

Ecological and environmental indicators of Brazil Nut Tree (*Bertholletia excelsa* Bonpl.) in Flona do Jamari, Rondônia

Mapping Brazil nut trees in the Amazon is essential for indicating its distribution patterns within different ecosystems, while also being useful to estimate the species productive potential. This study aimed to evaluate the spatial distribution of Brazil nut trees in Flona do Jamari – RO, considering its environmental and topographic conditions. A census was performed for all individual trees sized = 35 cm in diameter at 1.30 m breast height (DBH) above the ground of six Annual Production Units (APU) in Forest Management Unit III (FMU-III), a 11,011.2 ha area of Flona do Jamari, RO. DBH and geographic location (GPS) were collected for each tree. Structure and diameter distribution were evaluated by abundance, density, dominance, and frequency. The Morisita index was used to identify the spatial distribution pattern. The environment was defined by the local relative height found along the drainage network, by the digital model Height Above the Nearest Drainage (HAND). Most trees were among DBH intermediate classes (60 to 140 cm), and only a few were young trees (DBH < 50 cm). Brazil nut trees present a random spatial distribution and a predominant distribution pattern of 'terra-firme (solid ground)'. Such information on the species structural, spatial, and ecological patterns serve as key elements for further studies on production potential.

Keywords: Western Amazon; Ecosystems; Ecological Patterns; HAND.

Indicadores ecológicos e ambientais da Castanheira-do-Brasil (*Bertholletia excelsa* Bonpl.) na Flona do Jamari, Rondônia

O mapeamento da castanha-do-pará na Amazônia é essencial para indicar seus padrões de distribuição em diferentes ecossistemas, além de ser útil para estimar o potencial produtivo da espécie. Este trabalho teve como objetivo avaliar a distribuição espacial das castanheiras do Brasil na Flona do Jamari - RO, considerando suas condições ambientais e topográficas. Um censo foi realizado para todas as árvores individuais de tamanho = 35 cm de diâmetro a 1,30 m de altura do peito (DAP) acima do solo de seis Unidades de Produção Anual (APU) na Unidade de Manejo Florestal III (UMF-III), uma área de 11.011,2 ha de Flona do Jamari, RO. DAP e localização geográfica (GPS) foram coletados para cada árvore. A estrutura e a distribuição do diâmetro foram avaliadas por abundância, densidade, dominância e frequência. O índice de Morisita foi utilizado para identificar o padrão de distribuição espacial. O ambiente foi definido pela altura relativa local encontrada ao longo da rede de drenagem, pelo modelo digital Height Above the Nearest Drainage (HAND). A maioria das árvores estava entre as classes intermediárias de DAP (60 a 140 cm), e apenas algumas eram árvores jovens (DAP < 50 cm). As castanheiras do Brasil apresentam uma distribuição espacial aleatória e um padrão de distribuição predominante de 'terra-firme (solo sólido)'. Essas informações sobre os padrões estruturais, espaciais e ecológicos das espécies servem como elementos-chave para estudos futuros sobre o potencial de produção.


Palavras-chave: Amazônia ocidental; Ecossistemas; Padrões ecológicos; HAND.

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INTRODUCTION

The Amazon Rainforest is recognized as one of the world's largest biodiversity reserves, harboring more than 16,000 tree species (TER STEEGE et al., 2013). Among such diversity, the Brazil nut tree (*Bertholletia excelsa* Bonpl.) symbolizes the Amazon, deserving emphasis for its socioeconomic and environmental relevance for the region (SALOMÃO, 2014).

The social dimension of this tree involves collecting and processing the nut tree fruit, creating jobs and contributing to the local livelihood of most host communities of extractive industries in the Amazon (SILVA et al., 2013). Regarding the economic perspective, the nut tree fruit is a source of revenue and moves a supply chain stemming from its increasing demand (SANTANA et al., 2017). From an environmental perspective, the product has an increasing relevance due to its sustainable use – despite being a non-timber forest product, managing the species demands expertise for preserving the trees (TONINI et al., 2014).

The distribution pattern of this species is often grouped and extensive in the form of chestnut groves (related to other forest species). However, it differs depending on the conditions imposed by the environment – the ecosystems –, requiring information about their morphometry due to the edaphoclimatic characteristics, typical of the Amazon region (SALOMÃO, 2009). This evinces the demand for studies on the spatial distribution of Brazil nut trees in the various ecosystems in which it occurs.

Flona do Jamari (RO) – Brazil's first Flona, or national forest – is under forest concession divided in Forest Management Units; Unit III (FMU-III), object of this study, is destined to the exploitation of timber and non-timber products. However, the Brazil nut tree is not part of the exploitation concession and, as it is a subsistence product for local communities, follow-up work is carried out together with them (AMATA, 2009).

This species still lacks data to forecast production potential, and to ground extractivists and government's planning in granting credit – as done in most rural production systems. Understanding the spatial distribution of this species is a primary element to propel subsequent studies on production potential.

Landscape information – when lacking resources to *in loco* data collection – can be acquired by Digital Elevation Models (DEMs), products of remote sensing and geoprocessing techniques (IORIO et al., 2012). This information may be associated with forest inventories to find specific answers on the dynamics of a given vegetation or species (SCHIETTI et al., 2013). The interaction between data obtained with DEM and forest inventories may generate models that enable studies on estimates that, without this mechanism, would be technically and economically unfeasible.

Mapping the spatial distribution of Brazil nut tree, regarding population structure and the ecosystems in which it occurs, is fundamental for understanding its ecological pattern and estimating its productive potential in the state of Rondônia. Thus, this study aims to evaluate the structure and spatial distribution of Brazil nut trees in Flona do Jamari – RO, considering its environmental conditions and using Geographic Information Systems (GIS).

MATERIALS AND METHODS

Location and Characterization of the study area

This study was performed in six Annual Production Units (APU) of the Forest Management Unit III (FMU-III) (46,184.25 ha): APUs 01 (1586.8 ha), 02 (1946.1 ha), 03 (1943.6 ha), 04 (1780.5 ha), 05 (1926.7 ha), and 06 (1827.5 ha). The total area evaluated was 11,011.2 ha of the Jamari National Forest (Flona), located in the municipality of Itapuã D'Oeste, Rondônia (Figure 1).

This region has a monsoon climate (ALVARES et al., 2013), annual rainfall from 1,843.7 to 2,008.2 mm, and dry season from June to August and rainy from December to February (FRANCA, 2015).

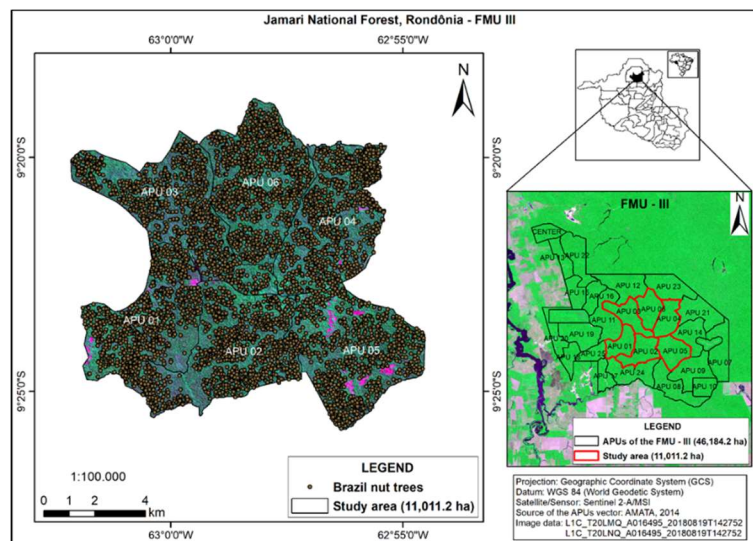


Figure 1: Forest Management Unit III (FMU - III) location, with emphasis on Annual Production Units (APU) and the distribution of Brazil nut trees (*Bertholletia excelsa* Bonpl.), and the Annual Production Units 01, 02, 03, 04, 05, and 06, in Flona do Jamari, Rondônia, 2018.

Data Collection

The instrument used for data collection on Brazil nut trees was the '100% inventory' provided by the concessionaire responsible for the Sustainable Management Plan of the FMU-III, in Flona do Jamari.

The '100% inventory' measured and mapped every Brazil nut tree with DBH equal to or greater than 35 cm (1.30 m above the ground). Diameters were measured using diameter tape, and coordinates (X and Y) were obtained by the Garmin GPS 62s, set in the geographic projection, and the coordinate system Datum WGS 84 (*World Geodetic System*, 1984).

Data Processing and Analysis

The following environmental and ecological aspects were covered: (1) Population horizontal structure, diametric distribution, and spatial distribution; (2) Drainage-related topographic (elevation and slope), and environmental variables (HAND – Height Above Nearest Drainage).

Horizontal structure, diameter, and spatial distribution

The horizontal structure (abundance, density, and dominance) was calculated from the results of the

'100% inventory' on Brazil nut trees.

Diametric distribution was analyzed by calculating the frequencies of diameter classes in the studied APUs; we adopted 20 cm intervals between DBH classes. Individual trees were categorized into young and adults following criteria based on reproductive status; young were those with DBH < 50 cm (WADT et al., 2005).

The Morisita Index (Id) was used to identify spatial distribution patterns. Regular distribution (no grouping) was considered for Id values lower than 1; random distribution equal to 1; and aggregate distribution greater than 1.

Environments Delimitation

Digital Elevation Models (DEM) were applied to analyze relief characteristics (elevation and slope), drainage, and groundwater depth (HAND – Height Above Nearest Drainage). Variables were assigned according to data on the location of Brazil nut trees, using SIG ArcGIS 10.3.1 for Desktop.

Minimum and maximum altitudes above sea level were acquired based on the altimetric image of the raster SRTM (Shuttle Radar Topography Mission), with 30 m spatial resolution. To classify slope, the following class intervals were adopted: Plain (0-3%), Smooth-wavy (3-8%), Wavy (8-20%), Abrupt-wavy (20-45%), Mountainous (45-75%), and Rugged (> 75%) (SANTOS et al., 2018).

The Height Above Nearest Drainage (HAND) was used to delimit environments considered close to drainage and '*terra-firme* (solid ground)'. The HAND model uses the difference between extracted DEM altitude above sea level and local drainage network to calculate relative heights; it is also related to groundwater depth and land topography (NOBRE et al., 2011; RENNÓ et al., 2008).

A raster with altitude above sea level (SRTM) was transformed into the HAND of the area. To define the head of a drainage network, that is, the zero-order drainage basin, the threshold set was 270 land pixels (SCHIETTI et al., 2013).

The direction of flow is determined by the slope of each SRTM cell, based on eight adjacent cells. Contributing area is defined by all stream cells that receive flow accumulation from over 30 other cells; otherwise it is defined as a "*terra-firme*" cell (NOBRE et al., 2011; RENNÓ et al., 2008). SIG TerraViewHydro 0.4.5 was applied to automatically extract drainage network – procedure used for generating HAND – and the model itself. Trees located between 0 and 5 m in the HAND were considered as close to drainage. When located above 5 m, tree species are unaffected by local drainage (NOBRE et al., 2011; RENNÓ et al., 2008; SCHIETTI et al., 2013).

RESULTS AND DISCUSSION

Population Horizontal Structure

This study recorded 6,027 Brazil nut trees in the study area (11,011.2 hectares). Table 1 shows data on abundance (n), density (ind.ha⁻¹), and dominance (m².ha⁻¹) of the Brazil nut tree population in Flona do

Jamari, as well as their average diameter (d).

Table 1: Brazil nut tree population (*Bertholletia excelsa* Bonpl.) horizontal structure and Annual Production Units (APU).

APU	n	Area (ha)	N (ind.ha ⁻¹)	d (cm)	G (m ² .ha ⁻¹)
1	873	1586.8	0.55	106.34 ± 32.13	0.5333
2	1048	1946.1	0.54	101.89 ± 31.39	0.4808
3	1024	1943.6	0.53	108.21 ± 37.01	0.5412
4	1073	1780.5	0.60	106.64 ± 38.13	0.6017
5	908	1926.7	0.47	100.28 ± 28.61	0.4025
6	1101	1827.5	0.60	101.13 ± 33.04	0.5355
P	6027	11011.2	0.55	104.07 ± 33.83	0.5148

n = abundance; N = density; d = average diameter; G = dominance; ± = standard deviation; P = population.

In Flona do Jamari, the mapped nut trees had 104.07 cm as the mean DBH (min = 38.85 cm and max = 312.10 cm). Our results were higher than those found by other studies conducted in the Amazon. Studies conducted in Acre reported mean DBH values of 82.5 cm, and in Roraima between 65.9 and 74.6 cm, corroborating the values obtained in Amapá (102.6 cm) (NEVES et al., 2016; TONINI et al., 2008). However, these studies adopted different methods for data collection.

Regarding dominance and density, our results were lower than other studies, which reported values ranging from 1.68 to 6.90 m².ha⁻¹ for dominance, and from 3.7 to 12.9 ind.ha⁻¹ for density in Roraima, as well as 0.25 to 12 ind.ha⁻¹ in sample inventory (plots) and 100% of sample intensity, respectively, in Pará (SALOMÃO, 2009; TONINI et al., 2008). This may be explained by disparities in study area sizes and edaphoclimatic conditions in the Eastern and Western regions of the Amazon.

The lack of standardization among forest inventories poses challenges for comparative analyses. (WADT et al., 2005). Variations in Brazil nut trees density occur at plot level and decrease when there is no significant differences between regions; that is, variations occur at both microscale (plot) and macroscale (Amazon), but at mesoscale (region) density patterns tend to be similar (NEVES et al., 2016). This justifies the little variation within population variables among the APUs.

The divergences in sampling methods and the edaphoclimatic conditions in the Amazon justify the different results obtained for the population structure of Brazil nut tree (NEVES et al., 2016; SALOMÃO, 2009; TONINI et al., 2008; WADT et al., 2005). The same occurs for the state of Rondônia (FRANCA, 2015; SCHLINDWEIN et al., 2012), evincing the demand for studies relating data on population structure and spatial distribution of the Brazil nut tree within the different ecosystems of the Legal Amazon.

Exploiting potential timber species requires regulation, which deems density as one of the main parameters. However, there are no technical regulations for non-timber forest products. The legislation recommends adopting sustainable techniques that respect collection periods and volumes set in specific regulations (BRASIL, 2012). In this case, the technician is responsible for interpreting and executing, considering the available stock in the forest. Such consideration stresses the importance on understanding population structure of the Brazil nut tree for managing the species (NEVES et al., 2016).

The horizontal structure is the basis for estimating the species productive potential in the FMU-III of Flona do Jamari - RO, considering its phytosociological parameters, individual density among the APUs, and the large diameters found.

Diametric Distribution

Figure 2 shows Brazil nut trees diametric distribution among the APUs in Flona do Jamari.

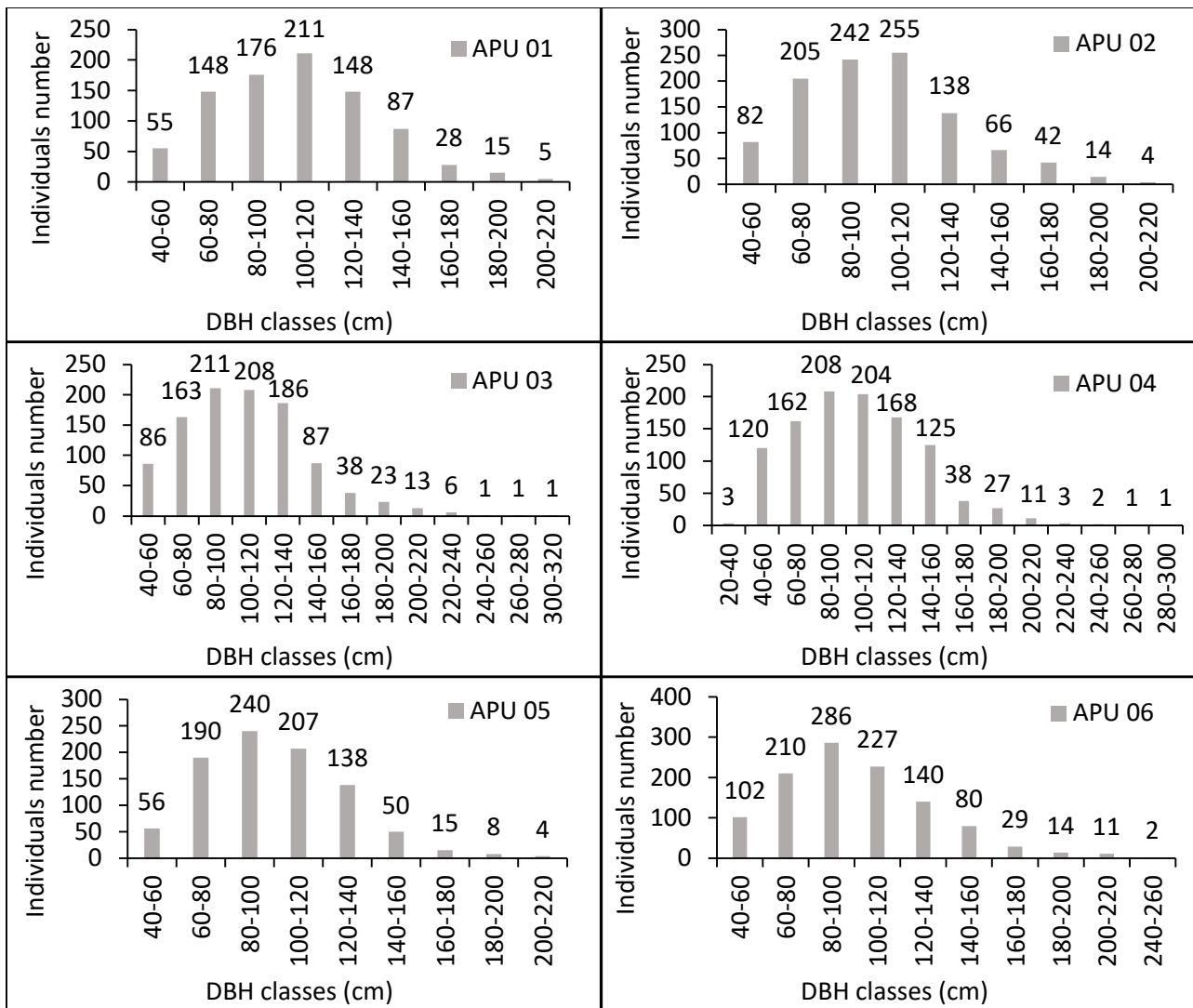


Figure 2: Brazil nut trees (*Bertholletia excelsa* Bonpl.) diametric structure among the APUs (01, 02, 03, 04, 05 and 06) in Flona do Jamari - RO.

Figure 2 shows Brazil nut trees diametric structure among the APUs in Flona do Jamari. We found the most common structure pattern, corroborating other studies in the Amazon (NEVES et al., 2016; SALOMÃO, 2009; TONINI et al., 2008; WADT et al., 2005).

Previous studies recorded few young nut trees, suggesting the species vulnerability in terms of sustainability (MYERS et al., 2000; PERES et al., 2003). Recent studies on population structure, with larger study areas and smaller minimum inclusion diameter (DBH ≥ 10 cm), found the opposite result (NEVES et al., 2016; SALOMÃO, 2009; TONINI et al., 2008; WADT et al., 2005). That means to say that, despite the few young individual trees, Brazil nut tree sustainability is not compromised in the FMU-III of Flona do Jamari, considering the minimum inclusion diameter adopted (DBH ≥ 35 cm).

In most cases (except for specific genetic disorders), Brazil nut trees with DBH between 10 and 50 cm are poorly productive; individual trees tend to reach reproductive maturity with DBH ≥ 100 cm (WADT et al., 2005). We recorded an abundance of trees (77.5%) with DBH between 60-140 cm – 104.07 cm on average, –

indicating a good reproductive capacity in Flona do Jamari.

Studies conducted in the Amazon show few individual trees in DBH classes below 60 cm. It occurs because the species demands radiation within the first stages of growth, and seedlings in conditions of larger clearings have better performance than those submitted to competition and shading, confirming the need for luminosity in early growth (SCOLES et al., 2011).

Spatial Distribution

The Morisita Index (Id) for the population was 1.01, indicating that Brazil nut trees present a random spatial distribution in the area. Other studies indicate regular distribution throughout much of the Amazon extension, as soils are ideal for the species development and distribution (COSTA et al., 2017; SPERA et al., 2019). However, defining the species distribution pattern is a complex task, considering the variations within the territory of a single state and within its growth stages (SALOMÃO, 2009; TONINI et al., 2008; WADT et al., 2005).

Brazil nut trees presented a random spatial distribution in the state of Roraima, and young trees showed a tendency to aggregate patterns (TONINI et al., 2008). Two evaluated plateaus in Pará showed the species distribution as aggregated and random. Such information evince the variability in Brazil Nut Trees ecological patterns in the Amazon. The diverse ecological patterns of distribution of Brazil nut trees and the different forest typologies in the Amazon denotes the importance in associating the environmental and topographic conditions of the species occurrence for understanding its dynamics and patterns.

Environmental And Topographic Conditions

Elevation

In the APUs of Flona do Jamari - RO, the observed altitude above sea level varies from 118 to 209 m, consistent with a 91 m amplitude. The mean value of the area under study was 105 m. Regarding the Brazil nut trees, we found the minimum value of 128 m, mean of 97 m, maximum of 193 m, and amplitude of 65 m (Figure 3).

Elevation influences ambient temperature and affects the evapotranspiration processes and, consequently, precipitation. Its climatic implications, combined with factors such as geology and geomorphology, may be related to the existing vegetation (CAGLIONI et al., 2018). Such influence is proportional to the higher precipitations recorded in the North of the state, compared to the South, as well as soil properties (FRANCA, 2015; SCHLINDWEIN et al., 2012).

The elevation of the region indicates the trend of higher temperatures and precipitation, suggesting greater weathering conditions commonly reflected in the soils groups of Argisol and Oxisol, favorable for the occurrence of Brazil nut tree (COSTA et al., 2017; SPERA et al., 2019).

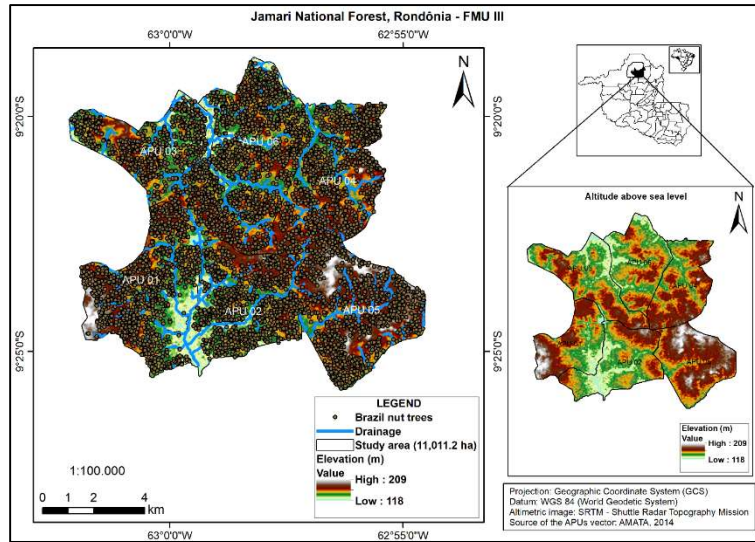


Figure 3: Brazil nut trees (*Bertholletia excelsa* Bonpl.) altitude above sea level (SRTM) and spatial distribution within the studied APUs of FMU-III, Flona do Jamari, RO.

Slope

Slope in the region ranges from 0 to 53.3%, classified into five classes of relief. Predominant classes were: smooth-wavy (54.96%), wavy (25.84%), and plain (18.70%), corresponding to 99.50% of the total area. The remaining 0.50% refers to abrupt-wavy (55.48 ha) and mountainous (0.08 ha) (Figure 4). We found a positive relationship between the number of Brazil nut trees and the smooth-wavy relief type (60.31%) (Table 2).

Table 2: Brazil nut trees (*Bertholletia excelsa* Bonpl.) structural parameters regarding classes of relief, in Flona do Jamari, RO.

Relief of the APUs	n	Area (ha)	N (ind.ha ⁻¹)	d (cm)	G (m ² .ha ⁻¹)
Plain	807	2059.1	0.39	103.98	0.3668
Smooth-wavy	3635	6051.6	0.60	104.35	0.5677
Wavy	1569	2845.1	0.55	103.40	0.5136
Abrupt-wavy	16	55.5	0.29	110.70	0.3075
Mountainous	-	0.1	-	-	-
Total	6027	11011.2	0.55	104.07	0.5148

n = abundance; N = density; d = average diameter; G = dominance.

The attributes obtained by the Digital Elevation Model (DEM), especially the slope, substantiate the derivation of relief units that can support stratification of soil attributes. Oxisols often occur in smaller slopes and regions of high and low elevation. In areas with higher slopes and intermediate hypsometry, Cambisols are more common. Areas with lower elevations combined with low slope categorize hydromorphic soils (SIRTOLI et al., 2008).

Reliefs amidst plain and wavy, with high levels of Aluminum (Al³⁺), are typical for the occurrence of Brazil nut trees and considered ideal for their development (COSTA et al., 2017; SPERA et al., 2019).

That is, the representative extent amidst plain and wavy reliefs combined with the low elevation of the region (indicated by slope and elevation) substantiate the typologies of the soil in Flona do Jamari. Our results tend to be associated with soils pertaining to the classes of Argisols and Oxisols, possibly with high levels of Aluminum (Al³⁺) (COSTA et al., 2017; SIRTOLI et al., 2008; SPERA et al., 2019). Such conditions are considered ideal for the species distribution, justifying the randomness found as ecological pattern.

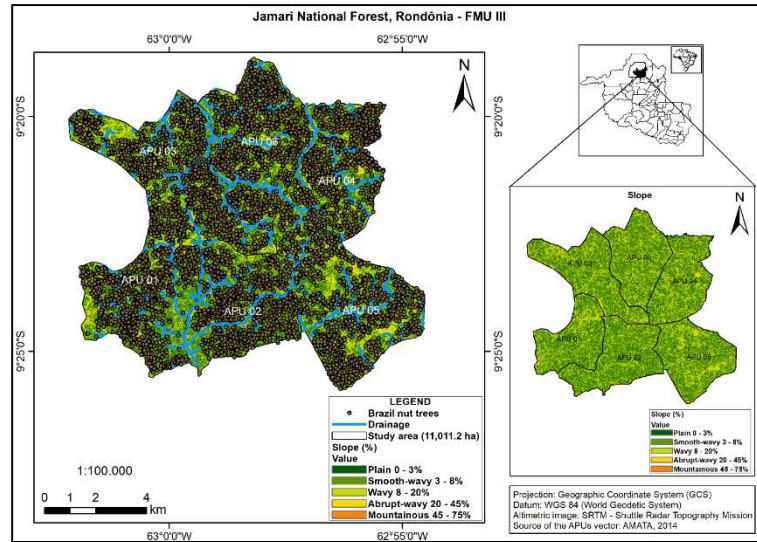


Figure 4: Brazil nut trees (*Bertholletia excelsa* Bonpl.) slope (SRTM) and spatial distribution within the studied APUs of FMU-III, Flona do Jamari, RO.

HAND – Height Above Nearest Drainage

We used the HAND to obtain the height regarding local drainage. Values ranged from 0 to 56 m, and were on average 28 m. However, the mapped Brazil nut trees showed a 44 m amplitude and 13.5 m vertical distance of the nearest water courses, on average (Figure 5). We found a positive relationship between the number of nut trees and HAND (68.2%). That is, the species has an ecological pattern of predominant distribution in ‘terra-firme’, showing no preference for areas near drainages (Table 3).

Table 3: Brazil nut trees (*Bertholletia excelsa* Bonpl.) structural parameters regarding HANDB model, in Flona do Jamari, RO.

HAND (m)	n	Area (ha)	N (ind.ha ⁻¹)	d (cm)	G (m ² .ha ⁻¹)
0 – 5	558	2232.9	0.25	100.50	0.2194
5 – 10	1359	2988.5	0.45	101.68	0.4091
> 10	4110	5789.9	0.71	105.35	0.6833
Total	6027	11011.2	0.55	104.07	0.5148

HAND = height on the local drainage, in m; n = abundance; N = density; d = average diameter; G = dominance.

The HAND model may stand out in vegetation analyses, since the model arises from the difference between the extracted drainage network and information on elevation contained in the SRTM. Thus, the reference level is no longer fixed regarding sea level, but it varies according with the local drainage (NOBRE et al., 2011; RENNÓ et al., 2008).

The model may indicate groundwater depth, and, consequently, variations within an area floristic composition, since it is strongly correlated to the vertical distance of the nearest drainage (SCHIETTI et al., 2013). In Amazonian environments, Brazil nut trees typically occur in areas far from drainage (COSTA et al., 2017; SPERA et al., 2019). Yet, there are records in sandy to medium-textured soils with unsoaked shallow groundwater (SPERA et al., 2019).

The HAND model indicates the relative distance of the mapped Brazil nut trees from the local drainage, in Flona do Jamari, as well as the typical environments for the species occurrence and its preference for areas distant from the drainages. Our results corroborate most studies conducted in the Amazon region (COSTA et al., 2017; SPERA et al., 2019).

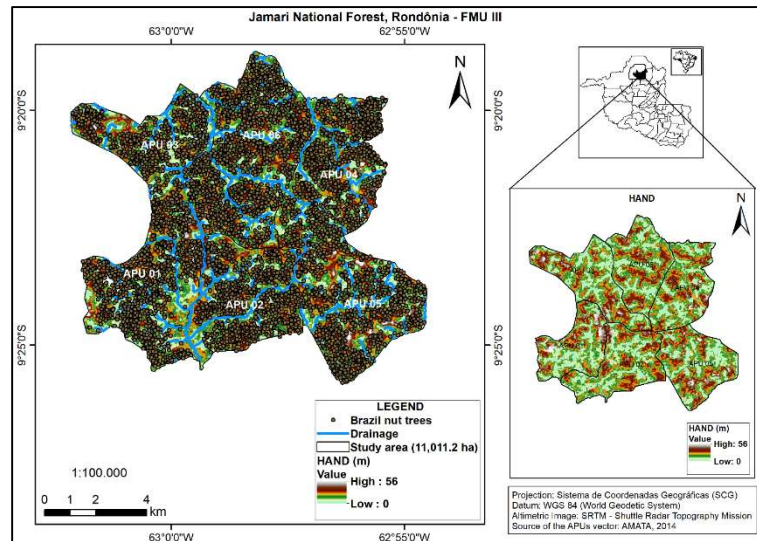


Figure 5: Brazil nut trees (*Bertholletia excelsa* Bonpl.) HAND (SRTM) and spatial distribution within the studied APUs of FMU-III, Flona do Jamari, RO.

CONCLUSIONS

Trees from intermediate DBH classes (60 to 140 cm, 104.07 cm on average) are the most indicated for the species sustainable management – considering their abundance and tendency to reach reproductive maturity within this DBH range (≥ 100 cm); We found a random spatial distribution pattern for the Brazil nut tree in Flona do Jamari; Flona do Jamari's elevation presents favorable conditions for the species distribution; The typical relief in which the species occurs is the smooth-wavy; Brazil nut trees present a predominant distribution ecology pattern of 'terra-firme' and no preference for areas near drainages in the northern region of Rondônia.

The study allowed us to visualize the ecological, spatial, and structural patterns of the Brazil nut tree species, by data acquired in forest inventories and Digital Elevation Models (DEM), in a technically feasible and economically viable way. Our results support further studies on production potential to be conducted in the state of Rondônia, and serve as a tool for decision-making processes related to the species management, and extractivists and government's planning in granting credit.

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