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EVALUATION OF THE IMPACT OF WOOD FOREST MANAGEMENT OPERATIONS ON AMAZON NUT TREES IN FOREST CONCESSION AREAS IN THE AMAZON

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ABSTRACT

The Amazon rainforest holds has immense biodiversity and offers various possibilities for use. Moreover, there is an increasing need for development models that reconcile the rational use of forest resources with socio-economic development. Multiple-use forest management emerges as a legal mechanism for the sustainable use of forest resources. In this context, a forest use system that appears suitable for multiple-use management is one where timber is selectively harvested from forests that are also sources of Amazon nuts. However, the effects of logging management on forests with a high density of Amazon nut trees needs to be studied, as the damage resulting from logging operations on *Bertholletia excelsa* Bonpl. trees may impact the long-term maintenance of these nut stands. This study aimed to assess the impact of logging operations for timber production on Amazon nut trees to evaluate the compatibility of logging management with the management of native nut stands in a forest concession area in the Amazon. The study was conducted in two National Forests (Jamari and Jacundá) in the state of Rondônia. The damage from cutting and logging operations on the canopy structure of Amazon nut trees was quantified and assessed using photogrammetry with remotely piloted aircraft. The Jamari National Forest showed 4.3% canopy damage to Amazon nut trees, while the Jacundá National Forest showed 3.2% damage. The results indicated that the damage to the canopies of Amazon nut trees due to timber extraction was minimal, suggesting potential compatibility between logging management and the management of native nut stands. However, further studies are needed, especially those focused on planning the collection of Amazon nuts, since access to the nut stands is essential for effectively structuring management, ensuring that the full production potential is sustainably managed and generates income for the extractivists.

Keywords: Non-timber forest product; Photogrammetry; Multiple use; Forest production

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AVALIAÇÃO DO IMPACTO DAS OPERAÇÕES DE MANEJO FLORESTAL NA CASTANHEIRA-DA-AMAZONIA EM ÁREAS DE CONCESSÃO FLORESTAL NA AMAZÔNIA

RESUMO – A Floresta Amazônica é detentora de imensa biodiversidade, a qual apresenta diferentes possibilidades de uso. Além disso, cada vez mais há necessidade de modelos de desenvolvimento que conciliem o uso racional dos recursos florestais ao desenvolvimento socioeconômico. O manejo florestal de uso múltiplo surge como um mecanismo legal para o uso sustentável dos recursos florestais e, nesse sentido, um sistema de uso florestal que parece passível de manejo de uso múltiplo é aquele cuja madeira é seletivamente extraída de florestas das quais também são coletadas castanhas-da-amazônia. No entanto, o efeito do manejo madeireiro em florestas com alta densidade de castanheiras precisa ser estudado, visto que os danos decorrentes do manejo madeireiro nas árvores de *Bertholletia excelsa* Bonpl. podem influenciar na manutenção dos castanhais no longo prazo. Este trabalho objetivou avaliar o impacto das operações florestais para produção de madeira em tora sobre os indivíduos de castanha-da-amazônia para avaliar a compatibilidade do manejo madeireiro com o manejo de castanhais nativos em área de concessão florestal na Amazônia. O estudo foi conduzido em duas Florestas Nacionais (Jamari e Jacundá) localizadas no estado de Rondônia. Foram quantificados e avaliados os danos decorrentes das operações de corte e extração madeireira na estrutura de copa das castanheiras a partir da fotogrametria com Aeronaves remotamente pilotadas. A FLONA do Jamari apresentou 4,3% de danos na copa das castanheiras e a FLONA de Jacundá apresentou 3,2% de danos. Os resultados mostraram que os danos na copa das castanheiras devido à extração de madeira foram pequenos, apontando para uma possível compatibilidade do manejo madeireiro e o manejo de castanhais nativos. Porém, mais estudos são necessários, especialmente aqueles voltados ao planejamento de coleta da castanha-da-amazônia, uma vez que o acesso aos castanhais é fundamental para a estruturação real do manejo, garantindo que todo seu potencial de produção seja de fato manejado de forma sustentável e gere renda para os extrativistas.

Palavras-Chave: Produto florestal não madeireiro; Fotogrametria; uso múltiplo; Produção florestal.

1. INTRODUCTION

The Amazon rainforest has immense biodiversity and offers various possibilities for use. Furthermore, there is an increasing need for development models that reconcile the rational use of forest resources with socio-economic development.

In this context, it is of utmost importance to ensure the sustainable use of multiple timber species, as well as various non-timber products and by-products. Sustainable Forest Management emerges as a legal mechanism for utilizing these forest resources through the Public Forest Management Law (Law 11,284/2006) (Brazil, 2006) and, additionally, the Brazilian Forest Code, which includes Laws 12,651/2012 (Brazil, 2012a) and 12,727/2012 (Brazil, 2012b). To achieve truly sustainable management of these forest resources, whether timber or non-timber, it is necessary to know the ecology of the forest community, based on its structural characterization. Thus, maintaining the sustainability of management will directly depend on conserving the forest's structure and ecological dynamics (Guedes et al., 2023).

However, the valorization of forest resources restricted to timber production has changed in a macroeconomic context, making the importance of other products and benefits increasingly evident (Santos et al., 2003). In this context, the extraction and commercialization of non-timber forest products (NTFPs) such as Amazon nuts, latex, and others by traditional communities have gained great prominence within the global concept of bioeconomy. These products serve as the economic base for these communities, contributing to regional economies that, in turn, support national and global economies (MAPA/SFB, 2019a).

The Amazon nut tree (*Bertholletia excelsa* Bonpl.) is a species that stands out in the forest, reaching 50 meters in height and 2 meters in diameter (Wadt et al., 2005). It occurs naturally in most of the dryland forests in the Amazon basin (Scoles 2010, Wadt et al., 2008) and is one of the main NTFPs managed in the Amazon region with high demand in both the national and international markets. It is the only commercialized nut that is collected almost exclusively from natural forests (Clay, 1997; Peres et al., 2003), contributing to the income of extractive families, which receive 44% of the total net revenue (Soriano et al., 2017).

Given the great importance of this species in the ecological, social, and economic context, a decree was published in 2006 prohibiting its logging (Decree No. 5,975/2006), although the collection of its seeds for commercialization is permitted, occurring during the heavy rain period in the Amazon states (October to April). The collection of Amazonian nuts is an activity with low environmental impact, as it is carried out intensively and primarily using traditional techniques involving pre-collection, collection, and post-collection stages (Embrapa, 2004; Scoles, 2010). Thus, it serves as an alternative for the conservation of forest resources through sustainable forest management.

In forest areas where roundwood production occurs (authorized through a Sustainable Forest Management Plan), Amazonian nuts could also be produced, provided that the species occurs naturally. This scenario of reconciliation between the two activities was reported by Guariguata et al. (2009) and Rockwell et al. (2015) as a proposal for multiple-use forest management, as it would allow the infrastructures built for timber production to be used for the collection and transportation of Amazonian nuts, among other advantages.

However, some limitations regarding the multiple use of timber and Amazon nuts have been identified, such as political barriers and lack of supervision, high management costs, minimal financial benefits, and damage to Amazon nut trees resulting from logging, which pose the main threat associated with the multiple use of timber and Amazon nuts (Duchelle et al., 2012). Therefore, to successfully integrate timber and non-timber management, the effect of timber management activities on native Amazon nut groves needs to be studied to understand and evaluate the impact of forestry operations for roundwood production on Amazon nut individuals within timber management areas.

The National Forest (FLONA) is a category of sustainable use conservation unit that allows for the sustainable multiple use of forest resources. Currently, Rondônia has two areas under forest concession: the Jamari National Forest (FLONA do Jamari) and the Jacundá National Forest (FLONA do Jacundá), where reduced impact management activities are carried out. In these areas, traditional populations can and do collect Amazon nuts within both FLONAs. In light of this, the concessionaire is concerned with developing a management plan for the native Amazon nut stands in the area, in a way that benefits both the company and the traditional populations, enabling multiple uses and economically valuing the forest between timber production cycles.

Forest assessment and monitoring activities are of utmost importance, as they assist in decision-making by providing technical information to support the expansion of timber forest planning to be compatible with Amazon nut management, thereby promoting multiple-use forest management in areas under Sustainable Forest Management. However, these assessment and monitoring activities can be expensive, labor-intensive, and time-consuming, becoming quite limited depending on the size of the area. In this context, geotechnology offers a set of products and processes that can be used as tools in the forestry context, among which digital photogrammetry using remotely piloted aircraft (RPAs) stands out. This technology is widely used in activities aimed at measuring objects through photographs, which are often used in mapping, allowing for fieldwork with lower operational costs, high spatial resolution data acquisition, and optimized time and labor effort.

Thus, the objective of this study was to evaluate the impact of forestry operations for roundwood production on individuals of Amazon nut trees to assess the compatibility of timber management with the management of native Amazon nut trees in a forest concession area in the Amazon. To this end, the crown structure of the Amazon nut trees was quantified and evaluated before and after the logging operation using digital photogrammetry. The hypothesis raised was that sustainably carried out timber management activities would not cause damage to individuals of *Bertholletia excelsa*, since the research area in question is a conservation unit for sustainable use under forest concession, which undergoes several audits throughout the management process.

2. MATERIAL AND METHODS

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2.1 Study area

The study was carried out in two National Forests (FLONA) under forest concession, FLONA do Jamari and FLONA de Jacundá, both located in the state of Rondônia (Figure 1).

The Jamari FLONA covers the municipalities of Itapuã do Oeste, Cujubim and Candeias do Jamari, with an approximate area of 223 thousand hectares, divided into three Forest Management Units (UMF), under concession since 2008. Data collection was carried out at UPA 07 of UMF I, with a total

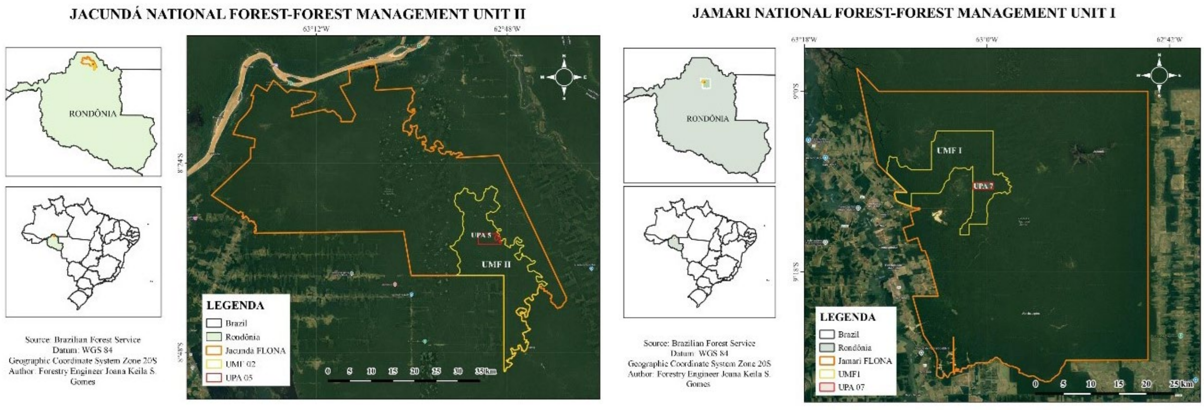

Figure 1. Study area location. Source: Author, 2022.

Figura 1. Localização das áreas de estudo. Fonte: Autor, 2022

area of 467.03 ha, with a cutting intensity in the effective management area of 18.81 m³ ha^{-1}, in which a total of 162 individuals of Amazon nut trees were counted in the UPA.

The Jacundá National Forest (FLONA) covers the municipalities of Porto Velho and Candeias do Jamari, with an area of 111,457 hectares, divided into three UMFs, under concession since 2009. Data collection was carried out at UPA 05 of UMF II, with a total area of 1,160.12 ha, with a cutting intensity in the effective management area of 11.49 m³ ha^{-1}, presenting a total of 219 individuals of Amazon nut trees in the UPA. In both areas, reduced-impact logging techniques were used. The selection of UPAs took place according to the concessionaire company's schedule to carry out exploratory activities, thus, the UPAs scheduled for exploration in 2020 were the focus of the research.

The predominant climate in the region is Aw Tropical Rainfall Climate, according to the Köppen classification, the average annual rainfall varies between 1,400-2,600 mm/year, with precipitation of less than 20 mm in June, July and August, while the average annual air temperature varies between 24 and 26 °C (Sedam, 2010). The predominant vegetation in the UMFs is of the Submontane Open Ombrophilous Forest type in the Jamari UMF and Dense Ombrophilous Tropical Forest in the Jacundá UFM (IBGE, 2006). The main soil types found in the UMF of the Jamari FLONA are Dystrophic Red-Yellow Latosol, Dystrophic Red-Yellow Argisol and Dystrophic Yellow Latosol. In the UMF of FLONA de Jacundá, only the Dystrophic Yellow Latosol is present (IBGE, 2001).

2.2 Data collection

The field data collection was carried out in three stages. The first necessarily before the trees were cut within the plots, and the other stages were carried out immediately after the primary and secondary log transportation activities within the UPAs.

The first stage was executed in July 2020, during which a 100% forest inventory and planning of forest roads within the selected UPAs were conducted to analyze the density and distribution of Amazon nut trees. This analysis aimed to quantify and locate those with productive size classes, according to Kainer et al. (2007), and subsequently, the evaluation plots were allocated for carrying out the study. A 200 ha plot was allocated in each of the two UPAs in a forest section with the highest density of productive Amazon nut trees

(0.54 and 0.46 individuals ha^{-1} in the Jamari FLONA and Jacundá FLONA, respectively), considering the intentional selection of plots. Then, flights were conducted over each plot using remotely piloted aircraft (RPAs) (Dji Phantom 4 Pro V2.0 drones) to capture images. The flights were performed with the following parameters: 120 m above the treetops, a speed of 10 m/s, an interval of 3 seconds between photos, a distance of 45 m between flight lines, a ground sample distance (GSD) of 3.16 cm, lateral and longitudinal coverage of 80.49%, and a maximum distortion of 1.19 pixels for a 1/200 second shutter speed. New Ground Control Points (GCPs) were collected at each flight with GNSS L1/L2 and post-processed with the RIOB 93911/RBMC reference base.

The second stage, carried out in October 2020, consisted of repeating the drone flyover considering the same flight plan as the first stage, however, the flight was carried out after the primary timber transportation activity from within the UPA.

From the images obtained in the first and second flights, the following variables were evaluated in each Amazon nut tree with DBH greater than or equal to 30 cm located within each plot: Crown length (m); Average crown diameter (m); Crown projection area (m²).

Finally, the third stage consisted of validating the information obtained after analyzing the images in the GIS, in which all Amazon nut trees that presented damage and 30% of the ones that did not present it were selected for verification and in loco validation.

2.3 Photogrammetry in the evaluation of Amazonian nut tree canopies

The aerial images obtained by executing the photogrammetric projects were processed using the SIFT algorithm - Scale Invariant Feature Transform (Lowe, 1999), available in the PIX4D Mapper software.

With the processed orthophotos and the location data of the Amazon nut trees, the stage of segmentation and classification of the crowns in the orthophoto began, the purpose of which was to vectorize the crown area individually before and after the logging operation. The tree crowns were manually vectorized, focusing solely on those located within the forest canopy.

2.4 Quantification and evaluation of the canopy structure of Amazon nut trees before and after logging operations

After the process of segmenting and classifying the tree crowns, the images were consolidated and analyzed in GIS software to determine the occurrence of damage to the crown. To this end, the crown area was calculated before and after logging, from which the percentage of crown loss was obtained and the occurrence of damage was determined, according to Holmes et al. (2002):

i) No damage (full canopy);

ii) Light damage (less than 1/3 of the canopy damaged);

iii) Moderate damage (more than 1/3 but less than 2/3 of the canopy destroyed);

iv) Heavy damage (more than 2/3 of the canopy destroyed).

3. RESULTS

3.1 Efficiency of photogrammetry in evaluating the canopy of Amazonian nut trees

Of the total number of Amazon nut trees in the two evaluated plots, 92% of the canopies were successfully vectorized. However, some Amazon nut tree canopies varied significantly from one another, particularly during the peak leaf change period, and/or were located beneath the forest canopy, which made the vectorization process difficult.

According to the analysis of the orthophotos, the Jamari FLONA presented an average canopy projection area of 352,60 m², an average canopy diameter of , 25,35m² and an average canopy length of 79.65 m. The Jacundá FLONA presented an average canopy projection area of 290.77 m², an average canopy diameter of 21.71 m² and an average canopy length of 68.21 m.

3.2 Canopy structure of Amazon nut trees before and after logging operations.

Damage was detected in both plots (Table 1), with 4.3% of damage in the Jamari FLONA concerning the total number of Amazon nut trees in the plot, and 3.2% of damage in the Jacundá FLONA.

Table 1. Estimation of damage to the canopies of Amazon nut trees within two plots of 200 ha each, in a forest concession area in the state of Rondônia

Tabela 1. Estimativa de danos às copas das castanheiras-da-amazônia em duas parcelas de 200ha cada, em área de concessão florestal no estado de Rondônia

	Location	
	Jamari's FLONA	**Jacundá's FLONA**
Total number of Amazon nut trees with heavy damage	5	1
Total number of Amazon nut trees with moderate damage	0	2
Total number of Amazon nut trees with light damage	0	0
Total number of damaged Amazon nut trees.ha^{-1}	0.025	0.015
Total number of Amazon nut trees	114	94

Source: Author
Fonte: Autores

Of the five Amazon nut trees found in the Jamari National Forest with damaged crowns, only two suffered damage resulting from logging (Figure 2), resulting in a loss of 339.7 m² of crown area. The other damages found were subsequent to the logging activities, but the crowns of these trees were not distinguishable in the orthophotos, as they were below the canopy and very similar to the trees around them, making it impossible to vectorize them (Figure 3). However, during field validation, it was found that their crowns were already damaged.

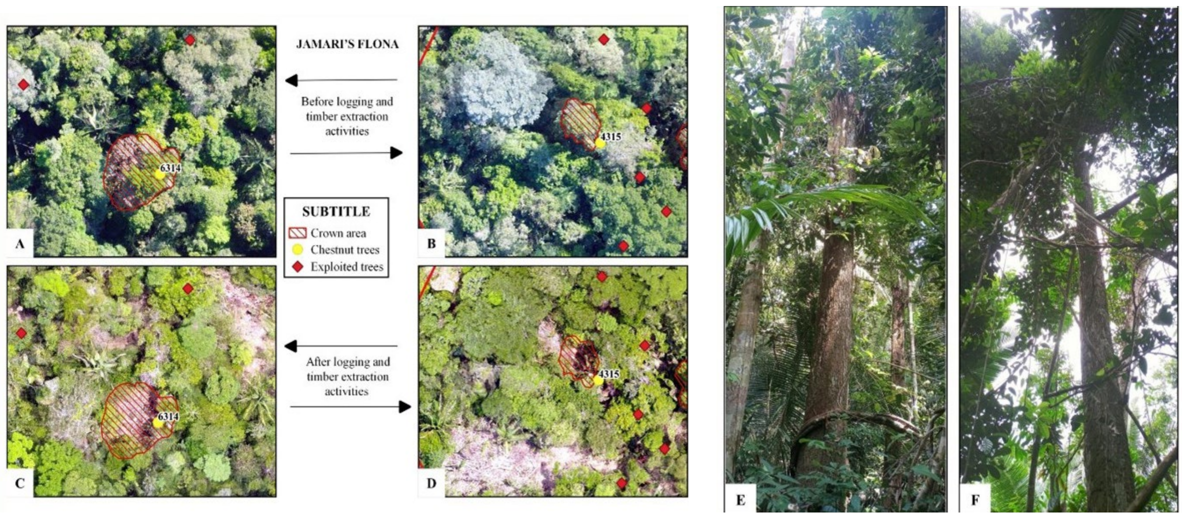

Figure 2. Amazon nut trees with damaged crowns resulting from cutting and wood extraction extraction in Jamari's FLONA (a, b, c, d). The Amazon nut trees suffered heavy damage, resulting in a 100% loss of crown area, totaling a loss of 339.7 m² of crown area. Field validation in Jamari's FLONA (e, f), which indicates that the Amazon nut trees suffered heavy damage, with completely damaged crowns. Source: Author, 2022

Figura 2. Castanheiras-da-amazônia com copas danificadas decorrentes do corte e extração da madeira na FLONA do Jamari (a, b, c, d). As castanheiras sofreram danos pesados, no qual tivera, 100% de perca da copa, totalizando uma perca de 339,7m² de área de copa. Validação em campo na FLONA do Jamari (e, f), no qual as castanheiras apresentaram danos pesados, com copa totalmente danificadas. Fonte: Autor, 2022

Figure 3. Amazon nut trees in Jamari's FLONA did not show any damage in the orthophoto, but, in the field validation, showed heavy damage to their canopies. The three Amazon nut trees had their canopies damaged, but the damage occurred after the cutting activities. Source: Author, 2022

Figura 3. As castanheiras da FLONA do Jamari não apresentaram danos na ortofoto, mas, na validação em campo, apresentaram grandes danos em suas copas. As três castanheiras tiveram suas copas danificadas, mas os danos ocorreram após as atividades de corte. Fonte: Autor, 2022

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Of the three Amazon nut trees found with damaged crowns in the Jacundá FLONA, two suffered damage resulting from logging (Figure 4), resulting in a loss of 224.77 m².

The damage found on the other Amazon nut tree was not caused by the cutting activities (Figure 5), which could not be vectorized, as the tree's crown had already been torn off before the first flight, that is, before the timber

Figure 4. Amazon nut tree with damaged crown resulting from the cutting and extraction of wood in the Jacundá National Forest. The trees suffered heavy and moderate damage, totaling a loss of 224.77 m². Source: Author, 2022

Figura 4. Castanheira-da-amazônia com copa danificada em decorrência do corte e extração de madeira na Floresta Nacional de Jacundá. As árvores sofreram danos pesados e moderados, totalizando uma perda de 224,77 m². Fonte: Autor, 2022

Figure 5. Amazon nut tree whose crown was not detected in the orthophoto, but when the presence of a stump was detected and during field validation, it was found that the crown had been damaged. The damage occurred before the forest management cutting activity. Source: Author, 2022

Figura 5. Castanheira-da-amazônia cuja copa não foi detectada na ortofoto, mas foi detectada a presença de um toco e durante a validação em campo constatou-se que a copa estava danificada. Os danos ocorreram antes da atividade de corte do manejo florestal. Fonte: Autor, 2022 management cutting activities.

During field validation, a large number of vines (+50%) were found in 36% of the Amazon nut trees visited, including those with damaged canopies (Figure 2). Therefore, it is important to cut vines not only on the trees that will be harvested but also on neighboring trees, especially if the species is protected by law, since on average, vines connect three to nine trees to each individual in the canopy of the Amazonian dryland forest (Vidal et al., 1997). Therefore, it is crucial to treat silviculturally the vines in such a way as to avoid intertwining the canopies when felling them.

4. DISCUSSION

The observed frequency of damage was low (Table 1), even though the cutting intensities were considered medium (11.49 and 18.81 m^3 ha^{-1} in Jacundá and Jamari, respectively) when compared with other studies conducted in the Brazilian Amazon, where the cutting intensities varied from 16 to 40 m^3 ha^{-1} (Martins et al., 1997; Verissimo et al., 1989; Verissimo et al., 1992). This indicates that greater volumes of wood managed per hectare are not necessarily correlated with a higher number of damaged trees per hectare.

However, the results of Matangaran et al. (2019) showed that the percentage of tree damage increased as the number of trees felled (felling intensity) increased. The number of damaged Amazon nut trees per hectare found in this study (0.025 and 0.015 damaged Amazon nut trees per hectare in Jamari's FLONA and Jacundá's FLONA, respectively) was quite similar to what was found by Guariguata et al. (2009) in a study conducted in Pando, Bolivia, where they recorded 0.1 damaged Amazon nut tree per hectare. They attributed these low damage frequencies to the low cutting intensity of timber management (approximately 0.5 trees per hectare and about 5 m^3 per hectare) and the use of reduced-impact management guidelines.

Forest management techniques are closely correlated with the level of damage (Sabogal et al., 2000; Holmes et al., 2002; Schulze & Zweede, 2006; Pokorny et al., 2008; Guariguata et al., 2009; Chaudhary et al., 2016). In this sense, it is worth highlighting the importance of the methods and techniques adopted by the concessionaire company in planning roads, cutting, and skidding of wood, since the execution of these activities drastically alters the amount of structural damage in the forest and increases the level of mortality of non-target trees.

Some authors, such as Holmes et al. (2002) and Schulze & Zweede (2006), emphasize the importance of applying reduced-impact logging techniques (RILT), such as pre-logging inventory, mapping of individuals to be extracted, planning of roads and storage yards, targeted cutting techniques, and cutting of vines attached to selected trees, among others (Sabogal et al., 2000; Pokorny et al., 2008; IFT, 2012), which can reduce the number of damaged trees in the residual forest.

In this study, the planning and execution of RILT activities proved to be efficient, as the damage was low. However, its guidelines could be better implemented, especially considering the reconciliation between timber management and Amazon nut management. For example, cutting the vines present in the Amazon nut trees could reduce damage caused by management, improve worker safety, and increase the production of Amazon nut, as suggested by Kainer et al. (2007). Rockwell et al. (2015) suggest that logging crews remain at least 100 m away from reproductive Amazon nut trees, providing the basis for proximal compatibility of the two subsistence strategies. Additionally, they recommend establishing a buffer zone around Amazon nut trees to provide an extra layer of protection against primary (e.g., direct damage to trees by logging activities) and secondary (e.g., windfall gains as a result of logging) damage. In this study, it was noted that there was no such buffer zone; however, it was found that the felling direction technique of the felled trees took into account the protection of nearby Amazon nut trees.

Overall, the results of this study support the findings of Guariguata et al. (2009) and Rockwell et al. (2015), suggesting that a forest management system suitable for multiple uses is one where timber is selectively managed in forests from which Amazon nuts are also harvested. The small damage observed in the canopies of Amazon nut trees and its lack of direct correlation with timber-cutting activities indicate that the concessionaire's sustainable forest management plan considers the protection of Amazon nut trees.

Another important point regarding the compatibility of multiple-use forest management for timber and native Amazon nut trees is that cutting Amazon nut trees is illegal in Brazil, eliminating any conflict of interest regarding management. Additionally, selective timber cutting in tropical forests and the collection of Amazon nuts usually occur in different periods, with timber harvesting typically taking place in the dry season and nut collection in the rainy season (Cronkleton, Guariguata & Albornoz, 2012). Furthermore, it is worth highlighting that the study area is a National Forest under a forest concession, and the permission to carry out sustainable forest management of timber and non-timber products is conditioned on a series of criteria that must be followed, such as: (i) the application of RILT techniques, ensuring that the forest remains ecologically balanced and maintains continuous production; (ii) respect for the rights and needs of traditional peoples and communities. This includes ensuring free access for local communities to the forest concession areas for the collection of non-timber products considered essential to their subsistence (such as Amazon nuts), in addition to the collection of seeds for the production of handicrafts (MAPA/SFB, 2019b).

These results show that damage to the Amazon nut tree canopy due to logging was minor. In parallel, other studies (Soriano et al., 2012; Moll-Rocek et al., 2014) indicate that roundwood production activities in forests with high densities of Amazon nut trees do not affect the natural regeneration of the species, as long as logging is of low intensity. However, discussions with residents of extractive communities in Pando suggest that the rapid growth of vegetation along trails after logging can make walking difficult and reduce the visibility of fruits on the ground, hindering collection (Guariguata et al., 2008). Field validation confirmed this difficulty in moving along both secondary roads and skid trails due to the abundant natural regeneration in the area, corroborating the discussions raised by Guariguata et al. (2008). Therefore, although these results indicate a possible compatibility between timber management and the management of native Amazon nut tree groves, there are still many limitations to making multiple-use forest management a more widespread practice in tropical forests under concession. Thus, more studies are needed, especially focused on planning the collection of Amazon nut trees, as access to their groves is essential for the actual structuring of management, ensuring that all their production potential is sustainably managed and generates income for extractivists.

5. CONCLUSION

Digital photogrammetry using remotely piloted aircraft proved to be an efficient tool for quantifying and evaluating the canopy structure of Amazon nut trees present in the study plots. This method allowed for the work to be carried out with less labor effort, reduced fieldwork time, and high spatial resolution data acquisition, resulting in a database with over 10,000 aerial photos. However, some limitations were identified, such as the difficulty in detecting the canopies of non-emerging Amazon nut trees and precisely identifying the Amazon nut trees themselves. This challenge arose due to variations during leaf shedding; some trees had new leaves, others were in the process of shedding leaves, and some were completely leafless.

The results obtained in this study indicate that the damage found in the canopies of the Amazon nut trees was minimal, suggesting that the forest management system adopted by the company, which employs reduced-impact techniques, has been effective in caring for the Amazon nut trees. This approach promotes the conservation of the species and maintains its essential ecological functions and environmental services.

6. ACKNOWLEDGEMENTS

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AUTHOR CONTRIBUTIONS

Gomes J.K. da S.: Writing, data acquisition, analysis and interpretation of images and data, validation of data in the field, discussions and general reviews. Cunha T.A. da: Analysis and review of data, support in the scientific methodology developed, validation of data in the field, support in writing and editing the article. Wadt L.H. de O.: Analysis and review of data, support in the scientific methodology developed, support in writing and editing the article. Figueiredo E.O.: Data acquisition, support in data analysis and interpretation, support in the scientific methodology developed.

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