

Article

Not peer-reviewed version

---

# Imprecision in Yield Estimates Using Timber Volume in Forest Management Plans in the Amazon

---

[Renato Bezerra da Silva Ribeiro](#)\*, Leila Sheila Silva Lisboa, [Carlos Tadeu dos Santos Dias](#), [Afonso Henrique Moraes Oliveira](#), [Emanuel José Gomes de Araújo](#), Dárlison Fernandes Carvalho de Andrade, [Lucieta Guerreiro Martorano](#)

Posted Date: 10 October 2024

doi: 10.20944/preprints2024071564.v2

Keywords: Annual Operating Plan; Commercial Height; Community Forest Management; Logging; Tapajós National Forest; Timber estimation



Preprints.org is a free multidiscipline platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article

# Imprecision in Yield Estimates Using Timber Volume in Forest Management Plans in the Amazon

Renato Bezerra da Silva Ribeiro <sup>1,\*</sup>, Leila Sheila Silva Lisboa <sup>2</sup>, Carlos Tadeu dos Santos Dias <sup>3</sup>, Afonso Henrique Moraes Oliveira <sup>1</sup>, Emanuel José Gomes de Araújo <sup>4</sup>, Dárlison Fernandes Carvalho de Andrade <sup>5</sup> and Lucieta Guerreiro Martorano <sup>6</sup>

<sup>1</sup> Programa de Pós-Graduação em Sociedade, Natureza e Desenvolvimento, Universidade Federal do Oeste do Pará, Rua Vera Paz—Salé, Santarém 68000-000, Brazil

<sup>2</sup> Secretaria Municipal de Belém SEMEC, Belém 66000-000, Brazil

<sup>3</sup> Programa de Pós-Graduação em Modelagem e Métodos Quantitativos, Departamento de Estatística e Matemática Aplicada – DEMA, Centro de Ciências, Campus do PICI, Bloco 910, Fortaleza-CE, 60440-900, Brazil

<sup>4</sup> Programa de Pós-Graduação em Ciências Ambientais e Florestais, Universidade Federal Rural do Rio de Janeiro, BR 465, km 7, Seropédica-RJ, Brazil

<sup>5</sup> Coordenação Geral de Informação Florestal, Diretoria de Fomento Florestal, Serviço Florestal Brasileiro, SCEN Trecho 2 - Bloco G - L4 Norte – Brasília-DF, 70818-900, Brazil

<sup>6</sup> Embrapa Amazônia Oriental, Programa de Pós-Graduação em Sociedade, Natureza e Desenvolvimento e Programa de Pós-Graduação Rede Bionorte, Travessa NS Um A, 98, Santarém 68000-000, Brazil

\* Correspondence: florestalrenatoribeiro@gmail.com

**Abstract:** The evaluation of logging in a forest management area using only the volume variable is not sufficient to assess the effectiveness of the harvest. The objective was to evaluate harvested volume using different logging variables to point out possible divergences between what was planned and what was actually carried out, in order to indicate adjustments to next annual operating plans (AOPs). The database comes from a community forest management area in the Tapajós National Forest, considering three sources: forest inventory, AOP planning and the post-exploration report. The yield considering the number of trees felled and the effective volume were compared with the AOP planning. The volume estimated by the generic equation was compared with the cubed volume and the commercial height variable was evaluated. Of the 6,267 trees selected, 5,090 trees were harvested (3.2 trees ha<sup>-1</sup>), indicating a yield of 85% of the estimated volume. Of the 25 commercial species logged, the most representative were: *Manilkara huberi*, *Vochysia maxima*, *Lecythis lurida*, *Couratari guianensis* and *Hymenaea courbaril*. It can be concluded that the number of trees, cubed volume and commercial height are post-exploration yield response variables and not just volume, as is currently used in Sustainable Forest Management Plans (SFMPs).

**Keywords:** annual operating plan; commercial height; community forest management; logging; tapajós national forest; timber estimation

## 1. Introduction

The Tapajós National Forest (better known by the name Flona Tapajós), is a Sustainable Use Conservation Unit that was created in 1974 with the basic objective of promoting the sustainable multiple use of forest resources and encouraging scientific research, with an emphasis on methods for the sustainable exploitation of native forests [1,2]. The first experiments with forest management in the Amazon were carried out in Flona Tapajós, one of them in 1999 to 2003 funded by ITTO (International Tropical Timber Organization) and DFID (UK Department for International Development) to subsidize a realistic low-impact logging venture under the coordination of Brazilian Institute of the Environment and Renewable Resources - IBAMA [2,3]. Another important experience

was the experimental management carried out by Embrapa Amazônia Oriental in 1979, located at km 67 of the Tapajós National Forest, which is one of the oldest study sites on the sustainability of timber forest management in the Amazon [4,5], and which was the first to carry out a second cycle of timber harvesting in 2014, after 35 years [5,6].

Currently, part of the Flona Tapajós is granted on a non-remunerative basis to the Tapajós Flona Mixed Cooperative - COOMFLONA for timber harvesting [7,8]. COOMFLONA (founded on February 16, 2005 by 24 cooperative members with the aim of managing the natural resources of the conservation unit, always valuing social and environmental issues) is made up of traditional residents who operate and manage full community forest management, bringing direct economic, ecological and social benefits to the cooperative members and indirectly to the communities that make up the inhabitants of Flona Tapajós [3].

COOMFLONA is a social organization currently made up of 313 cooperative members, who are residents of the Tapajós National Forest who and directly manage the commercialization, financial and administrative aspects of forest management in this Sustainable Use Conservation Unit. The cooperative was created in 2005 with the support of the Pilot Program for the Protection of Tropical Forests (PPG7), better known by the acronym ProManejo/IBAMA, which was one of the projects funded to promote sustainable forest management in the Amazon [7].

As part of the strategies to train residents, 900 hectares of forest were initially managed, subdivided into three APUs of 100 hectares, 300 hectares and 500 hectares, with the costs of exploitation during this period being financed outright [7]. From 2009 onwards, the cooperative began to manage its activities with its own resources. Throughout the consolidation process, that is, overcoming the initial difficulties, COOMFLONA has already managed more than 12,000 hectares, equivalent to 15% of the total area available for forest management in the Tapajós Flona [9]. COOMFLONA exploits an average of 24 species every year [10] and its management model is currently a benchmark in Latin America, generating more than R\$10 million a year in annual production areas ranging from 1,500 ha to 2,000 ha [9].

Forest management is made up of a set of activities aimed at minimizing the impacts resulting from forest exploitation, with a view to making better use of timber and non-timber forest resources, maintaining forest cover and ensuring continuous production [11,12]. Its key principle is action planning [13], which ranges from pre-exploitation, exploitation to post-exploitation. It is a forest management activity that makes it possible to obtain economic, social and environmental benefits at the same time, as long as the ecosystem's support mechanisms are respected [14,15].

The ordering and planning of annual production, considering the planned cutting cycle, is legally known as the annual operating plan (AOP). The AOP is based on the commercial stock of an Annual Production Unit (APU), presented after carrying out an inventory of commercial species selected for exploitation [16,17]. It provides information on technical harvesting capacity, the number of trees per species and the estimated volume of standing timber [18]. Selective logging is planned by selecting trees that must have a diameter at breast height (DBH) equal to or greater than 50 cm as a minimum dimension [14,18,19] and a maximum diameter of 200 cm [19]. For this selection process, the restrictions described in the forestry legislation must be complied with, which generally stipulates a minimum of 3 to 4 trees per 100 ha and a maximum cutting intensity of 30 m<sup>3</sup> ha<sup>-1</sup> [14,18–20].

The volume of standing wood is, by definition, the most important variable in the process of defining production [21–23], especially of the stem, as it is the most highly valued commercial part of the tree [24]. For the first year of implementation of the Sustainable Forest Management Plan (SFMP), the volume of standing timber is obtained indirectly by applying the cylinder volume equation using the variables DBH and commercial height and using the shape factor of 0.7 to consider the taper of the trees [12,25,26]. After the first year of logging, SFMPs must present a specific equation for estimating the volume of standing timber [14]. Therefore, yield is based on the estimated volume of standing timber, with the final report containing the actual volume, i.e. that which was harvested and transported, to be presented after logging [18,19]. This way, the accuracy of determining the volume of round wood is of fundamental importance in planning and accounting for the individual

processes involved in the wood raw material trade [27]. Based on this information, it is possible to assess the yield or efficiency of the harvest in terms of volume [28].

In fact, whether using the shape factor or equations, volume can be underestimated or overestimated [12]. The main factors for this to happen are related to: i) errors in commercial height measurements/estimates [12,29], ii) the use of generic equations [12,30,31], iii) the occurrence of hollows, problems with the execution of logging techniques in the field [32–36], such as the direction in which the tree fell with a high impact [33], iv) deviation of cylindrical form [37] and annotation errors in the forest inventory [38].

The logging and harvesting process, involving chainsaws, harvesters, skidders and forwarders, directly impacts wood quality. Skilled handling is essential to avoid defects like splintering or physical damage during felling and transport. Chainsaws require precision, while harvesters need careful operation to prevent environmental damage. Skidders and forwarders, crucial for moving logs, must be used properly to avoid harming the wood. Personnel such as fellers, machine operators, and supervisors play a key role in maintaining timber quality [39].

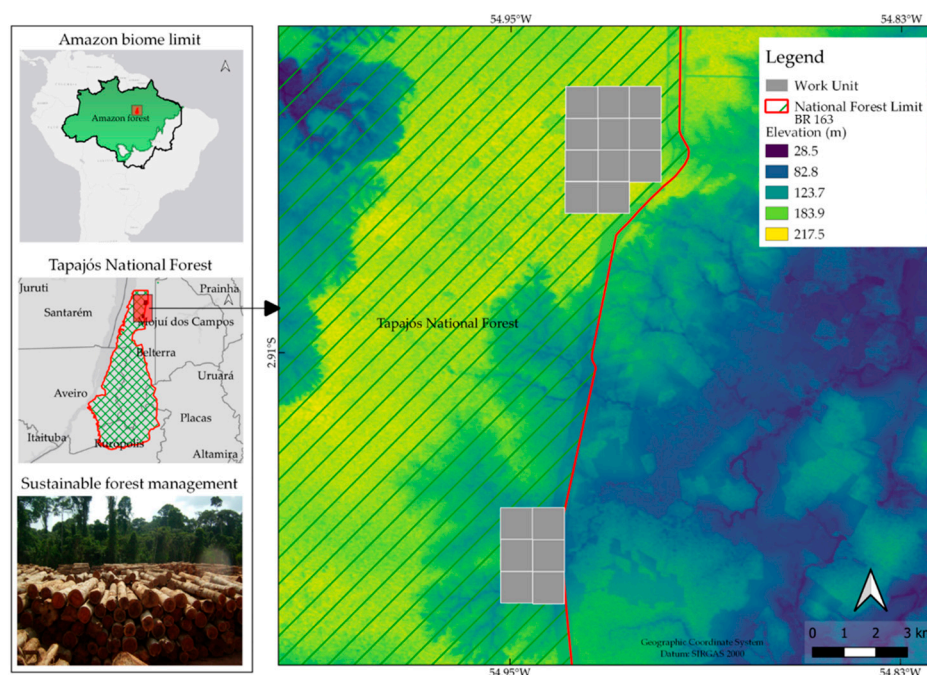
In view of this, post-exploration evaluation is an important tool for assessing the efficiency of the management carried out and can point to indicators that were not sufficient or that need to be adjusted in the next planning stage, with a view to improving yield results.

Predominantly, the studies that partially address logging yield make a general assessment considering total volumes before and after the activity [35,40], not considering an assessment with the number of trees selected and felled. The hypothesis of this study is that a joint analysis between the variables volume and number of trees can indicate the effective yield, but also an evaluation of the efficiency of the volumetric equation. It is also possible to analyze the estimates and measurements of commercial height and DBH to assess the consistency of this data, especially in relation to commercial height because it is a difficult variable to obtain in natural forests [29,41,42], largely due to the difficulty of using sophisticated equipment in dense environments, leaving ocular estimation as the most common option [42]. However, there is no standardized way of evaluating post-exploitation yield, nor what indicators can be considered so that they can be implemented in future planning aimed at improving long-term production in forest management plans in the Amazon. In view of this, the aim of this study was to propose an analysis of yield using different logging variables to point out possible discrepancies between what was planned and what was carried out, as well as to evaluate the results.

## 2. Materials and Methods

### 2.1. Study area

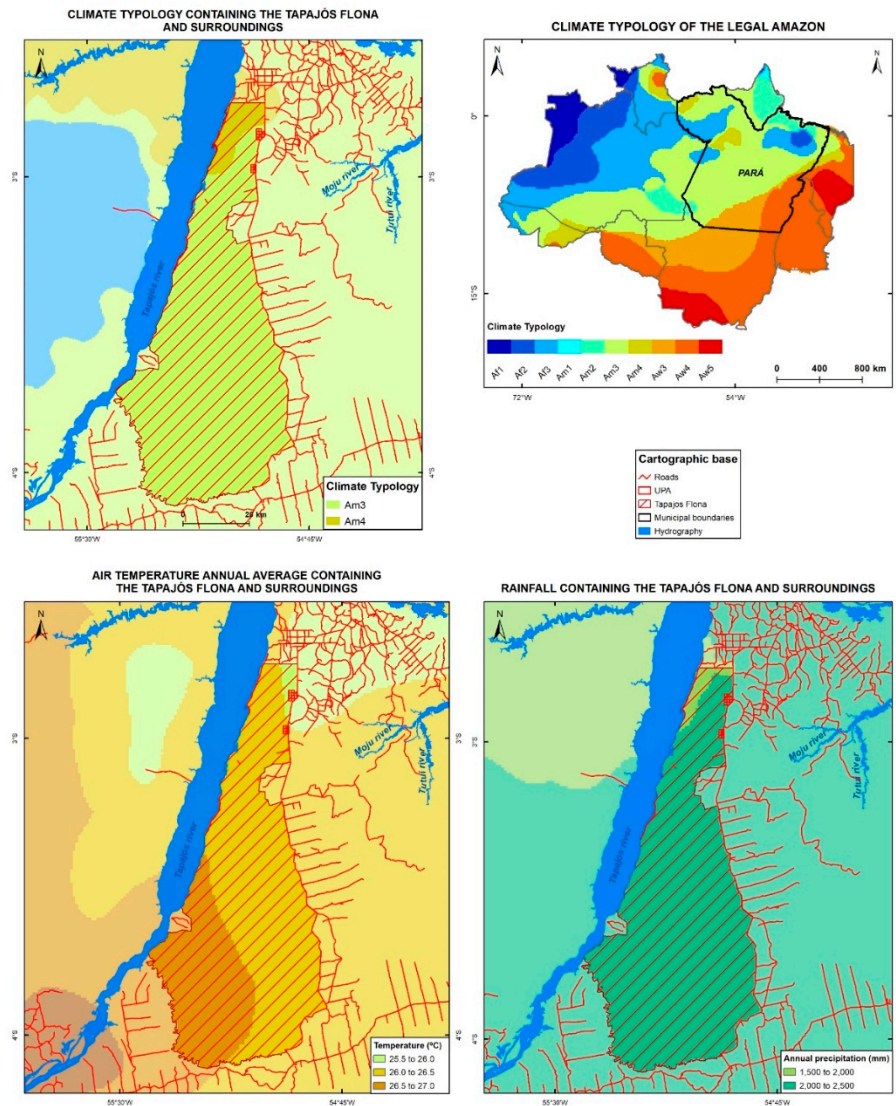
The study area is in the Tapajós National Forest, specifically in the Annual Production Unit 9 (UPA 9), which is part of the Community Forest Management (MFC) area that is under a non-remunerated concession from COOMFLONA. UPA 9 was explored in 2015 and has a total area of 1,600 ha that is subdivided into 15 work units, 10 units along kilometer 67 and 5 units along kilometer 83, both with reference to the BR 163 highway (Figure 1). It is important to note that the Tapajós Flona is in an area that has six altimetric elevation bands, but APU 9 is concentrated between 100 and 200 m.



**Figure 1.** – Location of Annual Production Unit 9 in the Tapajós National Forest, Pará state, Brazil, South America.

When evaluating the climatic variables in the study area, it can be seen that APU 9 falls into the  $Am_3$  climatic subtype (Tropical transition climate between  $Af$  and  $Aw$ ), indicating that in the least rainy month the average rainfall totals are below 60 mm and the average annual rainfall varies between 2,000 mm and 2,500 mm. It is worth noting that in the northernmost part of the Flona the typology changes to subtype  $Am_4$ , which is an indicator of reductions in annual rainfall [43]. The annual thermal regime, in terms of average air temperature, shows temperatures varying between 25.5°C and 27.0°C and in APU 9 the thermal range of variation goes from 25.5°C to 26.5°C (Figure 2), indicating that these variations can help in the analysis of possible phenotypic expressions in a management area, as is the case with the APUs in the Flona Tapajós.

The predominant soils in the Flona Tapajós belong to the Latossols, Argisols and Arenosols classes, with topography varying from flat to undulating [44]. Flona Tapajós has typical vegetation of Submontane Ombrophilous Dense Forest, which predominates in the western region of the state of Pará [45], characterized by the occurrence of species of high commercial value, such as: *Manilkara huberi* (Ducke) Cheval. (maçaranduba); *Dinizia excelsa* Ducke (angelim); *Mezilaurus itauba* (Meisn.) Taub. Ex Mez (itaúba); *Handroanthus serratifolius* (Vahl) Nich. (ipê-amarelo) and *Hymenaea courbaril* L., (jatobá) [9].



**Figure 2.** – Climatic typology of the Legal Amazon in which Annual Production Unit 9 is in the Tapajós National Forest, Pará state, Brazil, South America.

## 2.2. Database

The data analyzed in this study came from three sources, provided by an institutional cooperation agreement: 1) Forest Inventory: this includes data on the types, sizes, and distribution of trees within a specific forest area. It's used to assess the forest's composition and potential for sustainable exploitation. 2) Annual Operating Plan (AOP): This document outlines the planned logging activities, specifying the volume of wood (Table 1) to be harvested, and the methods to be used, ensuring alignment with sustainable practices. 3) Post-Exploration Report: This report details the outcomes of logging activities, including the actual volume of wood extracted and any deviations from the AOP. It helps evaluate the impact of the logging and the effectiveness of the management practices.

During the inventory, the circumference was measured at 1.30 m from the ground with a tape measure, and the commercial height of the stem was estimated visually. These data were recorded on field sheets and tabulated in electronic spreadsheets for later analysis by the technical manager. The cutting intensity approved by the environmental agency in AOP 9 was 28.62 m<sup>3</sup> ha<sup>-1</sup>, which was equivalent to an estimated harvest of 4.08 trees ha<sup>-1</sup>.

**Table 1.** - Vernacular name, scientific name, minimum cutting diameter, number of trees and estimated volume of trees suitable and selected for logging in the Annual Operational Plan for APU 9.

Vernacular name	Scientific name	MCD (cm)	Susceptible to exploitation		Selected for exploitation	
			NT	Vol. (m <sup>3</sup> )	NT	Vol. (m <sup>3</sup> )
Angelim pedra <sup>1</sup>	<i>Hymenolobium petraeum</i> Ducke	50	91	901.524	45	587.392
Breu amescla <sup>2</sup>	<i>Trattinnickia rhoifolia</i> Willd.	50	108	813.150	59	542.455
Cedro vermelho <sup>3</sup>	<i>Cedrela odorata</i> L.	50	44	272.477	15	123.235
Cedrorana <sup>4</sup>	<i>Cedrelinga catenaeformis</i> Ducke	50	231	2,017.859	151	1,650.019
Cuiarana <sup>5</sup>	<i>Terminalia dichotoma</i> G. Mey.	50	300	1,433.679	199	1,134.631
Cumarú <sup>6</sup>	<i>Dipteryx odorata</i> (Aubl.) Willd.	50	230	1,084.961	170	915.286
Fava amargosa <sup>7</sup>	<i>Vatairea paraensis</i> Ducke <i>Enterolobium schomburgkii</i>	50	60	560.812	30	384.290
Fava rosca <sup>8</sup>	(Benth.) Benth.	50	133	576.015	74	392.390
Fava timborana <sup>9</sup>	<i>Pseudopiptadenia psilostachya</i> (Benth.) G.P.Lewis & L.Rico	50	470	2,274.976	317	1,800.010
Fava tucupi <sup>10</sup>	<i>Parkia multijuga</i> Benth.	50	190	916.598	125	709.113
Garapeira <sup>11</sup>	<i>Apuleia moralis</i> Spruce ex Benth. <i>Handroanthus serratifolius</i> (Vahl)	50	123	825.581	85	655.028
Ipê amarelo <sup>12</sup>	Nichols. <i>Mezilaurus itauba</i> (Meisn.) Taub.	50	114	570.515	68	391.956
Itaúba <sup>13</sup>	ex Mez	50	337	2,170.500	237	1,764.814
Jarana <sup>14</sup>	<i>Lecythis lurida</i> (Miers) S.A. Mori	50	1,413	6,725.749	699	4,023.381
Jatobá <sup>15</sup>	<i>Hymenaea courbaril</i> L.	70	678	7,197.455	576	6,599.200
Jutaí mirim <sup>16</sup>	<i>Hymenaea parvifolia</i> Huber	50	314	1,768.412	217	1,398.118
Louro preto <sup>17</sup>	<i>Ocotea baturitensis</i> Vattimo <i>Manilkara huberi</i> (Ducke)	50	220	836.007	155	655.370
Maçaranduba <sup>18</sup>	Chevalier	50	1,384	6,905.416	868	4,993.089
Melancieira <sup>19</sup>	<i>Alexa grandiflora</i> Ducke	50	336	1,289.437	187	892.568
Muiracatiara <sup>20</sup>	<i>Astronium lecointei</i> Ducke	50	346	2,189.567	271	1,910.905
Quaruba <sup>21</sup>	<i>Vochysia maxima</i> Ducke	50	1,535	8,870.185	817	6,085.643
Sapucaia <sup>22</sup>	<i>Lecythis pisonis</i> Cambess.	70	162	870.976	114	682.648
Tatajuba <sup>23</sup>	<i>Bagassa guianensis</i> Aubl.	50	94	579.700	66	452.720
Tauari <sup>24</sup>	<i>Couratari guianensis</i> Aubl. <i>Virola melinonii</i> (R.Benoist)	50	1,059	6,874.440	591	4,681.336
Virola <sup>25</sup>	A.C.Sm.	50	277	906.241	131	513.313
<b>Total</b>		-	<b>10,249</b>	<b>59,432.231</b>	<b>6,267</b>	<b>43,938.909</b>

<sup>1</sup> to <sup>25</sup> - vernacular and scientific name linkage; NT – number of trees; MCD – minimum cutting diameter in centimeters; Vol.- volume in cubic meters. **Source:** Adapted from AOP COOMFLONA 2015.

Tree volume was estimated using the generic equation (1) given in the AOP for APU 9, which was based on the Schumacher and Hall model:

$$\ln V = 8,9525703778108 + 1,88437411839699 \ln \text{DBH} + 0,807002832127167 \ln H \quad (1)$$

where:  $V$  - estimated volume with bark in cubic meters,  $\text{DBH}$  - diameter at breast height in centimeters,  $H$  - commercial height in meters and  $\ln$  - neperian logarithm.

In addition to the trees selected, the AOP also showed the number of trees that could be cut down. These trees can be selected a posteriori if they need to be replaced in the field, as there may be a prominent hollow that makes it impossible to cut down the previously selected tree. The hollow test was carried out in preparation for felling the tree, where the chainsaw operator inserted the saber at the cutting height, discarding those trees with a prominent hollow. In cases where the hollow was small, the tree could still be felled.

The post-exploration report included the volume logged. The effective volume is related to the cubing carried out in the storage yard based on the Smalian equation, taking into account the diameter at the ends of the log and its length, which varied by 5 m on average for each log, as follows:

$$V_{\text{Smalian}} = \frac{g_1 + g_2}{2} L \quad (2)$$

where:  $V_{\text{Smalian}}$  - Smalian volume, in cubic meters;  $g_1$  and  $g_2$  - sectional areas at the ends of the log, in square meters and  $L$  - length of the log in meters.

To analyze logging yield, we first calculated the Logging Yield in Volume ( $IREF_{vol}$ ) and Logging Yield in Number of Trees ( $IREF_{na}$ ) indices by species, both based on the work carried out by [28]. The following expressions were used to calculate  $IREF_{vol}\%$  and  $IREF_{na}\%$ :

$$IREF_{vol}\% = \frac{VEE}{VA} 100 \quad (3)$$

$$IREF_{na}\% = \frac{NAE}{NAA} 100 \quad (3)$$

where:  $VEE$  - Volume logged;  $VA$  - Authorized Volume;  $NAE$  - Number of Trees Logged;  $NAA$  - Number of Trees Authorized.

Based on the volume and number of authorized trees, as well as the effective volume and number of trees felled per species, we applied a t-test with a 95% probability to check that what was planned in the AOP was statistically the same as what was carried out.

In addition, we carried out a more detailed volumetric analysis with the felled trees, in which case we used the paired t-test with a 95% probability to check the difference between the volume estimated by the generic AOP equation and the volume measured in the field, in the hypothesis of attesting to the efficiency of the equation among the species logged.

Finally, we evaluated the commercial height variable estimated visually in the forest inventory with the commercial height based on the sum of the logs of each felled tree, this sum being considered the "real" commercial height of the tree. To ascertain the difference between them and their impact on the volumetric estimate, we applied a paired t-test with a 95% probability. The following expression was used to calculate the difference:

$$Error_{Hc} = Hc_{\text{measured}} - Hc_{\text{estimated}} \quad (5)$$

where:  $Error_{Hc}$  - difference in commercial height;  $Hc_{\text{measured}}$  - commercial height from the sum of the logs per tree;  $Hc_{\text{estimated}}$  - commercial height estimated in the forest inventory.

The data was tabulated and organized in an Excel spreadsheet and the statistics were processed in SAS.

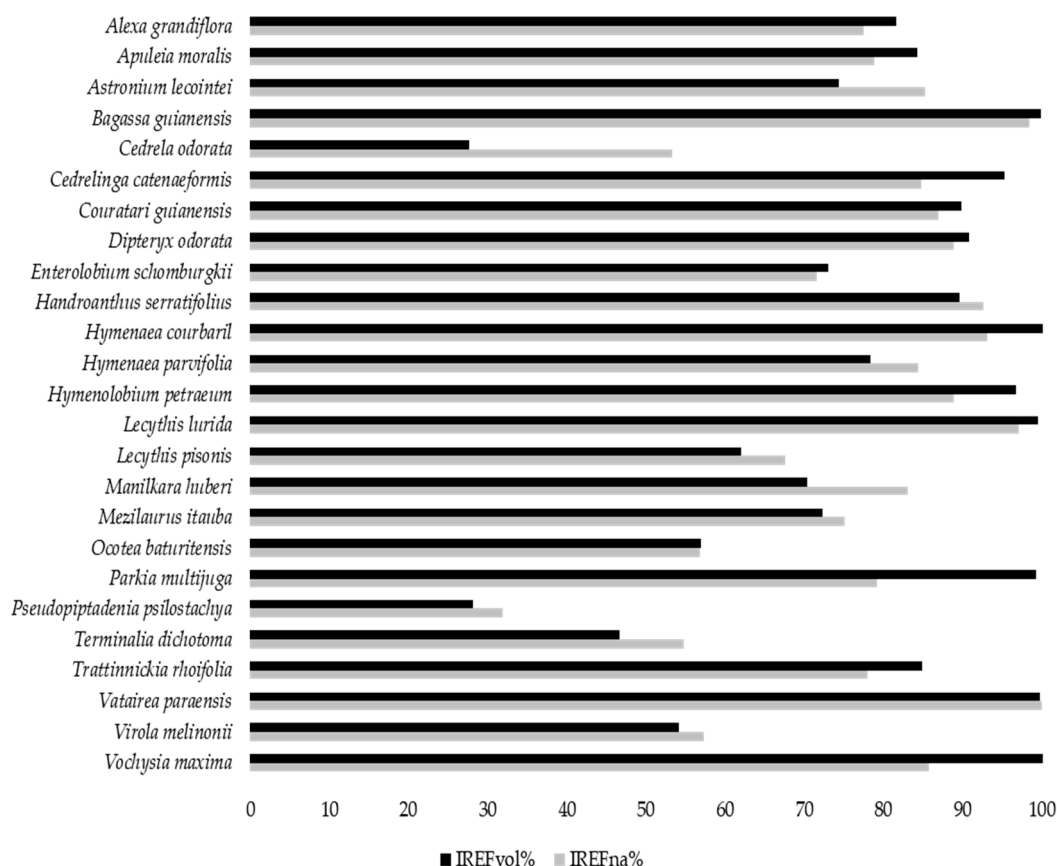
### 3. Results

The results showed that in the forest inventory 26,097 trees with  $\text{DBH} \geq 35$  cm were recorded, distributed among 99 species. The five species with the highest number of trees recorded were:

*Lecythis lurida* (11.4%), *Manilkara huberi* (8.7%), *Vochysia maxima* (7.9%), *Couratari guianensis* (7.0%) and *Carapa guianensis* (5.4%). Of these species, only *Carapa guianensis* was not included in the list for timber harvesting, as in COOMFLONA's Management Plan it is intended for non-timber use.

When planning the AOP, 6,267 trees were previously selected for felling, representing 19.5% of the entire forest inventory. Of the 25 commercial species, *Manilkara huberi*, *Vochysia maxima*, *Lecythis lurida*, *Couratari guianensis* and *Hymenaea courbaril* stood out as representing 56.7% of the number of trees selected for felling and consequently 60% of the estimated volume.

After logging, 5,090 trees were felled over the 1,600 ha, representing an average of 3.2 trees per hectare. The effective volume was 37,331.031 m<sup>3</sup>, which corresponded to 85.0% of the volume estimated during the forest management planning phase (Figure 3).



**Figure 3.** - Forestry yield indices by species. Where IREFna% - Logging Yield Index in number of trees and IREFvol% - Logging Yield Index in volume.

The species that achieved logging values close to the planned volume and number of trees felled were: *Hymenolobium petraeum*<sup>1</sup>, *Cedrelinga catenaeformis*<sup>4</sup>, *Dipteryx odorata*<sup>6</sup>, *Vatairea paraensis*<sup>7</sup>, *Parkia multijuga*<sup>10</sup>, *Handroanthus serratifolius*<sup>12</sup>, *Lecythis lurida*<sup>14</sup>, *Hymenaea courbaril*<sup>15</sup>, *Vochysia maxima*<sup>21</sup>, *Bagassa guianensis*<sup>23</sup> and *Couratari guianensis*<sup>24</sup>. These showed a yield of 85% in volume and 75% of trees felled, respectively. It should also be noted that these species together accounted for 69.3% of the effective volume in the APU area.

The species with the biggest discrepancies between plan and execution were: *Cedrela odorata*<sup>3</sup>, *Terminalia dichotoma*<sup>5</sup> and *Pseudopiptadenia psilostachya*<sup>9</sup>. However, these species together accounted for only 2.9% of the APU's effective volume. The other species accounted for between 55% and 85%, both in terms of volume and number of trees felled.

Considering the statistical analysis using the t-test at 95% probability, a significant difference was found (p-value < 0.05), both for the number of trees authorized and felled, as well as for the volume authorized and the effective volume. In general, there was a difference between the volume

and number of trees planned in the AOP and the number of trees and volume logged in the actual harvest, as shown in the post-exploration report.

Table 2 lists the statistics by species using the paired t-test with 95% probability. In this evaluation, the trees that were felled were analyzed using the volume estimated by the AOP equation, with the volume cubed after logging.

Of the 25 species logged, 10 had statistically similar authorized and cubed volumes using the paired t-test with 5% significance and 15 had different volumes. In general, the generic equation used in AOP 9 tended to underestimate most of the species logged.

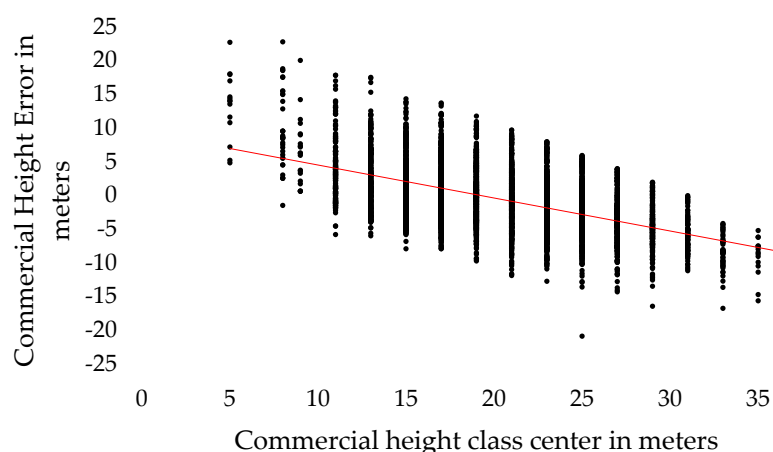
**Table 2.** - Analysis between estimated volume and cubed volume of APU 9 with paired t-test with 95% significance.

Scientific name	NTH	Estimated Volume	Cubed Volume	p-value
<i>Hymenolobium petraeum</i> <sup>1</sup>	40	488.831	567.857	0.00095897*
<i>Trattinnickia rhoifolia</i> <sup>2</sup>	46	403.171	460.110	0.00141063*
<i>Cedrela odorata</i> <sup>3</sup>	8	46.172	34.008	0.00465273*
<i>Cedrelinga catenaeformis</i> <sup>4</sup>	128	1,349.000	1,572.311	0.00001480*
<i>Terminalia dichotoma</i> <sup>5</sup>	109	622.857	529.399	0.00792930*
<i>Dipteryx odorata</i> <sup>6</sup>	151	767.024	831.517	0.00546452*
<i>Vatairea paraensis</i> <sup>7</sup>	33	387.699	383.256	NS
<i>Enterolobium schomburgkii</i> <sup>8</sup>	53	267.477	286.463	NS
<i>Pseudopiptadenia psilostachya</i> <sup>9</sup>	101	508.731	505.334	NS
<i>Parkia multijuga</i> <sup>10</sup>	99	554.459	704.137	0,00000008*
<i>Apuleia moralis</i> <sup>11</sup>	67	504.444	551.658	0.02308588*
<i>Handroanthus serratifolius</i> <sup>12</sup>	63	354.980	351.282	NS
<i>Mezilaurus itauba</i> <sup>13</sup>	178	1,250.539	1,275.293	NS
<i>Lecythis lurida</i> <sup>14</sup>	679	3,749.010	4,003.557	0.00000003*
<i>Hymenaea courbaril</i> <sup>15</sup>	536	5,948.718	6,656.527	3.9685x10 <sup>-20</sup> *
<i>Hymenaea parvifolia</i> <sup>16</sup>	183	1,124.806	1,094.830	NS
<i>Ocotea baturitensis</i> <sup>17</sup>	88	373.437	372.742	NS
<i>Manilkara huberi</i> <sup>18</sup>	721	3,959.130	3,513.711	5.1660x10 <sup>-27</sup> *
<i>Alexa grandiflora</i> <sup>19</sup>	145	672.135	740.277	1.9526x10 <sup>-05</sup> *
<i>Astronium lecointei</i> <sup>20</sup>	231	1,587.729	1,420.082	1.3810x10 <sup>-06</sup> *
<i>Vochysia maxima</i> <sup>21</sup>	700	5,090.283	6,131.901	1.3082x10 <sup>-31</sup> *
<i>Lecythis pisonis</i> <sup>22</sup>	77	431.818	423.620	NS
<i>Bagassa guianensis</i> <sup>23</sup>	65	441.916	452.379	NS
<i>Couratari guianensis</i> <sup>24</sup>	514	3,883.514	4,202.914	3.2466x10 <sup>-08</sup> *
<i>Virola melinonii</i> <sup>25</sup>	75	268.533	277.681	NS
Total	5,090	35,036.414	37,342.846	-

\* significant at 5% significance level; NS - not significant at 5% significance level, NTH – Number of Trees Harvested.

There were differences in the commercial heights of most of the trees. Of the 5,090 trees felled, 2,884 trees (56.7%) had their commercial height underestimated, with an average error of 3.7 meters, which represented 20.7% of the average commercial height. For 2,165 trees (42.5%) there was an overestimation of commercial height with an average error of 3.8 meters, which represented 17.4% in relation to the average commercial height. Figure 4 shows that, in general, inventory estimation errors

did occur, but they tended to be greater at the ends of the height classes, with the smallest being overestimated and the largest underestimated.



**Figure 4.** - Distribution of commercial height errors by commercial height class center.

Estimated commercial heights and commercial heights based on log measurements were statistically different using the paired t-test at 5% significance ( $p$ -value = 0.000012).

#### 4. Discussion

In the APU analyzed, 25 species were on the list for exploitation out of a total of 99 species recorded in the census. This number, however, is in line with the average number of species managed annually by COOMFLONA, which is 24 species, according to a study by [10]. In a study with data from forestry enterprises in Amazonas and Rondônia, one of which is owned by a private company and the other by a concession in a public area, 78 and 139 species were recorded in the census, respectively, and 47 and 38 species were defined for felling [40]. The studies by [16], evaluating five APUs in the Jamari National Forest, found that an average of 79 species ( $\pm 27.3$  species) had been inventoried in the census, of which 37% were only indicated for logging. However, it is important to mention that the management areas were not equal in size and stock.

Considering the typology of Amazonian forests, where the greatest diversity of tree species is found in the tropics [46], it is not difficult to find a significant number of species in the census, the main source for planning the production of a forestry enterprise [13]. However, for harvesting, the selection of species is consequently reduced due to compliance with the cutting intensity restriction, which is limited to  $30 \text{ m}^3 \text{ ha}^{-1}$  and by the consumer market

Although the number of species to be logged was considerably high in the study area, the species *Manilkara huberi*<sup>18</sup>, *Vochysia maxima*<sup>21</sup>, *Lecythis lurida*<sup>14</sup>, *Couratari guianensis*<sup>24</sup> and *Hymenaea courbaril*<sup>15</sup> accounted for 60% of the entire planned volume. Although this was due to the consumer market, since *M. huberi*<sup>18</sup> and *H. courbaril*<sup>15</sup> were among the most exploited species in the state of Pará between 2006 and 2016 [47,48], these species also have a high stock in the Flona Tapajós. However, it is important to evaluate post-exploitation yields, not only in general, but also at the species level, to have a list of the best performers and adjust those with low yields.

The overall logging yield in APU 9 was 80% higher, considering both the number of trees felled and the actual volume logged. In a study comparing the operational efficiency of logging between a private area in Amazonas State and a public one in Rondônia State, [40] recorded an average yield in volume of 84.7% compared to what was planned in both locations.

In the state of Pará, 85 licensed management plans were evaluated [28], which were divided into three different categories (private, public and community), obtaining the following average volume yields of 90.54% (private areas), 61.77% (public concession areas) and 91.19% (community domain areas). Although the average volume yield in public concession areas was below the averages of the

other categories analyzed, there were plans that achieved yields of over 80%, but most were below 60%, justifying the average presented [28]. Analyzing logging yields due to the presence of hollows in a logging area in the Saracá-Taquera National Forest, [35] reported a net volume yield of 78.9%, largely due to the number of trees that were replaced.

In Flona Tapajós, analyzing some studies developed with logging data, it is possible to observe differences in yield. Analyzing data from 36 species logged in the second cycle at the Embrapa experimental site, [49] recorded a 61.84% yield in volume. Evaluating the efficiency of volume estimation in an APU in 2014, [29] found a yield of 84.04%. In an analysis of 10 years (2007 to 2016) of exploration activities at COOMFLONA, [10] found an average yield of 73%. It is important to note that the differences between the volumetric yields were related to different causes, including the presence of hollow trees with a low number of replaceable trees [35,49], technical issues involving felling direction, estimation of commercial height [29].

Although some situations in the field cannot be controlled, making a post-exploration diagnosis is important because we have the possibility of maintaining what was positive, implementing a new methodology or a negative factor to improve decision-making for future planning. For example, in situations where the presence of hollows is an intrinsic characteristic of a species due to the type of soil, this species can be removed from the exploration list for a future plan [34]. In a more generalized situation based on the set of trees, [40] and [12] pointed out that this issue could be improved by identifying hollow trees before planning the harvest, i.e. during the census, but that this is still a challenge to implement, given that the hollow test as it is carried out today is not efficient [34].

Predominantly, the studies on yield that have been presented have made a general analysis considering all species and focusing mainly on the volume variable to define harvest yield, without considering the number of trees felled. In this study, the number of trees was evaluated together with volume to show that the relationship between these variables facilitates the analysis of the tendency to underestimate or overestimate a volumetric equation. In Figure 2, for example, it can be seen that *C. catenaeformis*<sup>4</sup>, *P. multijuga*<sup>10</sup>, and *V. maxima*<sup>21</sup> reached almost 100% of their volume with approximately 80% of the trees selected for felling, i.e. there was an overestimation of the generic AOP equation for these species. In the case of *A. lecointei*<sup>20</sup> and *M. huberi*<sup>18</sup>, there was a tendency to underestimate, since the yield in the number of trees felled was higher than the effective volume. In a study in the Saracá-Taquera National Forest where [35] evaluated the impact of hollowing on volumetric yield, they found the highest net volumetric yield for *Hymenaea excelsum* (99.7%), followed by *Couratari guianensis* (99.6%), *Caryocar villosum* (97.4%) and *Manilkara elata* (76.2%).

In the statistical evaluation of these yields, both in terms of number of trees and volume, the t-test showed a significant difference between what was planned and what was harvested, even though the overall yield percentage was over 80%. This may have been due to the low yields of *C. odorata*<sup>3</sup>, *T. dichotoma*<sup>5</sup> and *P. psilostachya*<sup>9</sup>. The low yields of these species were related to volumetric underestimation of the equation and the high frequency of hollow trees. In a study on the quality of logging, [33] also found a high rate of hollowing in *P. psilostachya*. Species with low yields in the post-exploration analysis should be evaluated carefully when planning the next exploration, leaving them in second priority. On the other hand, species with high yields will be given priority in the next planning, with the condition that maintenance restrictions must be met and the concentration of trees assessed to avoid large clearings in the forest.

Comparison of the generic equation based on the Schumacher and Hall model with the "real" volume obtained using the Smalian equation revealed significant differences in the accuracy of volume estimation for 15 of 25 species. The Schumacher and Hall equation is widely used for fitting natural forest data [17,22,31,37,50–55] and has shown good results and is generally used on a species-by-species basis. In contrast, the Smalian equation, which calculates log-by-log volume based on specific measurements of the log ends and length, provided a more accurate representation of the real volume. This detailed approach considers variations in log dimensions, leading to more accurate volume estimates compared to the generalized estimates from the Schumacher and Hall equation.

The generic equation underestimated the volume, which was already expected according to studies by [12,26,31,56], since the existence of variability in the shape of the stems has a significant

impact on determining the volume exploited. This makes it necessary to use specific equations in future plans, or at least for groups of species with similar phenotypic characteristics, as these reduce the variability between species and improve accuracy [12,30,56,57].

Commercial height is a variable that is difficult to measure in tropical forests, due to the operational difficulty of using hypsometers, leaving eye estimation as the most used option in inventories [42]. In this study we found a difference of over 15% in the heights when compared to field measurements. This result does not differ much from [29], who found an average error of 18.93% in Flona Tapajós and [12] with underestimation errors of 22% in commercial height in a concession forest in the state of Pará. In fact, these differences may interfere with the accuracy of the double entry equation, but without this variable the volumetric adjustments are not good. Therefore, it is necessary to evaluate this variable whenever possible to try to reduce the difference between what is estimated in the field, in accordance with the recommendations already mentioned in the studies by [29,42,58,59], which concluded that trained teams can obtain a good estimate when measuring height, but even so, in larger trees there is a greater tendency for errors. An alternative would be to adjust a hypsometric equation [12], where DBH is used as an independent variable to estimate height, but the heterogeneity of natural forests [60] prevents good results, becoming a limiting factor in obtaining a good fit. It is therefore necessary to find strategies that can be effective for this problem in natural forests.

## 5. Conclusions

The analysis revealed notable discrepancies between the planned and actual volumes for various species. Some species, like *Hymenolobium petraeum* and *Vochysia maxima*, demonstrated high yield efficiency, while others, such as *Cedrela odorata* and *Pseudopiptadenia psilostachya*, showed lower yields due to factors like the presence of hollow trees and underestimation of volumes. There was a significant difference between the number of trees authorized for felling and the actual number felled, as well as between the authorized and effective volumes.

The study also highlighted that 56.7% of the trees had their commercial height underestimated, which affected the accuracy of the volume estimations. The differences in commercial height estimations ranged from an average error of 3.7 meters for underestimated trees to 3.8 meters for overestimated ones, affecting the overall accuracy of the logging plans.

The results suggest a need for more species-specific or phenotypically grouped volumetric equations to improve the accuracy of volume estimations. This would help reduce the discrepancy between planned and actual harvest volumes, particularly for species with significant yield variations.

For future harvest planning, prioritize species with high yield efficiency while carefully evaluating and possibly deprioritizing those with low yields. This approach will help in achieving better overall volumetric yields and ensuring sustainable forest management.

The post-harvest analysis using multiple variables proved to be a more reliable approach for assessing the yield of forest management in Flona Tapajós. Relying solely on timber yields based on volume tends to overlook potential adjustments that could enhance the planning of timber harvesting in the logged area. Therefore, it is crucial to explore statistically viable alternatives or strategies for accurately incorporating commercial height in natural forests.

**Author Contributions:** Conceptualization, R.B.S.R and L.G.M.; preparation of maps and characterization of climatic conditions L.G.M and L.S.S.L; methodology, R.B.S.R. and L.G.M.; investigation, R.B.S.R., L.G.M. and L.S.S.L.; writing - original draft preparation, R.B.S.R.; writing - review and editing, L.G.M., C.T.S.D., A.H.M.O., D.F.C.A and E.J.G.A.; supervision, L.G.M.; project administration, R.B.S.R. and L.G.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** Data are contained within the article and are also available from the corresponding author.

**Acknowledgments:** To Professor Dr. João Ricardo Vasconcellos Gama (*in memoriam*) for initial contributions to this study; To COOMFLONA for providing data for this research; To the Postgraduate Program in Society, Nature and Development at the Federal University of Western Pará.

**Conflicts of Interest:** The authors declare no conflicts of interest.

**Statement:** A preprint has previously been published [Silva Ribeiro et al., 2024]. See first reference about it.

## References

1. Silva Ribeiro, R. B. D.; Lisboa, L. S. S.; Dias, C. T. D. S.; Oliveira, A. H. M.; Araújo, E. J. G. D.; Andrade, D. F. C. D.; Martorano, L. G. Imprecision in Yield Estimates Using Timber Volume in Forest Management Plans in the Amazon. Preprints 2024, 2024071564. <https://doi.org/10.20944/preprints202407.1564.v1>
2. Brasil., 2000. Lei Federal N. 9.985, de 18 de julho de 2000. [https://www.planalto.gov.br/ccivil\\_03/LEIS/L9985.htm](https://www.planalto.gov.br/ccivil_03/LEIS/L9985.htm) (accessed in 05 April 2024).
3. Bacha, C.J.C.; Rodriguez, L.C.E. Profitability and social impacts of reduced impact logging in the Tapajós National Forest, Brazil – A case study. *Ecological Economics* **2007**, *63*, 70-73.
4. Humphries, J.; Holmes, T.P.; Kainer, K.; Koury, C.G.G.; Cruz, E.; Rocha, R.M. Are community-based forest enterprises in the tropics financially viable? Case studies from the Brazilian Amazon. *Ecological Economics* **2012**, *77*, 62-73.
5. Higuchi, N.; Santos, J.; Lima, A.J.N.; Higuchi, F.G.; Silva, R.P.; Souza, C.A.S.; Pinto, F.R.; Teixeira, L.M.; Carneiro, M.C.; Silva, S.R. Perspectivas do manejo florestal sustentável para a Amazônia brasileira. *Hiléia – Rev. Direito Ambient. Amaz.* **2007**, *8*, 78–93.
6. Mazzei, L.; Ruschel, A. Estoque comercial para o segundo ciclo de corte na Floresta Nacional do Tapajós—Área experimental km 67—Embrapa, Anais do II Seminário de Pesquisa Científica da Floresta Nacional do Tapajós; ICMBio: Belém, Brasil, 2014; pp. 161–166.
7. Rodrigues, M.I.; Souza, A.N.; Mazzei, L.; Silva, J.N.M.; Joaquim, M.S.; Pereira, R.S.; Biali, L.J.; Rodriguez, D.R.O.; Lustosa-Junior, I.M. Financial variability of the second cutting of forest management in Tapajós National Forest, Brazil. *Forest Policy and Economics* **2022**, *136*, 102694.
8. Ferreira-Neto, P.S. Projeto Ambé: Manejando a Floresta e Colhendo Conhecimentos, 1ª ed.; Ministério do Meio Ambiente: Brasília, Brasil, 2008; pp. 85.
9. Espada, A.L.V.; Sobrinho, M.V. Logging Community-Based Forest in the Amazon: An Analysis of External Influences, Multi-Partner Governance, and Resilience. *Forests* **2019**, *10*, 461.
10. Andrade, D.F.C.; Braga, C.R.; Silva, J.R.; Chaves, A.R.S. Do mil ao milhão: Estudo de caso do Manejo Florestal Comunitário na Floresta Nacional do Tapajós. *Biodiversidade Brasileira* **2022**, *12*, 5-17.
11. Almeida, B.R.S.; Melo, L.O.; Cruz, G.S.; Melo, M.S.; Santos, M.F.; Nicoletti, M.F.; Ribeiro, R.B.S. Índices de produtividade em uma área de manejo florestal comunitário na Amazônia brasileira. *Adv. For. Sci.* **2021**, *8*(1), 1271-1278.
12. Angelo, H.; Silva, J.C.; Almeida, A.N.; Pompermayer, R.S. Análise estratégica do Manejo Florestal na Amazônia Brasileira. *Floresta* **2014**, *44*(3), 341-348.
13. Cardoso, R.M.; Miguel, E.P.; Souza, H.J.; Souza, A.N.; Nascimento, R.G.M. Wood volume is overestimated in the Brazilian Amazon: Why not use generic volume prediction methods in tropical forest management? *Journal of Environmental Management* **2024**, *350*, 119593.
14. Reis, S.L.; Couto, C.S.; Pinheiro, C.S.; Espada, A.L.V.; Lima, J.A.; Lentini, M.W. Técnicas pré-exploratórias para o planejamento da Exploração de Impacto Reduzido no Manejo Florestal Comunitário e Familiar (Manual Técnico), 1a ed.; Instituto Floresta Tropical: Belém, Brasil, 2013; pp. 148.
15. Brasil., 2009. Resolução Conama N. 406, de 02 de fevereiro de 2009. <https://www.normasbrasil.com.br/norma/?id=110471> (accessed in 01 February 2024).
16. Brasil., 2012. Lei Federal N. 12.651, de 25 de maio de 2012. [https://www.planalto.gov.br/ccivil\\_03/\\_ato2011-2014/2012/lei/112651.htm](https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/112651.htm) (accessed in 01 February 2024).
17. Biazatti, S.C.; Mora, R.; Scoti, M.S.V.; Brito-Júnior, J.F.; Souza, L.A.; Souza, L. Planning and forest production in concession area in the western Amazon. *Brazilian Journal of Development* **2019**, *5*(7), 8938-8953.
18. Romero, F.M.B.; Jacovine, L.A.G.; Ribeiro, S.C.; Torres, C.M.M.E.; Silva, L.F.; Gaspar, R.O.; Rocha, S.J.S.S.; Staudhammer, C.L.; Fearnside, P.M. Allometric equations for volume, biomass and carbon in commercial stems harvested in a managed forest in the southwestern Amazon: A case study. *Forests* **2020**, *11*, 874.
19. Brasil., 2006. Instrução Normativa Ministério do Meio Ambiente N. 5, de 11 de dezembro de 2006. <http://www.diariodasleis.com.br/busca/exibelinck.php?numlink=216088> (accessed in 22 October 2023).
20. Semas – Secretaria de Meio Ambiente e Sustentabilidade do Estado do Pará., 2015. Instrução Normativa N. 5, de 10 de setembro de 2015. <https://www.legisweb.com.br/legislacao/?id=303363> (accessed in 22 October 2023).

21. Brasil., 2015. Instrução Normativa Ministério do Meio Ambiente N. 1, de 12 de fevereiro de 2015. <http://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=13/02/2015&jornal=1&pagina=67&totalArquivos=304> (accessed in 05 April 2024).
22. Thomas, C.; Andrade, C.M.; Schneider, P.R.; Finger, C.A.G. Comparação de equações volumétricas ajustadas com dados de cubagem e análise de tronco. *Ciência Florestal* 2006, 16(3), 319-327.
23. Colpini, C.; Travagin, D.P.; Soares, T.S.; Silva, V.S.M. Determinação do volume, do fator de forma e da porcentagem de casca de árvores individuais em uma Floresta Ombrófila Aberta na região noroeste de Mato Grosso. *Acta Amazonica* 2009, 39(1), 97-104.
24. Leão, F.M.; Nascimento, R.G.M.; Emmert, F.; Santos, G.G.A.; Caldeira, N.A.M.; Miranda, I.S. How many trees are necessary to fit an accurate volume model for the Amazon forest? A site-dependent analysis. *Forest Ecology and Management* 2021, 480, 118652.
25. Silva-Ribeiro, R.B.; Gama, J.R.V.; Souza, A.L.; Leite, H.G.; Soares, C.P.B.; Silva, G.F. Métodos para estimar o volume de fustes e galhos na Floresta Nacional do Tapajós. *Revista Árvore* 2016, 40(1), 81-88.
26. Heinsdijk, D.; Bastos, A.M. Inventários florestais na Amazônia. *Boletim do Serviço Florestal n. 6*, Ministério da Agricultura: Rio de Janeiro, Brasil, 1963; pp. 100.
27. Lanssanova, L.R.; Silva, F.A.; Schons, C.T.; Pereira, A.C.S. Comparação entre diferentes métodos para estimativa volumétrica de espécies comerciais da Amazônia. *BIOFIX Scientific Journal* 2018, 3(1), 109-115.
28. Moskalik, T.; Tymendorf, L.; Saar, J.V.D.; Trzcinski, G. Methods of Wood Volume Determining and Its Implications for Forest Transport. *Sensors* 2022, 22, 6028. <https://doi.org/10.3390/s22166028>.
29. Pereira, D.C.P.; Ruschel, A.R.; Pereira-Junior, R.A.; Silva, U.S.C. The use of volume yield and the number of trees to control forest management operations and combat illegal harvesting. *Journal of Agricultural Science* 2022, 14, 142-156.
30. Gomes, K.M.A.; Silva-Ribeiro, R.B.; Gama, J.R.V.; Andrade, D.F.C. Eficiência na estimativa volumétrica de madeira na Floresta Nacional do Tapajós. *Nativa* 2018, 6(2), 170-176.
31. Akindele, S.O.; LeMay, V.M. Development of tree volume equations for common timber species in the tropical rain forest area of Nigeria. *Forest Ecology and Management* 2006, 226, 41-46.
32. Cysneiros, V.C.; Pelissari, A.L.; Machado, S.A.; Figueiredo-Filho, A.; Souza, L. Modelos genéricos e específicos para estimativa do volume comercial em uma floresta sob concessão na Amazônia. *Scientia Forestalis* 2017, 45(114), 295-304.
33. Nogueira, E.M.; Nelson, B.W. Fearnside, P.M. Volume and biomass of trees in central Amazonia: influence of irregularly shaped and hollow trunks. *Forest Ecology and Management* 2006, 227, 14-21.
34. Ferreira, J.E.S.; Paraense, V.C. Controle de qualidade no processo de derruba em área de manejo florestal comunitário no Projeto de Desenvolvimento Sustentável Virola Jatobá, Anapú – PA. *Observatorio de la economía latinoamericana* 2016, 9p.
35. Medeiros, S.H.S.; Nascimento, C.C.; Oliveira, B.R.; Souza, M.A.S.; Barros, F.B. Diagnosis of hollow trees in an area of effective sustainable forest management in the Amazon forest. *International Journal for Innovation Education and Research* 2021, 9(1), 527-539.
36. Almeida, V.B.; Silva, J.N.M.; Steinbrenner, M.K.A. Impacto da ocorrência de árvores ocas no rendimento da colheita de madeira na Floresta Nacional de Saracá-Taquera, Pará. *Pesq. flor. bras.* 2022, 42, 1-12.
37. Santos, M.F.; Figueiredo-Filho, A.; Gama, J.R.V.; Retslaff, F.A.S.; Costa, D.L. Evaluation of the occurrence of hollow in trees in managed forest in the Eastern Brazilian Amazon. *Forest Science* 2023, 69, 397-414.
38. Silva, I.C.O.; Garlet, J.; Moraes, V.A.; Araújo, E.J.G.; Silva, J.R.O.; Curto, R.A. Equations and form factor by species increase the precision and accuracy for estimating tree volume in the amazon. *Floresta* 2022, 52(2), p. 268-276.
39. He, Mengying, et al. Timber Harvesting and Transportation: Impacts on Wood Quality. *Journal of Forestry Engineering* 2021, 38(4) p. 543-558.
40. Brancalion, P.H.S.; Almeida, D.R.A.; Vidal, E.; Molin, P.G.; Sontag, V.E.; Souza, S.E.X.F.; Schulze, M.D. Fake legal logging in the Brazilian Amazon. *Science Advances* 2018, 4(8), eaat1192.
41. Emmert, F. Combinação de dados de campo e métodos computacionais para o planejamento da exploração florestal na Amazônia. *Doutorado em Ciências Florestais*, Universidade de Brasília, Brasília, 2014.
42. Segura, M.; Kanninen, M. Allometric models for tree volume and total aboveground biomass in a Tropical Humid Forest in Costa Rica. *Biotropica* 2005, 37(1), 2-8.
43. Curto, R.A.; Silva, G.F.; Soares, C.P.B.; Martins, L.T.; David, H.C. Métodos de estimação de altura de árvores em Floresta Estacional Semidecidual. *Floresta* 2013, 45(1), 105-116.
44. Martorano, L.G.; Soares, W.B.; Moraes, J.R.S.C.; Nascimento, W.; Aparecido, L.E.O.; Villa, P.M. Climatology of Air Temperature in Belterra: Thermal Regulation Ecosystem Services Provided by the Tapajós National Forest in the Amazon. *Rev. Bras. Meteorologia* 2021, 36, 327-337.
45. Instituto Chico Mendes de Conservação da Biodiversidade – ICMBio. Plano de Manejo Floresta Nacional do Tapajós – Volume I – Diagnóstico, 1ªed.; Ministério do Meio Ambiente: Brasília, Brasil, 2019; pp. 316.
46. Instituto Brasileiro de Geografia e Estatística – IBGE. Manual técnico da vegetação brasileira, 2ªed.: Ministério do Planejamento, Orçamento e Gestão: Brasília, Brasil, 2012; pp. 272.

47. Cysneiros, V.C.; Mendonça-Júnior, J.O.; Lanza, T.R.; Moraes, J.C.R.; Samor, O.J.M. Espécies madeireiras da Amazônia: riqueza, nomes populares e suas peculiaridades. *Pesq. flor. bras.* 2018, 38, e201801567.
48. Santana, A.C.; Santos, M.A.S.; Santana, A.L.; Yared, A.G. O valor econômico da extração manejada de madeira no Baixo Amazonas, Estado do Pará. *Revista Árvore* 2012, 36(3), 527-536.
49. Conceição, A.K.C.; Lira, A.G.S.; Sousa, L.M.R.; Maestri, M.P.; Aquino, M.G.C. Exploração e valorização em tora de 10 espécies florestais no Baixo Amazonas, Estado do Pará, entre 2006-2016. *Enciclopédia Biosfera* 2020, 17(31), 80-86.
50. Buchmann, H.M. Exploração Florestal e seus impactos em áreas de primeiro e segundo ciclo de corte do manejo florestal na Amazônia Oriental, Brasil. Mestrado em Ciências Florestais, Universidade de Brasília, Brasília, 2016.
51. Rolim, S.G.; Couto, H.T.Z.; Jesus, R.M.; França, J.T. Modelos volumétricos para a Floresta Nacional do Taipé-Aquiri, Serra dos Carajás. *Acta Amazonica* 2006, 36(1), p. 106-114.
52. Thaines, F.; Braz, E.M.; Mattos, P.P.; Thaines, A.A.R. Equações para a estimativa de volume de madeira para a região da bacia do Rio Ituxi, Lábrea, AM. *Pesquisa Florestal Brasileira* 2010, 30(64), p. 283-289.
53. Silva-Ribeiro, R. B.; Gama, J.R.V.; Melo, L.O. Seccionamento para cubagem e escolha de equações de volume para a Floresta Nacional do Tapajós. *Cerne* 2014, 20(4), p. 605-612.
54. Tonini, H.; Borges, R.A. Equação de volume para espécies comerciais em Floresta Ombrófila Densa no Sul de Roraima. *Pesquisa Florestal Brasileira* 2015, 35(82), p. 11-17.
55. Gimenez, B.O.; Danielli, F.E.; Oliveira, C.K.A.; Santos, J.; Higuchi, N. Equações volumétricas para espécies comerciais madeireiras do sul do estado de Roraima. *Scientia Forestalis* 2015, 43(106), p. 291-301.
56. Silva, L.B.D.; Morais, V.A.; Caetano, M.G.; Bernardes, L.F.G.M. Equações para estimativa volumétrica de espécies arbóreas da Amazônia. *Revista de Ciências Agroambientais* 2020, 18(1), 16-26.
57. Santos, M.F.; Gama, J.R.V.; Costa, D.L.; Figueiredo-Filho, A.; Gomes, K.M.A.; Leite, R.S.; Dias, A.N. Generic and specific volumetric equations for individual trees in the Tapajós National Forest, Eastern Amazon. *Revista Brasileira de Ciências Agrárias* 2021, 16(1), e8527.
58. Lima, G.A.; Silva-Ribeiro, R.B.; Gomes, K.M.A.; Ximenes, L.C.; Cruz, G.S. Ajuste volumétrico por grupo e para 24 espécies comerciais em uma área de manejo florestal comunitário. *Rev. Agro. Amb.* 2022, 15(2), 497-505.
59. Bechtold, W.A.; Zarnoch, S.J.; Burkman, W.G. Comparisons of modeled height predictions to ocular height estimates. *South. J. Appl. For.* 1998, 22(4), 216-221.
60. Silva, G.F.; Curto, R.A.; Soares, C.P.B.; Piassi, L.C. Avaliação de métodos de medição de altura em florestas naturais. *Revista Árvore* 2012, 36(2), 341-348.
61. Oliveira, A.H.M.; Freitas, L.J.M.; Magliano, M.M.; Chaves, J.H.; Dias, C.T.S.; Martorano, L.G. Spatio-Temporal Assessment of Heterogeneity by Logging Intensity in a Federal Concession Area in the Brazilian Amazon. *Forests* 2024, 15, 1062.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.