected and authorized for harvest; ii) there was a high rate of substitution of authorized and discarded trees, and iii) the real harvested volume was equal to or very near the individual volume estimated for each authorized tree. These factors resulted in the harvest of more trees than was authorized in the AUTEF (Tables 4 and 5). These factors, especially the harvest of more trees than was authorized in the AUTEF, resulted in similar values of harvested and total authorized volumes in the AUTEFs, as shown by the median IREFvol of 94.56% (Table 2 and Figure 4). This resulted in a forest harvest credit of 5.44% which could be used to obtain fraudulent documents for forest products that are illegally harvested, although the value of this credit is small compared to those from management plans in public forests.

The values of IREFvol and IREFna from management plans in private forests demonstrates that there may be a strategy of harvesting trees until reaching the limit of authorized volume without keeping within the limit established for the number of trees by species authorized for harvesting. It is important to emphasize that during forest harvesting the official control systems impose limits on harvest volumes as a function of authorized volume, but this does not occur with the number of harvested trees in relation to the number of authorized ones. In this way, the official control systems "accept" the registration of the harvest of a number of trees greater than that authorized.

Analysis of the difference in the median values of IREFna and IREFvol between management plans in private and public forests showed greater yield in private forests (33.21% IREFvol and 29.12% IREFna), especially for private SFMP with a single APU where this difference reached 34.19% (Figures 2, 4 and 5). The yield of 29.12% for IREFna enabled SFMP in private forests to use almost the entire authorized volume (Table 2), thus generating an IREFvol 33.21% greater than for SFMP in public forests (Table 2). This difference in volumetric yield provides SFMP in private forests conditions to generate a forest harvest credit that can be used to obtain fraudulent documents for forest products that are illegally harvested through, i) in the AMF, harvesting of substituted trees above the quantity of trees authorized for harvest, harvesting more substituted trees than authorized ones (Tables 4 and 5); ii) in the AMF, declaration in the official control systems of overestimation of volume of harvested trees, and subsequent use of the surplus volume for transport of illegal wood or for volumetric conversion of sawn wood in the lumber industry; iii) in the AMF, filing of false declarations of tree harvesting in the official control systems. In this last example of fraud, the forest management plan registers unharvested trees as being harvested with the objective of using the difference between harvested and authorized volumes to legalize trees harvested at another site (Brancalion et al., 2018; Richardson & Peres, 2016). Finally, the fourth type of fraud (iv) is conducted outside of the AMF, wherein trees are harvested outside the area included in the SFMP, then incorporated in the control systems as authorized and harvested trees or as substitute ones. In this way, yields from management plans in private forests appear to represent the sum of volume used for local production plus the volume of virtual credits sold through the official control systems but without actual raw material, which increases the income of the owners of the SFMP. From the point of view of the owner of the SFMP this process makes sense because the objective of forest management is, above all else, to be in compliance with the applicable environmental legislation.

Management plans in public forests, whether state or federal, are projected based on a number of annual production units (APUs) that is compatible with the proposed cutting cycle, which is between 25 and 35 years. Furthermore, in SFMP in public forests, payments are made based on cubic meters harvested and are contingent upon recurring annual inspections. In contrast, management plans in private forests are projected based on a

single APU. Since the number of management plans in private forests is greater than those from public forests, government environmental compliance agencies have a deficit of human and financial resources needed to annually inspect all the SFMP. It is therefore important that the available monitoring mechanisms of official control systems are employed in a way that increases the efficiency of surveillance and compliance efforts.

The lack of parity between human and financial resources on the part of government environmental compliance agencies in the Amazon and the large area of forest that is impacted by harvesting activities prevents efficient field-level verification of harvest authorizations, and this situation becomes an open invitation for fraud and corruption (Brancalion et al., 2018). Environmental compliance agencies should therefore use the sampling done in technical inspection visits as a means to inspect harvest authorizations, but this process should be modified by selecting specific targets through analysis of information registered in the database of the official systems of control which register the approval, harvesting, and transport of logs from forest management plans. The objective of this would be to guarantee that the majority of inspection and control of forest products is conducted in the field and is not just relegated to being a standardized bureaucratic authorization process.

In the analysis of management plans as conducted by field-level inspections, it was revealed that there is apparently no control over the stock of timber in the SFMP. The control of volume has been customarily done by grouping of different species into their respective genera and not by individual species. Besides the lack of adoption of reduced impact harvesting techniques, such as the use of timber cutting and dragging maps to locate trees that will be harvested and placement of signage to indicate dragging routes of sawn trees as designated on maps. This situation prevents tracking of the origin of logs and is considered to be highly detrimental for any monitoring and control activity (Ferreira, 2012).

Beginning in 2018 the electronic systems used for control of forest products incorporated a formal declaration of cut trees or a packing list of logs as a way to increase the precision of the register of actual harvested volumes. The objective of this measure was to avoid that any differences between the volume registered in the forest inventory and that on the log packing list be improperly used, for example, through insertion of false data to obtain fraudulent documents for forest products that are illegally harvested. The motive of this change in the official Brazilian system of control of forest products was to permit that forest credits be used to emit forestry transport permits that originate from the log packing list as generated in the harvesting phase, and not from the estimated volumes in the forest harvest authorization. This means that managers understand that there is a lack of control over the volumes harvested based on the forest harvest authorizations. In contrast, the manager responsible for the execution of the management plan could simulate the volume on the log packing list in the cutting declaration registered in the electronic control systems until the estimated volume as listed in the forest harvest authorization is reached. It is recommended that agents from government environmental compliance agencies be trained to recognize the incompatibility between the declared harvested volume registered in the electronic control systems and the volume that is actually harvested in the field.

5. Conclusions

Volume yields in terms of the number of harvested trees were greater in management plans from private forests compared to those from public forests.

The difference in yields in terms of volume and the number of harvested trees between management plans from public and private forests cannot be explained by any technical factor related to harvesting activity.

The high yields in terms of volume and the number of harvested trees from management plans from private forests suggests that a significant part of these plans may deliberately and systematically be a source of virtual credits used to obtain fraudulent documents for forest products that are illegally harvested.

The absence or negligence with respect to monitoring conducted by government environmental compliance agencies, especially related to management plans from private forests, is fundamental to understanding the results of this study. This lack of monitoring, allied with outdated forestry regulations that require inspection and sampling in the field to evaluate the legality of timber production, appear to explain the results obtained in this study.

6. Recommendations

Government environmental compliance agencies and the Amazonian technical and scientific community need to discuss the practice of using fraudulent documents for forest products that are illegally harvested in the Amazon.

The volume of virtual forest credits corrupts the official control systems and allows the forest industry to benefit by adjusting for losses as a function of virtual conversion coefficients used for forest products and of physical processing of wood.

The manual used for inspection of forest harvest management plans in the Amazon should contain a chapter dedicated to the evaluation of the legality of forest harvesting and the compatibility of information registered in official control systems. This should be implemented through a resolution from the National Environment Council (CONAMA) so that it is applied to all states in the Brazilian Amazon.

The institutions that conduct forest harvest licensing in the Amazon should prioritize the guarantee of the legal origin of forest products and not allow that management plans be used to generate timber credits that surpass authorized volumes. Furthermore, these institutions must impede the practice of using fraudulent documents for forest products that are illegally harvested and the use of false information in official electronic control systems. Several studies have shown that SFMP oftentimes have volume yields below 80%, and this leads to investigation of those SFMP that have yields above this value.

The number of trees that are harvested must not surpass the number legally authorized in the AUTEF, and this measure should be included in the proposed CONAMA resolution on forest harvest management and immediately adopted by all states in the Amazon.

References

Almeida, V. B. (2018). *Impacto da ocorrência de oco no rendimento volumétrico e financeiro da colheita de madeira na Floresta Nacional de Saracá-Taquera, Pará* (Dissertação, Mestrado em Ciências Florestais, Universidade Federal Rural da Amazônia, Belém).

Amaral, P. H. C., Veríssimo, J. A. de O., Barreto, P. G., & Vidal, E. J. da S. (1998). *Floresta para sempre: um manual para produção de madeira na Amazônia* (p. 137). Belém: Imazon.

Barreto, P., Amaral, P., Vidal, E., & Uhl, C. (1998). Costs and benefits of forest management for timber production in eastern Amazonia. *Forest Ecology and Management, 108*, 9-26. https://doi.org/10.1016/S0378-1127(97)00251-X

Biazatti, S. C., Mora, R., Sccoti, M. S. V., Brito Júnior, J. F., Souza, L. A., & Souza, L. (2019). Planning and forest production in concession area in the western Amazon. *Brazilian Journal of Development, 5*(7), 8938-8953. https://doi.org/10.34117/bjdv5n7-097

Brancalion, P. H. S., Almeida, D. R. A., Vidal, E., Molin, P. G., Sontag, V. E., Souza, S. E. X. F., & Shulze, M. D. (2018). Fake legal logging in the Brazilian Amazon. *Science Advances, 4*, eaat1192. https://doi.org/10.1126/sciadv.aat1192

Brasil, Ministério do Meio Ambiente. (2019). *Resolução Conama nº 406, de 02 de Fevereiro de 2009*. Estabelece parâmetros técnicos a serem adotados na elaboração, apresentação, avaliação técnica e execução de Plano de Manejo Florestal Sustentável-SFMP com fins madeireiros, para florestas nativas e suas formas de sucessão no bioma Amazônia, Brasília. Retrieved from http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=597

Braz, E. M., Canetti, A., Mattos, P. P., Basso, R. O., & Figueiredo Filho, A. (2018). Alternative criteria to achieve sustainable management of mezilaurus itauba in the Brazilian Amazon. *Pesquisa Florestal Brasileira, 38*, 1-8. https://doi.org/10.4336/2018.pfb.38e201801648

Braz, E. M., Mattos, P. P. De, Oliveira, M. F., & Basso, R. O. (2014). Strategies for achieving sustainable logging rate in the Brazilian Amazon forest. *Open Journal of Forestry, 4*(2), 100-105. https://doi.org/10.4236/ojf.2014.42015

Buchmann, H. M. (2016). *Exploração florestal e seus impactos em áreas de primeiro e segundo ciclo de corte do manejo florestal na Amazônia oriental, Brasil* (Dissertação, Mestrado em Ciências Florestais, Universidade de Brasília, Brazil).

Dykstra, D. P., & Heinrich, R. (1996). *Código modelo de practicas de aprovechamiento florestal de la FAO* (p. 85). Roma: FAO.

Embrapa e Ibama. (2006). *Manual de vistoria de campo para planos de manejo florestal madeireiro na Amazônia* (p. 106). Brasília, Brazil.

Emmert, F. (2014). *Combinação de dados de campo e métodos computacionais para o planejamento da exploração florestal na Amazônia* (190 f. Tese, Doutorado em Ciências Florestais, Universidade de Brasília, Brasília).

Ferreira, M. A. C. (2008). *Critérios e indicadores de sustentabilidade para manejo florestal na Amazônia brasileira aplicados em 20 áreas de manejo florestal no norte do estado do Mato Grosso* (Tese, Doutorado em Ciências Florestais, Universidade de Brasília, Brasília).

Figueiredo, E. O., D'Oliveira, M. V. N., Braz, E. M., Papa, D. A., & Fearnside, P. M. (2016). Lidar-based estimation of bole biomass for precision management of an amazonian forest: comparisons of ground-based and remotely sensed estimates. *Remote Sensing of Environment, 187*, 281-293. https://doi.org/10.1016/j.rse.2016.10.026

Figueiredo, S. M. De M., Venticinque, E. M., Figueiredo, E. O., & Ferreira, E. J. L. (2015). Predicting the distribution of forest tree species using topographic variables and vegetation index in eastern Acre, Brazil. *Acta Amazonica, 45*, 167-174. https://doi.org/10.1590/1809-4392201402834

Gagarin, Y. N., Dobrovolsky, A., & Smirnov, A. (2019). Situation with protection of forests against illegal loggings in Russian Federation. *Forest Science, 2*(4), 1-22. https://doi.org/10.31509/2658-607x-2019-2-4-1-22

Gomes, K. M. A., Silva-Ribeiro, R. B., Gama, J. R. V., & Andrade, D. F. C. (2018). Eficiência na estimativa volumétrica de madeira na Floresta Nacional do Tapajós. *Nativa, 6*(2), 170-176. https://doi.org/10.31413/nativa.v6i2.5237

Gretzinger, S. P. (1996). *Evaluacíon de impactos ambientales en concessiones forestales en la reserva de la biosfera Maya, Peten, Guatemala* (p. 58). Turrialba: CATIE.

Holmes, T. P., Blate, G. M., Zweede, J. C., Pereira Junior, R., Barreto, P., Boltz, F., & Bauch, R. (2002). Financial and ecologycal indicators of reduced impact logging performance in the eastern amazon. *Forest Ecology and Management, 163*, 93-110. https://doi.org/10.1016/S0378-1127(01)00530-8

Lentini, M., Pereira D., Celentano, D., & Pereira, R. (2005). *Fatos Florestais da Amazônia*. Belem, Brazil: Imazon.

Papa, D. A. (2018). *Impacto do manejo de precisão em florestas tropicais* (Dissertação, Mestrado em Recursos Florestais, Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba).

Putz, F. E., & Pinard, M. A. (1993). Reduced-Impact Logging as a Carbon-Offset Method. *Conservation Biology, 7*(4), 755-757. Retrieved from http://www.jstor.org/stable/2386806

Richardson, V. A., & Peres, C. A. (2016). Temporal decay in timber species composition and value in amazonian logging concessions. *PLoS ONE, 11*(7), e0159035. https://doi.org/10.1371/journal.pone.0159035

Sabogal, C., Lentini, M., Pokorny, B., Silva, J. N. M., Zweede, J., Veríssimo, A., & Boscolo, M. (2006). *Manejo florestal empresarial na Amazônia brasileira: Restrições e oportunidades-relatório síntese*. Belém, PA: CIFOR.

Sabogal, C., Silva, J. N. M., Zweede, J., Pereira Junior, R., Barreto, P., & Guerreiro, C. A. (2000). *Diretrizes técnicas para a exploração de impacto reduzido em operações florestais de terra firme na Amazônia brasileira* (p. 52, Amazônia Oriental-Embrapa, Documento 64). Belém: Embrapa.

Siegel, S., & Castellan Júnior, N. J. (2006). *Estatística não-Paramétrica Para Ciências do Comportamento* (2nd ed., p. 448). Porto Alegre: Artmed.

Silgueiro, V., Cardoso, B., Bernasconi, P., & Valdiones, A. P. (2015). Mapeamento da ilegalidade na exploração madeireira. *Transparência Florestal, 5*(4), 12. https://doi.org/10.13140/RG.2.2.29941.32484

Silva, E. F., Silva, R. F., Vieira, G. C., Leite, C. C. C., Aguiar, M. O., Figueiredo, E. Ó., … Silva, G. F. (2018). Planning of production units for native forest management areas in the amazona. *Revista Brasileira de Ciências Agrárias, 13*(1), p.1-8. https://doi.org/10.5039/agraria.v13i1a5502

Silva, E.F., Silva, G. F., Figueiredo, E. O., Binoti, D. H. B., De Mendonça, A. R., Torres, C. M. M. E., & Pezzopane, J. E. M. (2018). Allocation of storage yards in management plans in the amazon by means of mathematical programming. *Forests, 9*(3), 127. https://doi.org/10.3390/f9030127

Silva, J. N. M., Carvalho, J. O. P. De, & Lopes, J. C. A. (1999). *Um sistema silvicultural policíclico para produção sustentada de madeira na Amazônia brasileira* (pp. 180-185, Embrapa/CPATU, Documentos 123). Simpósio Silvicultura na Amazônia Oriental: Contribuição do Projeto. Embrapa, Belém, DF.

Silva, P. H. D., Gomide, L. R., Figueiredo, E. O., Carvalho, L. M. T. D., & Ferraz-Filho, A. C. (2018). Optimal selective logging regime and log landing location models: A case study in the amazon forest. *Acta Amazonica, 48*(1), 18-27. https://doi.org/10.1590/1809-4392201603113

Souza, A. L., & Soares, C. P. B. (2013). *Florestas Nativas: estrutura, dinâmica e manejo*. Viçosa, MG: Ed. UFV.

Uhl, C., & Vieira, I. G. C. (1989). Ecological impacts of seletive logging in the Brazilian Amazon: A case study from the Paragominas region of the state of Pará. *Biotropica, 21*, 98-106. https://doi.org/10.2307/2388700

Uhl, C., Barreto, P., Veríssimo, A., Vidal, E., Amaral, P., Barros, A., … Gerwing, J. (1997). Natural resource management in the brazilian amazon. *Bioscience, 47*(3), 160-168. https://doi.org/10.2307/1313035

Veríssimo, A., Barreto, P., Mattos, M., Tarifa, R., & Uhl, C. (1992). Logging impacts and prospects for sustainable forest management an old amazonian frontier: the case of Paragominas. *Forest Ecology and Management, 55*, 169-199. https://doi.org/10.1590/1809-4392201802332