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Evaluation of methods for measuring hollows to estimate the yield of sawnwood in Amazonian species

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ABSTRACT: The presence of hollows in tropical logs compromises volumetric yield and the economic viability of industrial processing. This study evaluated the effectiveness of four hollow-scaling methods for predicting the sawnwood yield of *Pouteria* spp., *Manilkara* spp. and *Astronium* spp. in Santarém, Pará, Brazil. A total of 47 logs were analysed using four methodologies (Smalian, the IBDF Standard, IBDF method, and image analysis). The results indicated significant variation in the incidence of hollows among species, with the highest occurrence in *Manilkara* spp. (40%). Although the analysis of variance did not detect a statistically significant difference among the mean volumes estimated by the methods ($p = 0.189$), the predictive power varied substantially. The image-based method showed the best predictive performance ($R^2 = 0.197$), while the IBDF Standard (1984) overestimated the defect volume and exhibited the lowest predictive power ($R^2 = 0.148$). These findings indicate that hollow volume alone explains only a limited portion of yield variability ($R^2 < 0.20$), highlighting the multifactorial nature of sawing and the influence of other log quality parameters. The results reinforce the need for species-specific yield coefficients to optimize industrial planning in the Amazon.
Keywords: sawnwood yield; wood hollow; log cubing; timber industry; Amazonian timber.

Avaliação de métodos de cubagem de oco para estimativa do rendimento de madeira serrada em espécies amazônicas

RESUMO: A presença de ocos em toras tropicais compromete o rendimento volumétrico e a viabilidade econômica do processamento industrial. Este estudo avaliou a eficácia de quatro métodos de cubagem de oco para prever o rendimento de madeira serrada de *Pouteria* spp. e *Manilkara* spp. e *Astronium* spp. em Santarém, Pará. Foram analisadas 47 toras, comparando-se quatro metodologias (Smalian, Norma IBDF, Stragliotto e análise de imagens). Os resultados indicaram variação significativa na incidência de oco entre as espécies, com maior incidência em *Manilkara* spp. (40%). Embora a análise de variância não tenha detectado diferença estatisticamente significativa entre as médias de volume estimadas pelos métodos ($p = 0{,}189$), a capacidade preditiva variou substancialmente. O método por imagem apresentou o melhor ajuste ($R^2 = 0{,}197$), enquanto a Norma IBDF (1984) superestimou o volume do defeito e apresentou o menor poder preditivo ($R^2 = 0{,}148$). Conclui-se que o volume de oco, isoladamente, explica uma parcela limitada da variabilidade do rendimento ($R^2 < 0{,}20$), evidenciando a natureza multifatorial do desdobro e a influência de outros parâmetros de qualidade da tora. Os resultados reforçam a necessidade de coeficientes de rendimento específicos por espécie para otimizar o planejamento industrial amazônico.
Palavras-chave: rendimento de madeira serrada; oco da madeira; cubagem de toras; indústria madeireira; madeira amazônica.

1. INTRODUCTION

The harvesting and industrial processing of timber are consolidated as the sixth largest source of employment in the industrial sector of Brazil's Northern region (FIEPA, 2022). The high availability of tree species with suitable attributes for solid wood production places the country among the world's largest producers of tropical timber (STRAGLIOTTO et al., 2020).

Log breakdown in the Brazilian Amazon is characterized by low sawnwood yields, resulting in financial losses, increased residue generation, and intensified pressure on forest resources (PARENTE et al., 2024). In the region, yields are often below 25% (Andrade et al., 2023), which is lower than the minimum threshold of 35% established by Brazilian legislation for sawmills that do not have a specific technical study (BRAZIL, 2020). This inefficiency is associated with multiple factors, particularly limited technological resources, the shortage of specialized labor, the high diversity of processed species, and, above all, variability in raw material quality (STRAGLIOTTO et al., 2025).

The productivity of the timber industry can be assessed, among other indicators, by sawnwood yield. This parameter supports decision-making aimed at increasing sawnwood production and, consequently, directly influences the economic profitability of the industry (STRAGLIOTTO et al., 2020).

One of the main factors limiting yield is the presence of internal defects in logs, especially hollows and heart rot, as well as fissures, cracks, and splits in the central portion of the log (DANIELLI et al., 2016). In Amazonian trees, these defects are associated with the high incidence of decomposing organisms. In this context, the hollow area tends to increase as the basal area of the trunk expands, indicating greater susceptibility of larger trees to this type of internal defect (ELEUTÉRIO et al., 2020). As a consequence, the high incidence of hollows in species with high commercial value compromises wood utilization from harvesting to final processing (ALMEIDA et al., 2022).

In the sawmill yard, imprecise hollow assessment represents a direct financial risk, potentially leading to the purchase of log batches with low yield and to inadequate cutting planning (DANIELLI et al., 2016). Although it is a known challenge, there are still no standardized methodologies to rapidly and accurately quantify hollow volume in the field (SOGE et al., 2021). Scaling models based on classical geometries simplify the trunk shape, representing it by figures such as the cone and the neiloid, which limits accuracy in the presence of real variations in form. These simplifications result in volumetric deviations, since the Smalian method overestimates and the Huber method underestimates the real volume (DE LEÓN; URANGA-VALENCIA, 2013). This behavior indicates that, when adapted for hollow measurement, these methods maintain a tendency toward errors in the final volumetry, similarly to what occurs in conventional scaling. There is, therefore, a gap in the comparison of these practical methods regarding their predictive power for final yield.

In this context, predictive yield models emerge as a strategic tool, capable of estimating the volume of sawn timber from a batch of logs and, thus, guiding pricing and production decisions (LIMA et al., 2019). The effectiveness of these models, however, depends critically on the accuracy of input variables, such as diameter, taper, and, above all, defect volume. Inadequate quantification of hollows compromises the predictions and, ultimately, the economic viability of processing (SANTOS et al., 2020).

To fill this gap, this study aims to evaluate four distinct hollow scaling methods and develop predictive models that correlate hollow volume with sawn timber yield, aiming to strengthen timber production estimates and optimize industrial planning.

2. MATERIAL AND METHODS

The study was conducted in the municipality of Santarém, in the western region of the state of Pará, in Northern Brazil. The region has a hot and humid climate, classified as Am according to Köppen, with mean annual temperatures between 25°C and 26°C (IBGE, 2023). The predominant vegetation consists of equatorial terra firme forests, and the mean annual precipitation is approximately 2,000 mm (IBGE, 2023).

Three timber species were analyzed, totaling 47 wood logs, randomly selected in the yard of a local sawmill and identified at the genus level based on the log register sheet. The sampling comprised 13 logs of guajará-bolacha (*Pouteria* spp.), 15 of maçaranduba (*Manilkara* spp.), and 19 of muiracatiara (*Astronium* spp.).

2.1. Determination of hollow volume

For the quantification of hollow volume, four distinct methodologies were evaluated. In all cases, the same procedure was adopted to determine the length of the hollow. When the hollow simultaneously reached both ends of the log, the total length of the log was considered. In cases where the hollow did not extend through both ends, a partial length was considered, determined by inserting a rod into the interior of the log, and the length was measured with a measuring tape.

The first method (Hollow 1) was based on the Smalian equation (Equation 1), which considers the mean of the cross-sectional areas of the defect at the ends of the log (Figure 1).

$$\mathrm{V\ (Hollow\ 1)} = \left(\frac{\left(d1^2 \times \frac{\pi}{4}\right) + \left(d2^2 \times \frac{\pi}{4}\right)}{2}\right) \times L \qquad (01)$$

where: V (Hollow 1) – Volume of Hollow 1 in m³; d1 and d2 – mean diameter at the ends of the hollow in the log, in meters; L – length of the hollow, in meters.

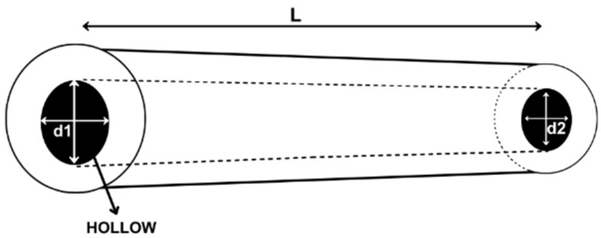

Figure 1. Schematic representation of the Hollow 1 method in a log, considering the mean of the diameters at each end (d1 and d2) along its length (L).
Figura 1. Representação esquemática do método Oco 1 em tora, considerando a média dos diâmetros em cada extremidade (d1 e d2) ao longo do comprimento (L).

The second method (Hollow 2) followed the equation proposed by the standard of the former Brazilian Institute for Forest Development (IBDF, 1984) (Equation 2), which uses the largest hollow diameter for the calculation (Figure 2).

$$\mathrm{V\ (Hollow\ 2)} = d^2 \times L \qquad (02)$$

where: V (Hollow 2) – Volume of Hollow 2 in m³; d – largest diameter at the ends of the hollow in the log, in meters; L – length of the hollow, in meters.

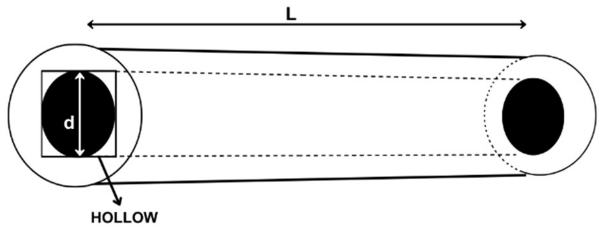

Figure 2. Schematic representation of the Hollow 2 applied to a log, based on the maximum end diameter (*d*) across its length (L).
Figura 2. Representação esquemática do método Oco 2 em tora, considerando o maior diâmetro da extremidade (d) ao longo do seu comprimento (L).

The third method (Hollow 3) employed a methodology developed by Stragliotto et al. (2025), which consists of an adaptation of the IBDF standard, incorporating both the largest and the smallest hollow diameters (Figure 3).

$$\text{V (Hollow 3)} = (\text{d1} \times \text{d2}) \times \text{L} \qquad (03)$$

where: V (Hollow 3) – Volume of Hollow 3 in m³; d1 – largest diameter at the ends of the hollow in the log, in meters; d2 – smallest diameter at the ends of the hollow in the log, in meters; L – length of the hollow, in meters.

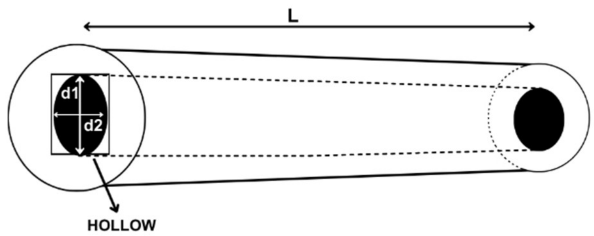

Figure 3. Schematic representation of the Hollow 3 method applied to a log, based on the maximum (d1) and minimum (d2) diameters at the end across its length (L).
Figura 3. Representação esquemática do método Oco 3 em tora, considerando os maiores (d1) e menores (d2) diâmetros da extremidade ao longo de seu comprimento (L).

The fourth method (Hollow 4), based on image analysis, was used to obtain a high-precision measurement of the defect area. The ends of the logs were photographed, and the images were processed using the software CorelDRAW® and Inkscape to quantify the hollow area (Figure 4) accurately.

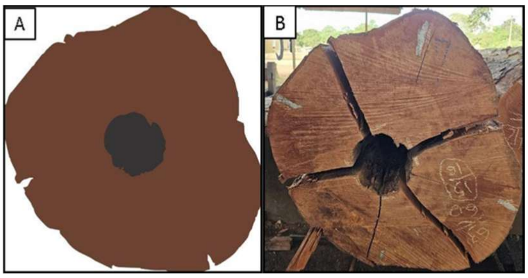

Figure 4. Image-based method – hollow segmentation by color highlighting: (A) processed image with the hollow area highlighted; (B) original photograph of the log end showing the hollow.
Figura 4. Método por imagem - Processo de destaque do oco por cor: A- Imagem editada para destacar o oco; B- Foto da extremidade da tora com oco.

2.2 Determination of sawnwood yield

Initially, the volume of the logs was determined using the Smalian equation. Subsequently, the selected logs were processed in a local sawmill using the tangential sawing system, chosen by the operator. The breakdown process began with cutting the logs on a single vertical band saw, a stage in which the slabs were removed. Subsequently, still using the vertical band saw, successive cuts were performed to obtain sawn pieces of different dimensions.

Subsequently, the pieces passed through a circular saw to adjust the width and, later, through a crosscut saw to standardize the length. The dimensions of the sawn pieces were measured with a caliper to determine thickness and with a measuring tape to measure width and length, allowing the calculation of the individual volume of each piece. The total volume of sawn timber per log was obtained by summing the volumes of the corresponding individual pieces. The sawnwood yield, expressed as a percentage, was calculated as the ratio between the total volume of sawnwood obtained after breakdown and the log volume, according to the methodology described by Stragliotto et al. (2025).

2.3. Statistical analysis

The collected data were subjected to descriptive statistics to calculate the mean and the standard error of the hollow percentage for each species and scaling method. To verify significant differences among the means estimated by the four methodologies, analysis of variance (ANOVA) was applied, along with tests for normality (Shapiro-Wilk) and homogeneity of variances (Levene).

The relationship between hollow percentage (independent variable) and sawnwood yield (dependent variable) was evaluated using Pearson's correlation analysis (r) and simple linear regression. The ability of each method to estimate sawn timber yield was quantified by the coefficient of determination (R^2) of the linear regression models and by the standard error of the estimate. For all inferential tests, a significance level of 5% ($p < 0.05$) was adopted.

3. RESULTS

3.1 Incidence and Hollow Scaling Methodologies

The analysis of the 47 logs indicated that hollow incidence is a species-dependent variable. The species *Manilkara* spp. (maçaranduba) was the most affected, with 40% of the samples compromised, followed by *Astronium* spp. (muiracatiara) with 21.1% and *Pouteria* spp. (guajará-bolacha) with 7.69%.

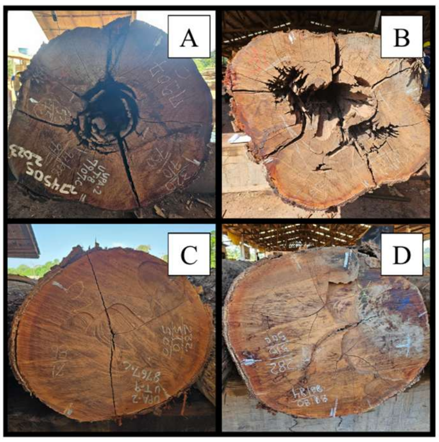

Figure 5. Maçaranduba (*Manilkara* spp.) logs showing the presence (A and B) and absence (C and D) of hollows.
Figura 5. Toras de maçaranduba com oco presente (A e B) e ausente (C e D).

The volumetric estimates of the defect varied according to the method employed (Table 1). The method based on the IBDF Standard (1984) (Hollow 2) presented the highest mean hollow volumes. The image-based determination method presented the lowest mean values and the lowest standard deviation.

Table 1. Descriptive statistics of hollow percentage for the different hollow-scaling methods evaluated.
Tabela 1. Estatística descritiva do percentual de oco nos diferentes métodos de cubagem avaliados.

Hollow	Species	Mean	Standard
Hollow 1	Guajará	1.79	NaN
	Maçaranduba	16.16	12.11
	Muiracatiara	8.08	5.37
Hollow 2	Guajará	2.28	NaN
	Maçaranduba	31.48	26.63
	Muiracatiara	16.34	8.94
Hollow 3	Guajará	2.28	NaN
	Maçaranduba	19.78	16.76
	Muiracatiara	9.16	7.49
Hollow 4	Guajará	1.25	NaN
	Maçaranduba	15.05	10.81
	Muiracatiara	5.64	3.59

Despite the nominal variations, the analysis of variance (ANOVA) did not detect statistically significant differences among the means of the four methodologies ($p = 0.189$).

3.2. Predictive Capacity of the Methods

The simple linear regression models confirmed hollow percentage as a significant predictor of the reduction in sawnwood yield ($p < 0.01$) (Table 2).

When comparing the scaling methods, it was observed that the image-based method (Hollow 4) presented the highest correlation coefficient ($r = -0.444$) and the highest predictive performance ($R^2 = 0.197$), followed by Hollow 1 ($R^2 = 0.175$). Both methods (Hollow 1 and Hollow 4) demonstrated greater sensitivity to the presence of internal defects, with yield reduction rates higher than 0.78% per unit of hollow volume. In contrast, the Hollow 3 method presented the lowest predictive performance among the tested models ($R^2 = 0.139$), indicating that its measurement captures a smaller portion of the variability in the breakdown process. On the other hand, the method recommended by the IBDF Standard (1984) (Hollow 2), although presenting a lower R^2 (0.148), resulted in the lowest standard error of the estimate (0.1196).

3.3 Sawnwood Yield by Species

The analyses of volumetric sawnwood yield revealed significant variations among the species. The Shapiro-Wilk ($W = 0.976$; $p = 0.444$) and Levene ($F = 1.51$; $p = 0.231$) tests confirmed the normality and homoscedasticity of the data, respectively, thus confirming the viability of applying parametric statistical analysis.

The Tukey test showed that muiracatiara statistically outperformed maçaranduba ($p = 0.009$), while guajará-bolacha presented intermediate behavior, with no significant difference in relation to the other groups ($p > 0.05$).

Table 2. Correlation and simple linear regression analysis of hollow percentages obtained through four distinct methods for the three evaluated species.
Tabela 2. Análise de correlação e regressão linear simples entre o percentual de oco, medido por quatro métodos distintos para as três espécies avaliadas

Scaling method	r	R²	Regression equation	p-value	Standard error(Syx)
Hollow 1	-0.418	0.175	SY = 51.21- 0.78 * Hollow	0.003**	0.2387
Hollow 2	-0.385	0.148	SY = 50.71- 0.33 * Hollow	0.008**	0.1196
Hollow 3	-0.372	0.139	SY = 50.94- 0.43 * Hollow	0.007**	0.1897
Hollow 4	-0.444	0.197	SY = 51.87- 0.87 * Hollow	0.002**	0.2629

where: (**) – indicates statistical significance at the level of $p < 0.01$; r – Correlation coefficient; R^2 – Coefficient of determination; SY – Sawnwood yield; Hollow – hollow percentage.
em que: (**) - indica significância estatística ao nível de $p < 0{,}01$; r - coeficiente de correlação; R^2 - coeficiente de determinação; SY – rendimento em madeira serrada; Oco – porcentagem de oco.

Table 3. Mean sawnwood yield, standard deviation, and coefficient of variation for three Amazonian species.
Tabela 3: Rendimento médio em madeira serrada, desvio padrão e coeficiente de variação de três espécies amazônicas.

Species	Mean (%)	Standard Deviation	CV (%)
Muiracatiara	54.3 a	11.34	20,89
Guajará	50.0 a b	8.61	17,81
Maçaranduba	41.9 b	13.68	32,63

Different letters indicate statistical differences among the means.
Letras diferentes indicam diferenças estatísticas entre as médias

4. DISCUSSION

4.1 Incidence and Characterization of Hollows by Species

Differences in hollow incidence were observed among the evaluated species, confirming the effect of the species factor on the occurrence of this structural defect. Maçaranduba (*Manilkara* spp.) presented the highest incidence of hollows among the evaluated species, reaching 40% of the analyzed logs, corroborating the results of Almeida et al. (2022), who reported a high occurrence of hollows in this genus. This occurrence may be associated both with the high longevity of the trees and with susceptibility to internal degradation processes resulting from the prolonged action of xylophagous fungi and decomposing organisms, especially in individuals of greater physiological age.

The species muiracatiara (*Astronium* spp.) presented a hollow incidence of 21.1% of the evaluated logs, a value higher than that reported by Almeida et al. (2022) for the same species. This discrepancy may be related to specific environmental factors in the area of origin of the study material, especially edaphic conditions, since soils with higher moisture content and lower drainage favor the activity of decay fungi and xylophagous insects, intensifying the formation of internal defects in wood. Additionally, microenvironmental variations, disturbance history, and management practices may contribute to regional differences in the incidence of this type of defect.

The literature indicates that the probability of hollow occurrence is strongly associated with species and tree diameter, being more frequent in individuals with DBH (diameter at 1.30 m above the ground) greater than 100 cm (Santos et al., 2025). However, the results of the present study partially diverge from this trend, since the hollow trees presented DBH ranging from 46 to 98 cm, indicating that hollow formation may also occur in individuals with smaller diameters. These observations suggest that, in addition to DBH, other factors, such as age, history of mechanical injuries, environmental stresses, and genetic susceptibility, may influence the occurrence of hollows.

The comparative analysis of hollow quantification methodologies revealed relevant systematic differences among the evaluated methods. The methodology recommended by the IBDF Standard (1984) showed a tendency to overestimate the hollow percentage, since it is based exclusively on the largest diameter observed in the cross-section, implicitly assuming a regular and constant geometry along the length of the stem. This simplification disregards both the morphological irregularity of the hollow and its longitudinal variation, resulting in conservative or distorted estimates of the volume effectively compromised. This may generate significant economic impacts, with underestimation of the potential utilization of the log, premature disposal of raw material with technical viability, and artificial reduction of the estimated sawnwood yield.

The methodology, adapted from Stragliotto et al. (2025), although based on the IBDF (1984) method, by considering the largest and the smallest hollow diameters, avoided overestimation of the volume. Even so, it is an approach based on simplified geometric models that assume regular and continuous forms along the estimated length of the hollow. Although better performance is observed, its applicability remains conditioned to the assumption of cavity homogeneity, which is rarely verified in tropical wood, especially in species with a history of internal degradation associated with fungi, insects, or mechanical injuries.

In contrast, the image-based estimation method presented the lowest mean values and the smallest standard deviation, indicating greater precision in the estimate, since it maps the irregular perimeter of the hollow more accurately than measurements based on mean diameters, approaching the anatomical reality of the log. This superior performance results from the method's ability to more faithfully map the irregular perimeter of the hollow, thereby approximating the anatomical reality of the log rather than assuming ideal geometries. From a technical standpoint, the bias associated with geometric simplification decreases, and the estimates become more compatible with the real conditions of the material, which is particularly relevant for industrial processes that require greater predictability of yield and quality.

The application of the Smalian formula, in turn, assumes that the areas of the internal cross sections adequately represent the actual shape of the cavity along the length of the log. This assumption tends to be more robust when the hollow presents an approximately cylindrical geometry. Still, it may lose accuracy in situations of high internal irregularity, a condition frequently observed in tropical species. Even so, the Smalian method is widely used as a volumetric reference, as it presents good performance when compared with the actual volumes obtained from felled trees, being employed as a base method for evaluating the bias of other methodologies (LEÃO et al., 2020).

The proximity observed between the results of the image-based method and the values estimated by Smalian suggests that both approaches are able to capture, to a greater extent, the effective geometric variation of the hollow along the log, unlike methods based on simplified geometric assumptions, such as conical, square, or rectangular forms.

Despite the differences observed among the method means, the analysis of variance (ANOVA) indicated the absence of statistically significant differences ($p = 0.189$). However, a high intrinsic variability of hollow data among the logs was observed, reflected by a wide standard deviation, which masked systematic differences among the methodologies. This result is expected in studies involving internal defects in tropical wood, where structural heterogeneity is an inherent characteristic of the material.

From an operational and productive perspective, the occurrence of hollow trees may affect the volumetric and financial yield of forest harvesting, being a relevant factor in production planning and in compensation through the replacement of trees (ALMEIDA et al., 2022). Hollow trunks and irregular forms introduce biases in traditional volume estimates, resulting in substantial overestimations of the stock of usable timber (NOGUEIRA et al., 2006). On the other hand, the underestimation of hollow volume may negatively compromise revenue forecasts and the efficiency of industrial planning. Thus, the choice of the estimation method should consider not only statistical accuracy criteria but also the economic consequences associated with estimation error, especially in operational decision-making contexts.

4.2. Predictive Capacity of the Methods

The statistical significance observed for all methods ($p < 0.01$) confirms that the presence of hollows is a determining factor in the reduction of sawnwood yield. However, the variation in predictive capacity among the methods highlights the complexity of measuring this defect.

The image-based method (Hollow 4) stood out for presenting greater sensitivity ($b = -0.87$; Table 2), suggesting that the use of digital tools allows a more faithful representation of the internal morphology of the log. However, its practical application may be limited by the complexity of data collection and measurement. The Hollow 1 method, based on the Smalian principle, presents itself as a viable intermediate alternative ($R^2 = 0.175$), combining a rigorous scaling standard, accepted in the forest science literature, with a simpler execution than the image-based method.

The tendency of the Hollow 2 method (IBDF, 1984) to overestimate results from its geometric simplification, which assumes a constant square base along the stem; thus, this model may induce the premature disposal of viable raw material, underestimating the economic potential of the batch. Although the predictive model shows high consistency with respect to data repeatability, attested by the lowest standard error of the estimate ($S_{yx} = 0.1196$), it demonstrates a tendency to underestimate the real impact of the defect on yield ($b = -0.33$). In contrast, the Hollow 3 method presented the lowest predictive performance among the tested models ($R^2 = 0.139$), indicating that its measurement captures a smaller portion of the variability in the breakdown process.

In addition, the low coefficient of determination ($R^2 < 20\%$) confirms that yield is a multifactorial variable. The quality of logs in the Amazon is defined by a set of parameters, such as taper, flattening, curvature, buttresses, and cracks, which interact with each other to determine volumetric utilization (STRAGLIOTTO et al., 2025). Thus, hollow volume influences yield only partially, being strongly modulated by its shape and position within the log, achieving greater predictability only when combined with other defects (MEDEIROS et al., 2020). Moreover, in studies with *Manilkara* spp., Danielli et al. (2016) reported that the central portion of non-hollow logs was frequently discarded due to the occurrence of cracks and splits, which equalized the yield between logs with and without hollows.

In this sense, estimation based solely on hollow volume is limited. The incorporation of additional variables, such as small-end diameter and log length, as suggested by Danielli et al. (2016) and Muñoz et al. (2013), tends to significantly improve the performance of regression models.

4.3 Sawnwood Yield by Species

The yield indices presented in Table 3 partially diverge from the patterns reported by Parente et al. (2024) for *Astronium* spp. (muiracatiara), the yields were similar, while for *Pouteria* spp. (guajará-bolacha), slightly lower values were observed. In contrast, *Manilkara* spp. (maçaranduba) presented considerably lower yield in the present study, highlighting greater sensitivity of this species to raw material quality and processing conditions.

The high standard deviation observed for the species maçaranduba can largely be explained by the high incidence of hollows in the evaluated logs, which reached 40% of the samples, reflecting greater heterogeneity in raw material quality and impacting sawnwood yield. In addition, the high density and low workability of maçaranduba result in greater losses during log breakdown, as observed by Parente et al. (2024). Although the mean yield value obtained in this study was lower than that observed for other species, Andrade et al. (2023) reported even lower yields for *Manilkara* spp. (23.4%), attributing this variation mainly to operational differences, log quality, and the presence of defects. In Amazonian species, reduced yield values have also been associated with the direction of production toward the export market, where stricter requirements for sawn timber quality exist, with restrictions on pieces with small defects and sapwood, as observed by Stragliotto et al. (2025), which results in lower yield.

Although approximately 20% of the muiracatiara logs presented hollow incidence, this species showed the highest sawnwood yield in this study. This result indicates that the presence of hollows, when analyzed in isolation, is not sufficient to explain sawnwood yield performance. The higher yield observed may be associated with the better overall quality of muiracatiara logs, which present a lower occurrence of structural defects (Aguiar et al., 2022), as evidenced in this study by the lower incidence of cracks and the greater straightness of the stems. These factors favor utilization during breakdown and reduce losses throughout industrial processing.

Although the breakdown was carried out in a timber industry using conventional systems, without cut optimization and without the use of modern equipment, the sawnwood yields obtained for all evaluated species exceeded the reference value of 35% established by CONAMA Resolution No. 411/2009, amended by CONAMA Resolution No. 497/2020, indicating that, even under traditional operational conditions, certain Amazonian species present high potential for industrial utilization. The variation in yield observed among the species evaluated in this study and in the literature (Andrade et al., 2023; Parente et al., 2024; Stragliotto et al., 2025) reinforces the inadequacy of using generic coefficients in official control systems, such as the Documento de Origem Florestal (DOF), and highlights the need to determine volumetric yield coefficients specific to genus and region (ANDRADE et al., 2023; PARENTE et al., 2024).

5. CONCLUSIONS

The Smalian method (Hollow 1) proved to be the most suitable for field application and was the best predictor of sawnwood yield among the evaluated field techniques ($R^2 = 0.175$).

The methodology of the IBDF Standard (1984) (Hollow 2) significantly overestimated hollow volume compared with the other methods and proved to be the least accurate predictor of yield. This result suggests that the assumption of considering a perfect square is flawed and may lead to incorrect management decisions.

Hollow volume shows a negative correlation with sawnwood yield. However, its low explanatory power ($R^2 < 0.20$) indicates that yield also depends on other variables and may be influenced by log quality variables and processing conditions.

The lower yield of maçaranduba may be partially explained by the higher incidence of hollow logs (40%), which highlights the influence of raw material quality on sawnwood utilization.

The differences observed in hollow incidence and sawnwood yield among the species demonstrate the inadequacy of adopting generic yield coefficients. Specific studies by species and region are recommended to support public policies and control systems with technical parameters more aligned with the Amazonian reality.

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