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ORIGINAL ARTICLE

Volumetric yield coefficient: the key to regulating virtual credits for Amazon wood

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ABSTRACT

In Brazil, all transport and storage of native forest products and by-products must be registered within the DOF (Document of Forestry Origin) system. This computerized platform exists to support control agencies in reducing the sale of forest products obtained illegally. However, this tool still shows only modest results in fulfilling its objectives, since gaps in the system allow illegal wood to be acquired and enter the system as legal wood. The objective of this study was to test whether the volumetric yield coefficient (CRV) of a sawmill on an industrial scale corresponds to the 35% established by Brazilian legislation. The focus was directed at a loophole that allows the accumulation of virtual credits in the DOF system by turning logs into lumber. For this purpose, we estimated the sawmill's CRV and mean percentage yield of 19 commercial species used by a timber company in the Brazilian Amazon with a sample size of 90 logs. The estimated CRV was 24.6 ± 2.4, showing 9.9% uncertainty. The mean CRV differed highly significantly ($p < 0.001$) from that proposed by the DOF, with a 10.35% difference. Based on these results, the difference between the observed yield and that proposed by the legislation can generate the accumulation of virtual log credits. With this accumulation, managers encounter difficulties in acquiring new logging permits and, consequently, do not meet the actual demand for logs to the sawmill's capacity.

KEYWORDS: forest origin document, sawn wood, residue, forest management

Coeficiente de rendimento volumétrico: uma peça-chave para disciplinar créditos virtuais de madeira amazônica

RESUMO

No Brasil, todo transporte e armazenamento de produtos e subprodutos florestais nativos deve ser registrado no sistema DOF (Documento de Origem Florestal). Essa plataforma informatizada existe para apoiar agências de controle na redução da venda de produtos florestais obtidos ilegalmente. No entanto, essa ferramenta ainda apresenta resultados modestos no cumprimento de seus objetivos, uma vez que lacunas no sistema permitem que madeira ilegal adquira caráter legal. O objetivo desse estudo foi testar se o coeficiente de rendimento volumétrico (CRV) de uma serraria em escala empresarial corresponde aos 35% estabelecidos pela legislação brasileira. O foco foi direcionado para uma brecha que permite o acúmulo de créditos virtuais no sistema DOF, por meio da transformação de toras em material serrado. Para tanto, estimamos o CRV da serraria e os rendimentos percentuais médios de 19 espécies comercializadas por uma empresa de base florestal na Amazônia brasileira, com um esforço amostral de 90 toras. O CRV estimado foi de 24,6 ± 2,4, mostrando incerteza de 9,9%. O CRV médio diferiu altamente significativamente ($p < 0{,}001$) do proposto pelo DOF, com uma diferença de 10,35%. Com base nesses resultados, a diferença entre o rendimento observado e o proposto pela legislação pode gerar um acúmulo de créditos em toras virtuais. Com esse acúmulo, os gestores enfrentam dificuldades para adquirir novas licenças de exploração e, consequentemente, não atendem à real demanda por toras da capacidade instalada de sua serraria.

PALAVRAS-CHAVE: documento de origem florestal, madeira serrada, resíduo, manejo florestal

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INTRODUCTION

The Brazilian Amazon is one of the main producers of tropical roundwood in the world. The production between 2019 and 2020 was over 29.2 million m³, making it the fourth largest global producer, after Indonesia, India and Vietnam, with respective productions over 80, 48 and 36 million m³ of logs in the same period (ITTO 2021). Southeast Asian countries have been the main producers and exporters, but their dominance of the international market is threatened as their areas of mature forests are rapidly and intensively being logged and deforested, signaling a collapse of their timber resreves in the near future (Higuchi *et al*. 2006; Shearman *et al*. 2012; ITTO 2021). In this scenario, the redirection of international demand for forest products and services to the Amazon can become an opportunity for sustainable development.

The Amazon has enormous timber potential, but a variety of obstacles exist for the implementation of a sustainable forest management program. One of these obstacles involves the low recovery of volume by sawmills, which makes it difficult to maximize the volume potential of logs extracted from the forest, and which constitutes an important barrier to regional development of sustainable wood management (Clement and Higuchi 2006). Forest management and wood-processing methods must be technologically aligned to improve the utilization of raw materials along the entire production chain.

In an effort to increase control over the flow of forest raw materials and to curb illegal marketing, Brazil has adopted a computerized system to monitor and track the origin of timber products and document their sale. The system is based on the Document of Forest Origin (DOF). According to Normative Instruction # 9/2016 of the federal environmental oversight agency IBAMA, the DOF is a key component of the National System for the Control of the Origin of Forest Products (Sinaflor), with the designated purpose of controlling the origin of wood, charcoal and other wood-based forest products, in addition to integrating the respective data from different national stakeholders (MMA 2016).

Any conversion of forest products or by-products via industrial processing must be reported through Sinaflor, following the guidelines laid out in Resolution # 497/2020 (CONAMA 2020) of the National Council for the Environment (CONAMA), a deliberative organ of the Brazilian Ministry of the Environment (MMA). This resolution amended the annex to CONAMA Resolution # 411/2009 (CONAMA 2009) and sets the volumetric yield coefficient (CRV, from the Portuguese *coeficiente de rendimento volumétrico*) for sawn wood at 35%. CRV is the index that establishes how much of the volume of round wood is transformed into sawn wood, without considering the residue or the use.

Several variables influence sawmill performance, including the characteristics of the timber species being processed, the cutting machinery used, and the diameter and quality of the logs (Marchesan *et al*. 2014; Danielli *et al*. 2016; Mendonza *et al*. 2017; Romero *et al.* 2020). Together, these factors make it difficult to calculate an accurate generalized ratio of original volume of logs entering the system, and the final volume of processed wood that leaves it. Losses during tropical wood processing are high, and have challenged the timber industry for decades. Also, sawmills using advanced technology processing are not yet common in the Amazon. However, the current regulations allow for an increase in the industry's CRV, if technical improvements provide viable means of attaining higher yields. This mechanism is intended to reduce the possibility of financial losses and prevent wood from the most commonly used species from entering the market illegally.

The processed volume of wood is calculated based on the volume of available logs and a fixed volumetric yield factor, and then authorized for sale. However, in practice, losses during processing in Amazonian sawmills may be higher than the coefficient established by the current legistlation. This difference between the low actual yield of industrial sawmills and the overestimated coefficient proposed by the legislation can generate an accumulation of virtual log credits in the DOF system, enabling an illegal timber trade that damages the forestry sector as a whole and compromises the accuracy of production statistics (Adeodato *et al.* 2011).

Here we present a case study with the largest sawmill in the state of Amazonas, northern Brazil, which is supplied by timber from its own forests under a system of sustainable forest management. We measured logs from 19 commercial species harvested during the 2015/2016 logging season to determine the actual average CRV of the sawmill from the log input and the output of processed lumber and compared it with the CRV defined by CONAMA Resolution # 497/2020.

MATERIAL AND METHODS

The study was carried out at the sawmill of the timber company Mil Madeiras Preciosas Ltd. (03º03'08.14"S, 58º43.1'17.68"W), located 227 km east of Manaus, the capital city of the state of Amazonas, in the municipality of Itacoatiara. The sawmill is supplied by logs from a total area of 202,104 ha of tropical lowland forest located throughout the municipalities of Itacoatiara, Silves and Itapiranga, owned by the company and sustainably managed. The sawmill has five processing lines, with a total log procesing capacity of more than 100 m³ day^{-1}. End products are either finished or semi-finished, with most products destined for the international market. The wood waste (i.e., residues) generated by the sawmill are used as raw material for generating electricity in a thermoelectric plant in Itacoatiara.

The primary sawing of logs is carried out with a log conveyor chain, main band saw attached to a motor, a loader and a hydraulic log turner. At this stage, cuts are made tangentially to the growth rings, removing the slab, the first boards and the cants, which are forwarded to secondary sawing. The secondary processing of the cants is carried out with an automatic circular saw, which reduces the size of the cants, conveyor chains for lumber and mill trim, a band saw, which determines lumber dimensions with greater refinement, main and auxiliary circular chop saws, where the final lengths of each processed piece of lumber is determined. The main products sold by the company are boards, beams, rafters, battens, joists and planks, meeting the demands of the local and export markets.

Species selection

The species were selected for this study according to the recommendations in CONAMA Resolution # 474/2016 (CONAMA 2016). The estimation of the actual average CRV of the sawmill was based on the yield of 19 species, 50% + 1 of the total processed in the year prior to the 2015/2016 harvesting season (Table 1). Secondary species selection criteria were the availability of timber stored in the sawmill's log deck during the logging season and the market demand. It is worth noting that logs originating from a same tree received different DOF numbers in the log deck. This practice implies that the registered numbering cannot be traced back to individual extracted tree.

Marking and scaling of selected logs

To calculate log volume, the length and diameter of the base and top of the log were measured (obtained from the mean of the largest and smallest cross-sectional diameters). The length was obtained using a 50-m measuring tape with 0.1 cm precision (HI-VIZ Lufkin 50 m). The diameter was measured with a Haglöf Mantax Blue Caliper (127 cm maximum length, 1-cm precision). The volume of logs with bark was calculated using the Smalian strict cubing equation, following CONAMA Resolution # 411/2009.

$$V_{log} = 0.7854 \times (\frac{D_b + D_c}{2})^2 \times l$$

where, V_{log} = volume of an individual log including bark in m³; D_b = diameter at the base of the log in meters (obtained from the mean of the largest and smallest cross-sectional diameters); D_c = diameter of the top of the log in meters (obtained from the mean of the largest and smallest cross-sectional diameters); l = length of the log in meters.

After scaling, logs were sectioned into merchantable sizes according to the desired end product. Log ends were painted with a single color, to facilitate identification throughout processing (Figure 1).

Determination of sawn wood volumes

To obtain sawn wood volumes, we measured the length, width and thickness of each piece of lumber. For this purpose, we used a digimatic caliper (CD-S15CT – Mitutoyo Corporation) with a precision of 0.01 mm and a measuring tape of 8 m with a precision of 0.1 cm. The volume of individual boards was calculated with the following equation:

$$V_{piece} = l \times b \times e$$

where V_{piece} = volume of an individual board, in m³; l = length of individual board, in m; b = mean width of a board, in m; e = mean thickness of a board, in m.

The percentage of sawn wood yield per log was calculated using the following equation:

$$R\% = (\frac{\sum V_{piece}}{V_{log}}) * 100$$

where R = yield or percentage of utilization, as a %; ΣV_{piece} = total volume of sawn wood per log, in m³; V_{log} = volume of log including bark, in m³.

The volumetric yield coefficient for the sawmill was calculated with the following equation:

$$CRV_{sawn} = \frac{\sum R}{n}$$

where CRV_{sawn} = coefficient of volumetric yield of sawmill, as a %; ΣR = sum of yields, as a %; n = number of processed logs.

Figure 1. Example of the use of colored water-based ink to mark logs in the sawmill yard (A) for their identification throughout the lumbering process (B). This figure is in color in the electronic version.

Statistical analysis

The Z-statistic (a two-tailed test for large samples) (Cochran 1977; Gill 1981) was used to test for a statistical difference between the sawmill CRV and the CRV as defined by CONAMA Resolution # 474/2016. Statistical analysis was conducted with R Studio (R Core Team 2020).

The following hypotheses were tested:

H0: $\mu = 35\%$ (null hypothesis)

H1: $\mu \neq 35\%$ or $\mu < 35$ or $\mu > 35$ (alternative hypothesis)

RESULTS

Following the recommendation of CONAMA Resolution # 411/2009, the present study covered 52.7% of the species processed by the company in 2015, corresponding to 19 species and a total sample of 90 logs (Table 1). The diameter of logs varied from 26.5 to 107 centimeters at the top and 43 to 121 centimeters at the base. Log length ranged from 4.94 to 18.25 m. The total volume of scaled logs was 295.09 m³, with a mean of 3.30 ± 0.29 m³ (mean ± standard error) per

Table 1. Mean and standard deviation of volumetric yeld coefficient and its related parameters calculated for 90 logs of 19 timber species harvested and processed by Mil Madeiras Preciosas Ltd. (Amazonas. Brazil) in 2015. The common name is the vernacular name used in Amazonas state (Brazil). N = number of logs; LV = log volume (m³); SWV = sawn wood volume (m³); CRV = volumetric yield coefficient (%).

Family/Species	Common name	N	LV (m³)	SWV (m³)	CRV (%)
Burseraceae					
Protium paniculatum Engl.	breu-branco	4	2.9 ± 1.31	0.9 ± 0.60	26.9 ± 9.3
Protium puncticulatum J.F.Macbr.	breu-vermelho	4	2.8 ± 0.90	0.6 ± 0.26	20.4 ± 2.8
Caryocaraceae					
Caryocar villosum (Aubl.) Pers.	pequiá	4	5.0 ± 1.92	1.7 ± 0.85	32.6 ± 8.2
Fabaceae					
Hymenolobium modestum Ducke	angelim-pedra	6	3.0 ± 0.37	0.6 ± 0.25	21.1 ± 8.3
Zygia racemosa (Ducke) Barneby & J.W.Grimes	angelim-rajado	3	2.9 ± 0.95	0.2 ± 0.09	6.9 ± 2.8
Dinizia excelsa Ducke	angelim-vermelho	6	4.7 ± 1.79	2.2 ± 0.69	48.9 ± 8.2
Dipteryx odorata (Aubl.) Willd.	cumarú	4	2.9 ± 0.82	0.8 ± 0.37	27.2 ± 11.2
Hymenaea courbaril L.	jatobá	3	4.8 ± 0.79	0.6 ± 0.21	12.1 ± 3.0
Goupiaceae					
Goupia glabra Aubl.	cupiúba	4	2.3 ± 0.27	0.6 ± 0.25	24.4 ± 8.9
Humiriaceae					
Endopleura uchi (Huber) Cuatrec.	uxi	4	2.3 ± 0.74	0.5 ± 0.41	20.5 ± 12.4
Lauraceae					
Ocotea rubra Mez	louro-gamela	6	3.4 ± 0.93	0.8 ± 0.66	21.7 ± 12.0
Mezilaurus itauba (Meisn.) Taub. ex Mez	louro-itaúba	5	4.0 ± 1.85	1.0 ± 0.68	22.8 ± 6.6
Ocotea neesiana (Miq.) Kosterm.	louro-preto	8	2.3 ± 1.05	0.4 ± 0.29	19.6 ± 10.0
Malvaceae					
Scleronema micranthum (Ducke) Ducke	cedrinho	3	3.1 ± 1.45	0.7 ± 0.33	23.8 ± 2.0
Moraceae					
Brosimum parinarioides Ducke	amapá	3	3.2 ± 0.34	0.5 ± 0.24	15.5 ± 6.0
Clarisia racemosa Ruiz & Pav.	guariúba	4	5.4 ± 0.91	1.2 ± 0.41	23.7 ± 11.2
Myristicaceae					
Iryanthera paraensis Huber	arurá-vermelho	7	2.8 ± 1.08	0.9 ± 0.51	28.5 ± 4.6
Sapotaceae					
Manilkara elata (Allemão ex Miq.)	maçaranduba	8	2.6 ± 1.33	0.6 ± 0.46	23.4 ± 8.5
Vochysiaceae					
Qualea paraensis Ducke	mandioqueira	4	2.9 ± 1.12	0.8 ± 0.56	28.4 ± 17.4

log. The total sawn wood volume was 76.5 m³, with a mean of 0.85 ± 0.13 m³ per log.

The CRV value was 24.65% ± 2.44% (mean ± standard error), corresponding to an uncertainty of 9.89% (n = 90; 95% IC), slightly below the 10% of the variation limit allowed by law for calculating the sawnwood CRV from logs (CONAMA 2009). Uncertainty was calculated based on variance of the average CRVs obtained from the 90 sawn logs. The average CRV of 24.65% obtained from our sample differed significantly ($p < 0.001$) from the CRV of 35% proposed in CONAMA Resolution # 497/2020, thus the null equality hypothesis was rejected. The average CRV measured showed that 75.35 ± 2.44% (mean ± standard error) from a log become wood residue, corresponding to over 2.48 m³ per log or 222m³ from our sampled logs.

Of the 19 species investigated here, the only one in which all measured logs attained yields higher than the 35% proposed by the current legislation was *Dinizia excelsa* Ducke (angelim-vermelho). In contrast, all individuals of *Zygia racemosa* (Ducke) Barneby & JWGrimes (angelim-rajado), *Hymenaea courbaril* L. (jatobá) and *Protium puncticulatum* JFMacbr (breu-vermelho) reached yields below the mean CRV value of the total sample (Figure 2). For the species in our sample, which includes part of the main species marketed by the company, the probability of obtaining CRV values equal to or higher than 35% was only 18% (17 out of 90 logs). This implies that, for 82% of the logs, surplus virtual credits were generated in the DOF system by the conversion of logs into sawn material.

DISCUSSION

The mean volumetric yield coefficient obtained in this study was below the 35% proposed by CONAMA Resolution # 497/2020. The production of sawn material was close to the 27% described by Lima *et al.* (2005) for sawmills in Amazonas state, but below the 30% estimated by Clement and Higuchi (2006). In another study in Amazonas state, the mean CRV for 20 timber species varied from 41.9% to 61.8%, with an overall mean of 52.9% (Iwakiri 1990). However, it is worth noting that the latter study was conducted under optimal and controlled conditions, with the aim of maximizing the number of pieces per log. In practice, the Amazon timber industry uses a low technological apparatus in their sawmills and generates a considerable amount of wood waste that is discarded. Sawmills are limited to meeting the demand of their buyers' orders to remain competitive in the market (Mendonza *et al.* 2017).

An analysis of 71 wood processing centers concentrated in the Brazilian Amazon, estimated an average CRV of 41.1% overall, and of 39.2% for industries in the state of Amazonas, below the average for the Amazon region (Pereira *et al.* 2010). Other authors obtained lower CRV values for timber species logged in the Amazon region than those estimated by Pereira *et al.* (2010) (e.g., Gerwing *et al.* 2001; Nascimento *et al.* 2006; Danielli *et al.* 2016).

The considerable variation among the mean yields for the 19 species studied are owed to the amount of salable material, which can be owed to quality issues with logs (taper, cracks, form, knots and hollows), the time of exposure of the logs to the weather in the log deck and the damage caused by wood-degrading insects, as well as the type of final product demanded (Valério *et al.* 2007; Garcia *et al.* 2012; Melo *et al.* 2016). The CRVs in our study ranged from 4.2% to 65.1% per species. Logs of *D. excelsa*, for example, which had a higher CRV, were used to produce pieces of greater length, with an average of 3.7 m. To this end, greater care was taken in processing the logs of this species, which greatly reduced wood waste. Even with the presence of hollow areas in some of the logs, the average CRV of *D. excelsa* was 48.9% (see Figure 2), which is 80% higher than the upper limit of the confidence interval of the overall mean of our sample (27.1%). The volume of the lumber affects the lumber yield in Amazon

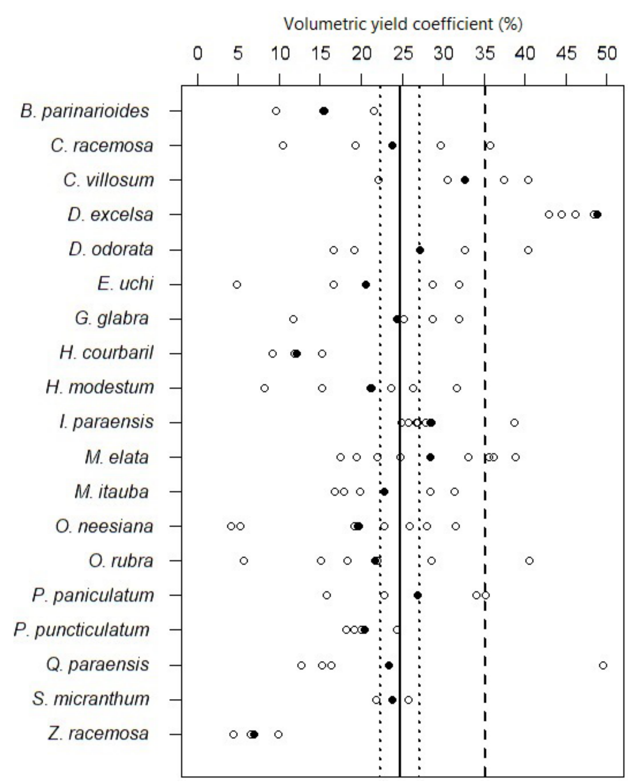

Figure 2. Distribution of volumetric yield coefficients of logs belonging to 19 timber species processed at the sawmill of Mil Madeiras Preciosas Ltd. (Amazonas, Brazil) in 2015/2016. Open circles correspond to the individual log yield coefficients for each species; solid circles correspond to the mean volumetric yield coefficient per species; the continuous line corresponds to the average yield coefficient for the whole sample of 90 logs; dotted lines correspond to the confidence interval (one standard deviation) of the mean; the dashed line marks the volumetric yield coefficient of 35% proposed by CONAMA Resolution 497/2020. An individual of *Dinizia excelsa* Ducke with CRV% 65.1 is not plotted on the graph, as it is outside the proposed scale.

species, as there is a negative relationship between the number of passes of a log through the saw and the yield, hence the CRV (Stragliotto *et al.* 2019).

The overestimation of the volumetric conversion coefficient for sawmills in view of the low yields that they present, results in the accumulation of virtual credits within the DOF system. The DOF electronic system works as a checking account where transactions for the transport of forest products take place. After logging, credit for the wood is offered and transferred through the system to a sawmill or lumber company which then receives the timber in its physical form and proceeds with the sawing process.

The studied company had an estimated mean monthly roundwood consumption of 11216.8 m³, which, according to the direct conversion of 35% CRV used in the DOF system, would yield a mean monthly total of 3925.8 m³ of processed sawn wood. However, the observed CRV of 24.65% for our sample of 90 logs results in an actual production of 2764.9 m³ of sawn wood per month, generating the accumulation of virtual credits equivalent to 1160.9 m³ per month. This would correspond to approximately 14000 m³ (about 4270 logs) per year in virtual credits. Since the virtual credits are the functional currency of the DOF system, the monitoring agency will therefore consider that the remaining 1166.5 m³ of this unfulfilled conversion would still be available as unprocessed logs in the company's log deck. Given the variable mean volumetric yield among the sampled species, and among tropical Amazonian timber species in general (Mendoza *et al.* 2019; Santos *et al.* 2019; Lima *et al.* 2020) it becomes clear that attributing a fixed value to CRV based on a general average does not match the reality of yield variations across the various aspects involved in industrial comercial timber production (multiple species, products and processing lines, among others). This makes the control process ineffective and may favor the illegal log trade.

This gap in the system, which results from an over-reliance on the use of mathematical models, allows the "legalization" of illegal timber through a false or counterfit legality, derived from the trade in surplus virtual credits from the DOF system. As a result, there is not always a close match between the original volume of logs scaled and the final volume of processed lumber (Hummel 2014).

An analysis of the processed log yield in sawmills and plywood-producing mills in the municipality of Jaru, in Rondônia state, Brazil, concluded that, given the variation in yield values, the public agency responsible for forest management policy should demand technical reports from companies including data on log sawing yields, to produce individual conversion rates per sawmill instead of using a generalized value (Martins *et al.* 2002). In addition, the authors emphasize that such a measure would require company owners and management to improve the workforce, methods of scaling and sawing of timber, in addition to encouraging loggers to purchase more modern machinery and equipment. This is unlikely to happen voluntarily and would require fincancial incentives and an accompanying legal framework. Recent advances in DNA timber tracking technology, together with the forest certification program, can further reinforce the legality of the tropical timber trade (Sasaki *et al* 2016).

In a technical note that revises CONAMA Resolution # 411/2009, the Ministry of the Environment gives a negative opinion on the request of some industries to increse the reference CRV above 35% (MMA 2017). The note concludes that the increase in the volumetric conversion coefficient would increase the surplus of credits in the DOF or Sisflora systems, which is commonly supplied by illegally extracted wood from deforestation or illegal logging. The request for a volumetric yield coefficient higher than 35% was based on a technical study by companies that invest in high-performance industrial processes and efficient use of forest resources to achieve a competitive advantage and contribute to the establishment of a sustainable forest market (MMA 2017). A possible key to discipline the production of virtual credits would be the combination of a mandatory technical study regarding the CRV of sawmills registered in the DOF with a self-declaration procedure of yield by species and product generated in the computerized platform. In this way, confidence intervals for species yields can be created, avoiding the insertion of discrepant yield values in the system and, at the same time, giving autonomy to industrialists, who would be able to declare the real production of the company.

The DOF system is an important information integrator in the control of forest product transportation in Brazil, but it still needs to be significantly improved to be effective in controlling the illegal timber trade (Brancalion *et al.* 2018). Today, falsely legalized wood is offered on the market at a price lower than that which was legally extracted (CNI 2018), generating an unfair competitiveness for illegal loggers in detriment of the companies that harvest timber legally, complying with all requiremnts and regulations.

CONCLUSIONS

The volumetric yield coefficient of the studied sawmill was lower than that provided for in CONAMA Resolution 474/2016. A specific technical study to determine the average CRV and its associated uncertainty for each timber processing industry would reduce the possibility of accumulating virtual credits in the system that enables potential fraud related to the illegal wood trade. The sustainability of forest management requires the adoption of general principles and technical resources for the adequate use of the harvested raw material, including greater investments in wood technology research, better use of wood waste and improvement of sawing techniques for Amazonian species.

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