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Sustainable forest management for timber and non-timber resources in the Amazon forest under concession

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Abstract
The Amazon biome is one of the largest in terms of area and biodiversity. It provides impressive ecosystem services that are crucial to planetary functions, for example global precipitation patterns. Besides, it provides important timber and non-timber products that are crucial for local communities and even international markets. The aim of this study was to conduct a phytosociological analysis to select the species with important ecological functions and with commercial interest for timber and non-timber forest products (NTFP). Forest inventory data were collected were collected from 4 Annual Production Units (APUs) at the Paru State Forest. The 5 species with highest Importance Value Index (IVI) were: *Chrysophyllum lucentifolium*, *Micropholis venulosa, Handroanthus serratifolius*, *Handroanthus impetiginosus* and *Manilkara huberi.* These species presented commercial volume in the diameter classes of 40 to $\geq$ 170 cm. The species providing NTFP (*Carapa guianensis*, *Bertholletia excelsa* and *Copaifera guianensis*) presented IVI in the 1, 9, and 34 positions, respectively. The species *Carapa guianensis* presented more individuals in the 40 and 80 DBH classes. *Bertholletia excelsa* was the only one presenting individuals with DBHs exceeding 140 cm. *Copaifera guianensis* was the less common species. We concluded that all the 5 species producing timber are viable for sustainable forest management. Regarding the non-timber forest species, forest management need to be focused in *Carapa guianensis* and *Bertholletia excelsa.*

Keywords
Forest concession — Horizontal structure — Importance Value Index — Timber Products — Nom-timber Forest Products

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1. Introduction

The Amazon biome occupies 59% of Brazilian territory (IBGE, 2021) and is one of the most important biodiversity hotspots on the planet (Ter Steege et al., 2020; Castuera-Oliveira et al., 2020). It is crucial to protect and preserve the forest, which is threatened by climate change and deforestation, and to increase efforts towards restoring degraded areas and storing carbon (Flores et al., 2024). One of the main strategies to combat deforestation (INPE, 2024) is to establish Conservation Units (CUs) by public authorities. CUs are protected lands created with the goal of reducing irregular occupation, improper land use, and other illegal activities contributing to deforestation (Brasil, 2000; Silva; Sauer, 2022).

According to the National System of Conservation Units (Brazil, 2000), CUs are divided into two groups: for Full Protection and for Sustainable Use. As the name suggests, Sustainable Use CUs are more permissive regarding natural resources management, as long as these uses are specified in the CU creation Act and the CU Management Plan. The sustainable use of natural resources is achieved through the application of Sustainable Forest Management principles, which, according to law nº 11.284 (Brasil, 2006), involves forest administration aimed at obtaining economic, social, and environmental benefits, while respecting the balance of ecosystem functions and considering both timber and non-timber species.

CUs can be sustainably managed through Concession agreements on public lands in Brazil (Brasil, 2006). Forest Concessions attract forestry companies committed to sustainable forest management practices and socio-environmental responsibility (Soares; Bezerra, 2021). Although forest concessions can be applied for throughout Brazil, the biome with the highest number of concession agreements is the Amazon forest, particularly in the state of Pará (Soares; Bezerra, 2021; SFB, 2023). One exam-

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ple of an area under concession is the Paru State Forest, established by Act 2.608/2006 (Pará, 2006), characterized by old-growth forest with high average individual volume and abundant non-timber forest species (Imazon, 2011).

In addition to generating direct socioeconomic benefits through the sustainable use of forest resources, forest concessions enable research in areas with minimal human intervention, providing data on floristic composition, horizontal forest structure (Cunha; Dias, 2023), floristic similarity (Araújo, 2023), canopy openness assessment (Moraes et al., 2016), biomass, and carbon (Ferreira, 2019).

In this context, the aim of this study was to conduct phytosociological analysis to identify species of great ecological importance and commercial potential for both timber and non-timber forest products (NTFPs).

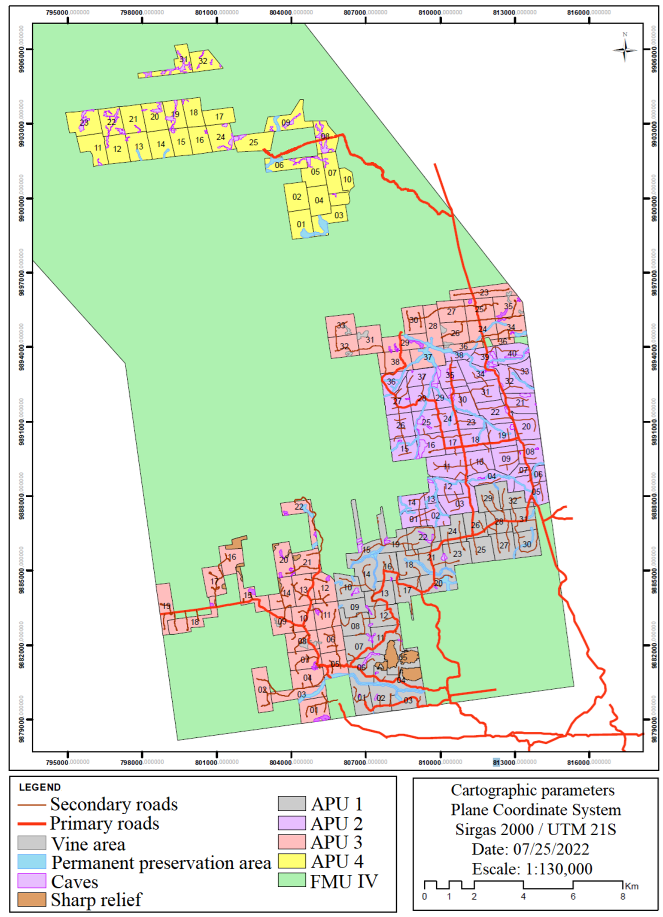
2. Material and Methods

2.1 Study Area

The study site is located within the Amazon Forest, State of Pará, specifically in the Paru State Forest. The Paru State Forest spans 3,612,914 hectares and includes portions of the municipalities of Almeirim (58%), Monte Alegre (18%), Alenquer (18%), Óbidos (4%), and Prainha (2%) (Pará, 2010).

The region's climate is classified as type "Am" according to the Köppen classification, falling within the tropical range. This climate type typically features temperatures ranging between 18 and 30 ℃ throughout most of the year, accompanied by high humidity and frequent rainfall, with no distinct dry season (Alvares et al., 2013). According to the Paru State Forest Management Plan (Pará, 2010), average monthly rainfall totals 215 millimeters, peaking from January to June (250 to 450 mm) and decreasing from July to November (50 to 150 mm). The predominant soil types are red-yellow argisol, red-yellow latosol, and litholic neosol. The vegetation is primarily characterized by dense submontane rainforest.

Within the Paru State Forest, the area selected for the study corresponds to the Forest Management Unit (FMU) IV, which spans 50,938.44 hectares (Blue Timber Florestal, 2023). FMU IV has been subdivided into 30 Annual Production Units (APUs); this study was conducted using the data available to date from APUs 1, 2, 3, and 4. Within each APU, subdivision into Work Units (WUs) of approximately 100 hectares is still being considered to facilitate the operationalization of field activities. APU 1 was subdivided into 32 WUs, APU 2 into 40 WUs, APU 3 into 38 WUs, and APU 4 into 27 WUs. A 100% forest inventory was conducted in the Effective Exploration Area (EEA) of each APU, excluding areas with roads, abundant lianas, permanent preservation areas, caves, and steep relief (Figure 1). The EEA of APU 1 corresponds to 2,974.3435 hectares, APU 2 to 3,138.0858 hectares, APU 3 to 3,535.2631 hectares, and APU 4 to 2,235.0594 hectares, totaling 11,882.7518 hectares sampled.



Source: Blue Timber Florestal (2022)

Figure 1. Annual Production Units 1, 2, 3 and 4 subdivided into Work Units, considering the Effective Exploration Area and other areas (roads, abundance of vines, permanent preservation, caves and steep relief).

2.2 Database

Data was collected and provided by the company Blue Timber Florestal, which carried out the 100% forest inventory in the EEA of the 1, 2, 3 and 4 APUs in the years 2019, 2020, 2021 and 2022, respectively. The criteria for inclusion of tree individuals in the sampling were a minimum diameter of inclusion (MDI) $\geq$ 40 cm and be listed as commercial or potential for commercial use. All sampled individuals were measured on its diameter at breast height of 1.3 m or for breast height (DBH) and

Table 1. Phytosociological parameters of absolute density (AD), relative density (DR), absolute dominance (ADo), relative dominance (RDo), absolute frequency (AF), relative frequency (RF), coverage value index (CVI) and importance value index (IVI).

Variables	Minimum	Maximum	Mean	Standard deviation
DBH (cm)	40.00	286.48	70.92	22.68
TH (m)	10.00	28.00	14.81	3.26
B (m²)	0.1243	6.45	0.44	0.31
V (m³)	0.0085	68.27	3.42	3.83

Table 2. Minimum, maximum, mean and standard deviation values of the DBH, TH, B and V variables, considering the individuals sampled in Annual Production Units 1, 2, 3 and 4, in Forest Management Unit IV, in the Paru State Forest.

Parameters	Absolute values	Relative values
Absolute Density	$AD = \frac{n_i}{A}$	$RD = \frac{n_i}{N}.100$
Dominance	$ADo = \frac{B_i}{A}$	$RDo = \frac{ADo}{\sum_{i=1}^{S} ADo}.100$
Frequency	$AF = \frac{U_i}{U_T}.100$	$RF = \frac{AF}{\sum_{i=1}^{S} AF}$
Coverage value index	-	$CVI = \frac{RD+RDo}{2}$
Importance value index	-	$IVI = \frac{RD+RDo+RF}{3}$

Where: i= species ranging from 1, 2,..., S; n_i = number of individuals of the i-th species; A = area sampled in hectares; N= total number of individuals sampled; B_i= basal area of the i-th species; U_i= number of sampling units in which i-th species was found; U_T= total number of sampling units.

total height (TH). In addition, botanical identification at species level, geographical location, and the quality of the stem was assessed (1 - straight stem and no defects, with maximum use of the logs; 2 - crooked stem and no defects, with partial use of the logs; 3- crooked and defective stem, with minimal use of the logs). Basal area (B) was calculated from DBH data. Mean individual volume (V) was calculated using an equation from data at APU 1. Table 1 summarizes inventory data from the APUs 1, 2, 3 and 4.

2.3 Phytosociology

Absolute density (AD), relative density (DR), absolute dominance (ADo), relative dominance (RDo), absolute frequency (AF), relative frequency (RF), coverage value index (CVI) and importance value index (IVI) were calculated using Excel (Table 2) (Souza; Soares, 2013), considering the 4 APUs. The area of each WU within the APUs was used as a sampling unit.

After obtaining the phytosociological parameters, the Importance Value Index (IVI) was considered to filter the commercial species with the greatest ecological importance in the area. Ecological importance takes into account the number of individuals of the species (relative density), the distribution of the species in the area (relative frequency) and the degree of occupancy in relation to the basal area of the species (relative dominance).

Table 3. List of commercial species managed by the company Blue Timber Florestal in the Paru State Forest.

Number	Scientific name	Common name
1	*Apuleia leiocarpa (Vogel) J.F.Macbr.*	Garapeira
2	*Astronium lecointei Ducke*	Muiracatiara
3	*Bagassa guianensis Aubl.*	Tatajuba
4	*Bowdichia nitida Spruce ex Benth.*	Yellow sucupira
5	*Cedrela odorata L.*	Cedro
6	*Chrysophyllum lucentifolium Cronquist*	Goiabão
7	*Dipteryx odorata (Aubl.) Forsyth f.*	Cumaru
8	*Handroanthus impetiginosus (Mart. ex DC.) Mattos*	Purple ipê
9	*Handroanthus serratifolius (Vahl) S.Grose*	Yellow ipê
10	*Hymenaea courbaril L.*	Jatobá
11	*Hymenolobium excelsum Ducke*	Angelim Pedra
12	*Manilkara elata (Allemão ex Miq.) Monach.*	Maçaranduba
13	*Mezilaurus itauba (Meisn.) Taub. ex Mez*	Itaúba
14	*Micropholis venulosa (Mart. & Eichler) Pierre*	Currupixá

2.4 Commercial timber species

The timber species with commercial interest were identified according to the list of species managed by Blue Timber Florestal (2024), shown in Table 3. Among these species, the 5 with the highest IVI in the phytosociological analysis were selected. The 5 filtered species were analyzed in terms of number of individuals and volume in each APU.

2.5 Potential non-timber species with commercial interest

The main non-timber species with commercial interest were identified according to the literature on non-timber forest products (NTFP) in the Amazon (Pinto et al., 2010; Wadt et al., 2017): andiroba (*Carapa guianensis* Aubl.), Brazil nut (*Bertholletia excelsa* Humb. & Bonpl.) and copaíba (*Copaifera guianensis* Desf.). For these species, information on IVI, number of individuals in each APU and distribution of individuals among the WUs of each APU were analyzed. Furthermore, the number of individuals/ha was analyzed in relation to the diameter distribution.

3. Results

3.1 Phytosociology

The species *Carapa guianensis* (andiroba) presented the highest IVI due to the higher number of individuals (density) and better distribution in all sampled WUs (frequency). In terms of degree of occupancy (dominance), *Chrysophyllum lucentifolium* (goiabão) was the second species with the highest IVI. This indicates that, on average, andiroba individuals have lower DBH than guava

Table 4. Phytosociological parameters of species ordered in relation to the Importance Value Index, present in Annual Production Units 1, 2, 3 and 4, in Forest Management Unit IV, in the Paru State Forest.

Nº	Scientific name	AD	ADo	AF	RD	RDo	RF	CVI	IVI
1	*Carapa guianensis*	191.72	48.07	120	17.26	10.00	3.16	13.63	10.14
2	*Chrysophyllum lucentifolium*	149.24	53.67	110	13.43	11.17	2.90	12.30	9.17
3	*Micropholis venulosa*	62.19	48.40	104	5.60	10.08	2.74	7.84	6.14
4	*Handroanthus serratifolius*	81.14	28.63	137	7.30	5.96	3.61	6.63	5.62
5	*Handroanthus impetiginosus*	61.87	28.96	133	5.57	6.03	3.50	5.80	5.03
6	*Poecilanthe parviflora*	72.19	28.22	76	6.50	5.87	2.00	6.19	4.79
7	*Manilkara huberi*	53.85	27.46	79	4.85	5.72	2.08	5.28	4.21
8	*Bagassa guianensis*	39.20	23.28	137	3.53	4.85	3.61	4.19	3.99
9	*Bertholletia excelsa*	36.48	23.58	55	3.28	4.91	1.45	4.10	3.21
10	*Lecythis pisonis*	23.91	16.48	124	2.15	3.43	3.26	2.79	2.95
11	*Hymenaea courbaril*	22.90	17.49	109	2.06	3.64	2.87	2.85	2.86
12	*Mezilaurus itauba*	23.02	10.39	136	2.07	2.16	3.58	2.12	2.61
13	*Cedrelinga cateneiformis*	38.82	16.62	32	3.49	3.46	0.84	3.48	2.60
14	*Cedrela odorata*	22.48	9.31	134	2.02	1.94	3.53	1.98	2.50
15	*Newtonia suaveolens*	19.96	8.22	103	1.80	1.71	2.71	1.75	2.07
16	*Apuleia leiocarpa*	17.14	8.50	105	1.54	1.77	2.76	1.66	2.03
17	*Cariniana micrantha*	13.40	6.24	130	1.21	1.30	3.42	1.25	1.98
18	*Buchenavia parvifolia*	18.67	7.15	104	1.68	1.49	2.74	1.58	1.97
19	*Astronium lecointei*	16.86	6.76	103	1.52	1.41	2.71	1.46	1.88
20	*Erisma lanceolatum*	8.82	6.05	102	0.79	1.26	2.68	1.03	1.58
21	*Dipteryx odorata*	7.23	2.98	122	0.65	0.62	3.21	0.64	1.49
22	*Ocotea fragrantissima*	10.10	2.56	115	0.91	0.53	3.03	0.72	1.49
23	*Vatairea paraensis*	8.72	3.65	111	0.79	0.76	2.92	0.77	1.49
24	*Hymenolobium petraeum*	5.86	3.47	121	0.53	0.72	3.19	0.63	1.48
25	*Bowdichia nitida*	6.83	2.22	112	0.61	0.46	2.95	0.54	1.34
26	*Mahurea speciosa*	17.47	6.29	33	1.57	1.31	0.87	1.44	1.25
27	*Clarisia racemosa*	3.99	1.15	114	0.36	0.24	3.00	0.30	1.20
28	*Diplotropis purpurea*	2.36	0.59	90	0.21	0.12	2.37	0.17	0.90
29	*Hymenaea sp*	6.24	4.84	38	0.56	1.01	1.00	0.78	0.86
30	*Diplotropis racemosa*	4.98	1.38	60	0.45	0.29	1.58	0.37	0.77
31	*Enterolobium schomburgkii*	5.31	2.26	51	0.48	0.47	1.34	0.47	0.76
32	*Manilkara bidentada*	5.66	2.45	45	0.51	0.51	1.18	0.51	0.73
33	*Euplassa sp.*	4.66	3.66	27	0.42	0.76	0.71	0.59	0.63
34	*Copaifera guianensis*	2.35	0.91	49	0.21	0.19	1.29	0.20	0.56
35	*Bowdichia brasiliensis*	1.19	0.35	57	0.11	0.07	1.50	0.09	0.56
36	*Apuleia molaris*	3.74	2.15	32	0.34	0.45	0.84	0.39	0.54
37	*Buchenavia capitata*	3.72	1.83	27	0.33	0.38	0.71	0.36	0.48
38	*Erisma fuscum*	5.29	2.38	16	0.48	0.50	0.42	0.49	0.46
39	*Erisma uncinatum*	2.94	1.56	29	0.26	0.32	0.76	0.29	0.45
40	*Pouteria elegans*	4.31	1.76	19	0.39	0.37	0.50	0.38	0.42
41	*Aspidosperma eteanum*	0.97	0.21	42	0.09	0.04	1.11	0.07	0.41
42	*Citharexylum cinerium*	3.00	0.70	27	0.27	0.15	0.71	0.21	0.38
43	*Vochysia maxima*	1.88	1.10	27	0.17	0.23	0.71	0.20	0.37
44	*Vochysia inundata*	1.91	1.23	25	0.17	0.26	0.66	0.21	0.36
45	*Platymiscium duckei*	1.46	0.34	30	0.13	0.07	0.79	0.10	0.33
46	*Tachigali paraensis*	2.24	0.62	24	0.20	0.13	0.63	0.17	0.32
47	*Hymenaea reticulata*	0.85	0.61	25	0.08	0.13	0.66	0.10	0.29
48	*Vochysia guianensis*	1.55	0.78	20	0.14	0.16	0.53	0.15	0.28
49	*Tetragastris panamensis*	1.73	0.42	22	0.16	0.09	0.58	0.12	0.27
50	*Helicostylis pedunculata*	3.43	0.72	12	0.31	0.15	0.32	0.23	0.26
51	*Parkia oppositifolia*	0.35	0.22	17	0.03	0.05	0.45	0.04	0.18
52	*Lecythis idatimon*	1.69	0.45	10	0.15	0.09	0.26	0.12	0.17
53	*Cordia bicolor*	0.26	0.06	13	0.02	0.01	0.34	0.02	0.13
54	*Buchenavia grandis*	0.30	0.16	11	0.03	0.03	0.29	0.03	0.12
55	*Brosimum paraense*	0.48	0.14	9	0.04	0.03	0.24	0.04	0.10
56	*Andira fraxinifolia*	0.17	0.06	10	0.02	0.01	0.26	0.01	0.10
57	*Goupia glabra*	0.28	0.13	9	0.02	0.03	0.24	0.03	0.10
58	*Ocotea diospyrifolia*	0.16	0.05	8	0.01	0.01	0.21	0.01	0.08
59	*Caraipa grandiflora*	0.17	0.07	7	0.02	0.01	0.18	0.01	0.07
60	*Parkia pendula*	0.19	0.09	6	0.02	0.02	0.16	0.02	0.06
61	*Pithecellobium racemosum*	0.10	0.02	6	0.01	0.00	0.16	0.01	0.06
62	*Aniba canelilla*	0.08	0.03	5	0.01	0.01	0.13	0.01	0.05
63	*Acrodiclidium brasiliense*	0.18	0.05	4	0.02	0.01	0.11	0.01	0.04
64	*Alexa grandiflora*	0.32	0.10	3	0.03	0.02	0.08	0.02	0.04
65	*Euxylophora paraensis*	0.05	0.02	3	0.00	0.00	0.08	0.00	0.03
66	*Caryocar microcarpum*	0.02	0.01	2	0.00	0.00	0.05	0.00	0.02
67	*Nectandra rubra*	0.02	0.01	2	0.00	0.00	0.05	0.00	0.02
68	*Alchornea triplinervia*	0.02	0.01	2	0.00	0.00	0.05	0.00	0.02
69	*Ocotea puberula*	0.02	0.01	2	0.00	0.00	0.05	0.00	0.02
70	*Protium sagotianum*	0.02	0.01	2	0.00	0.00	0.05	0.00	0.02
71	*Virola minutiflora*	0.02	0.01	1	0.00	0.00	0.03	0.00	0.01
72	*Parkia paraensis*	0.02	0.01	1	0.00	0.00	0.03	0.00	0.01
73	*Trattinnickia burseraefolia*	0.02	0.01	1	0.00	0.00	0.03	0.00	0.01
74	*Brosimum acutifolium*	0.01	0.01	1	0.00	0.00	0.03	0.00	0.01
75	*Capirona huberiana*	0.01	0.01	1	0.00	0.00	0.03	0.00	0.01
76	*Sagotia brachysepala*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01
77	*Parkia multijuga*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01
78	*Euplassa pinnata*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01
79	*Ceiba pentandra*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01
80	*Pterocarpus officinalis*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01
81	*Jacaranda copaia*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01
82	*Couepia paraensis*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01
83	*Qualea albiflora*	0.01	0.00	1	0.00	0.00	0.03	0.00	0.01

Where: AD = absolute density (individuals/ha), Ado = absolute dominance (m^2/ha), AF = absolute frequency, RD = relative density (%); Rdo = relative Dominance (%); CVI = coverage value index and IVI = importance value index.

Table 5. Number of individuals and volume of the 5 commercial timber species with the highest importance value index.

Scientific name (common name)	APU	Number of individuals	Number of individuals/ha	Volume (m^3)	Volume (m^3/ha)
Chrysophyllum lucentifolium (goiabão)	1	575.0	6.5	2586.6	29.2
	2	1471.0	18.3	4460.9	54.2
	3	4049.0	43.9	15926.4	172.4
	4	6347.0	80.7	358.3	4.7
Micropholis venulosa (currupixá)	1	1779.0	19.0	14674.7	156.5
	2	2502.0	30.4	16628.5	198.7
	3	1173.0	13.0	9899.4	109.2
	4	-	-	-	-
Handroanthus serratifolius (yellow ipê)	1	2479.0	26.6	11923.5	128.1
	2	2772.0	34.9	7728.6	96.9
	3	886.0	9.7	3095.0	33.8
	4	815.0	10.3	46.2	0.6
Handroanthus impetiginosus (purple ipê)	1	890.0	9.6	6161.1	66.7
	2	1991.0	26.7	9500.8	128.3
	3	1425.0	15.3	7686.5	82.9
	4	836.0	10.3	53.5	0.7
Manilkara huberi (maçaranduba)	1	11.0	0.1	58.2	0.6
	2	969.0	12.9	5005.7	67.1
	3	2329.0	25.3	13840.7	149.9
	4	1390.0	15.5	80.2	0.9

individuals, which is not a problem since andiroba is under the NTFPs group, and guava use is timber. The next 3 species with the highest IVI are of commercial timber interest: currupixá, yellow ipê and purple ipê.

3.2 Commercial timber species

The species with commercial timber interest presenting the highest IVI rankings are: 2nd) *Chrysophyllum lucentifolium* (goiabão), 3rd) *Micropholis venulosa* (currupixá), 4th) *Handroanthus serratifolius* (yellow ipê), 5th) *Handroanthus impetiginosus* (purple ipê), and 7th) *Manilkara huberi* (maçaranduba) (Table 3 and 4).

Table 5 details the number of individuals and volume of these species within each APU. It shows that goiabão had the highest number of individuals in APU 4 and the greatest volume in APU 3; currupixá had both the highest number of individuals and volume in APU 2; yellow ipê had the greatest number of individuals in APU 2 and the highest volume in APU 1; purple ipê had the highest number of individuals and volume in APU 2; and maçaranduba had the highest number of individuals and volume in APU 3.

Figure 2 shows the volume distribution across diameter classes for the 4 APUs. It can be observed that all 5 species have volume (m^3/ha) represented in every DBH class, ranging from 40 and 50 cm to $\geq$ 170 cm. Guava stands out in classes with lower DBH, while currupixá stands out in classes with higher DBH.

3.3 Potential non-timber species with commercial interest

According to Table 4, the species *Carapa guianensis* (andiroba), *Bertholletia excelsa* (Brazil nut) and *Copaifera*

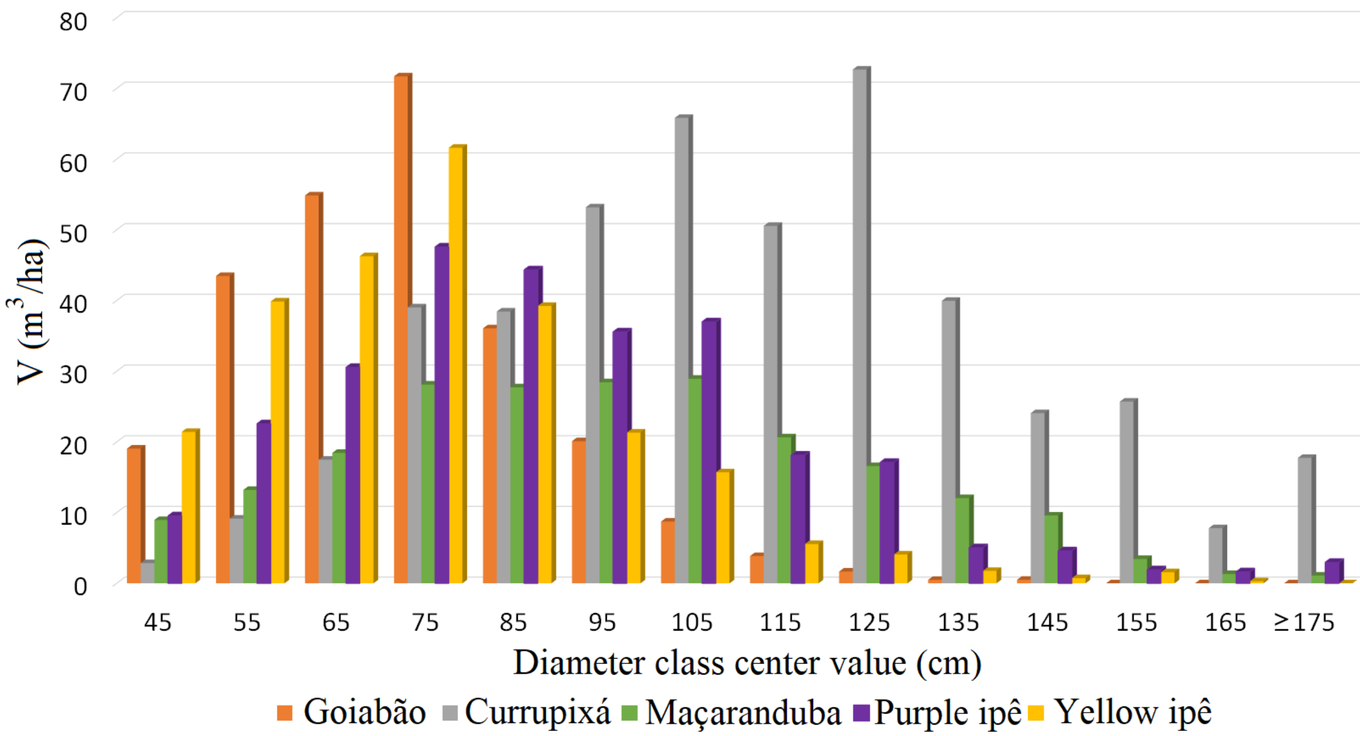


Figure 2. Volume (m³/ha) of the 5 species of commercial timber interest with the highest importance value index, distributed in diameter classes (cm), present in Annual Production Units 1, 2, 3 and 4, in Forest Management Unit IV, in the Paru State Forest

guianensis (copaíba) ranked 1st, 9th and 34th respectively in terms of IVI. The number of individuals in each APU and the distribution of individuals among the WUs of each APU (frequency) are presented in Table 6. Andiroba is the one with the highest number of individuals and is best distributed, for example, in all WUs of APUs 1 and 2. The Brazil nut tree also has individuals in all APUs, but its abundance is lower than that of andiroba in all APUs. Furthermore, these individuals appear in about half of the WUs of APUs 1 and 2. Finally, it is observed that the copaíba does not present individuals in APU 2, but the number of individuals in APU 4 is slightly higher in relation to that found for the Brazil nut tree.

According to Figure 3, andiroba shows a higher density of individuals between 40 and 80 cm in diameter. The Brazil nut was the only species with individuals having a DBH greater than 140 cm, while the copaíba tree had a relatively low number of individuals compared to the other species and did not stand out in any diameter class.

Table 6. Number of individuals and distribution of individuals throughout the Work Units of each Annual Production Unit of the 3 species of non-timber commercial interest considered.

Scientific name (common name)	APU	Number of individuals	Number of individuals/ha	Absolute frequency (%)
Carapa guianensis (andiroba)	1	5373	58,1	100
	2	7875	100,7	100
	3	2866	30,8	92
	4	294	3,3	48
Bertholletia excelsa (castanheira-do-brasil)	1	452	4,7	53
	2	1846	21,7	55
	3	853	8,6	34
	4	134	1,5	11
Copaifera guianensis (copaíba)	1	35	0,4	56
	2	-	-	-
	3	15	0,2	18
	4	148	1,8	89

4. Discussion

Legislation associated with sustainable forest management in the Amazon demands a 100% forest inventory (census) of the Ecological-Economic Zoning (EEA) of each APU as a requirement for granting Exploration Authorization (Brasil, 2009). This inventory serves as a crucial database for scientific research. In this study, 83 species were identified across the total sampled area (11,882.7 ha), which is lower compared to the 121 species documented by Guedes (2022) in the Paru State Forest. This disparity can be attributed to the high Minimum Diameter at Inventory (MDI) used in the 100% forest inventory, which includes only individuals with a DBH of 40 cm or

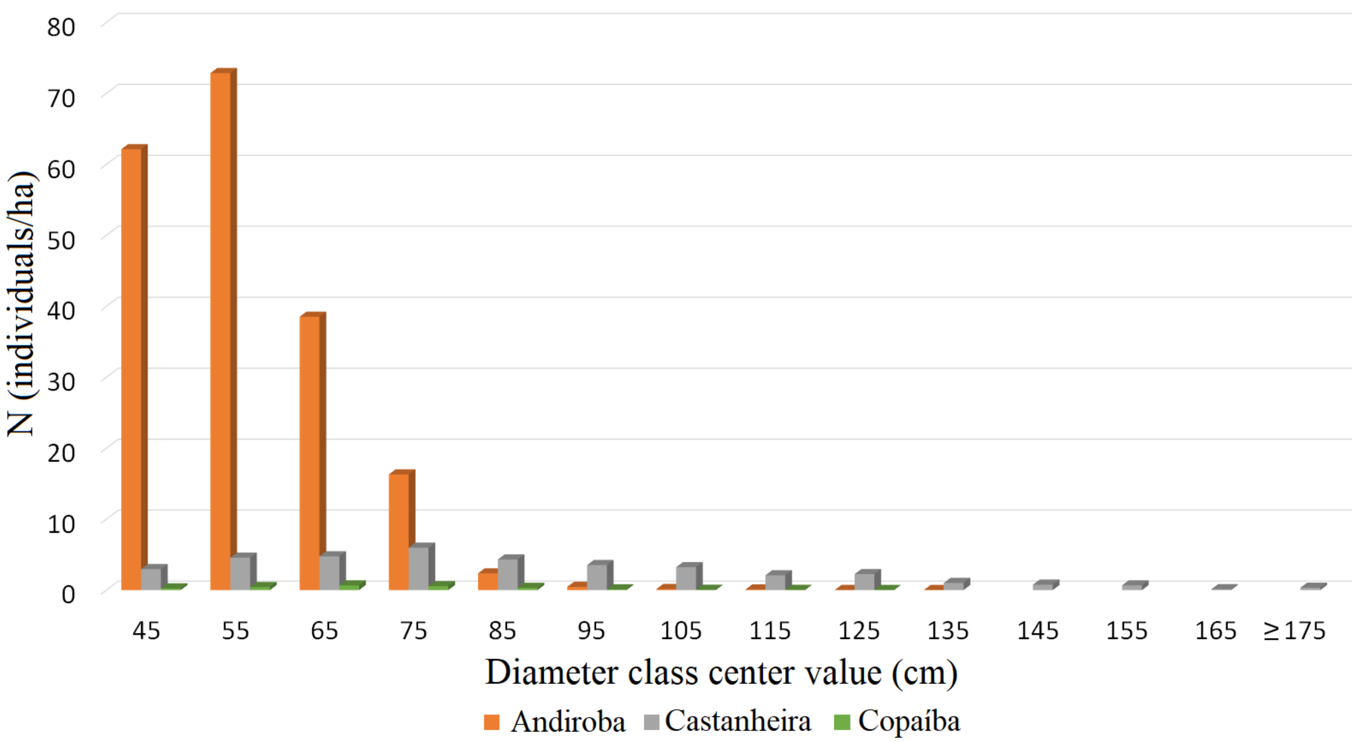


Figure 3. Number of individuals/ha of the 3 species of non-timber commercial interest, distributed in diameter classes (cm), present in Annual Production Units 1, 2, 3 and 4, in Forest Management Unit IV, in the Paru State Forest.

more, whereas Guedes (2022) observed a high density concentrated in diameter classes from 10 to 40 cm. This pattern is explained by the skewed (inverted J-shaped) distribution typical of uneven-aged forests (Missio et al., 2021). Additionally, the 100% forest inventory employs the selection of commercially valuable and potentially valuable species as a criterion. The 5 species filtered by Importance Value Index (IVI) for their commercial timber value are significant at national and international markets due to their high-quality wood, aligned with the sustainable practices required for FSC forest certification (Blue Timber Florestal, 2024). Furthermore, the distribution of volume (m^3/ha) of these 5 species across the analyzed APUs and diameter ranges contributes to minimizing the impact of logging operations.

According to the Brazilian Forest Service (SFB, 2024) and the Brazilian Agricultural Research Corporation (Embrapa, 2021), wood from *Chrysophyllum lucentifolium* and *Micropholis venulosa* can be used for construction, furniture, decorative household items, turning, toys, utilitarian household items, and metal plates. Ipe wood (*Handroanthus serratifolius* and *Handroanthus impetiginosus*) wood can be used in carpentry, general construction, sleepers, flooring, heavy construction, industrial components, bridge and maritime constructions (above water), poles, small stakes, sports equipment, hand tools, turning, veneers, and plywood. *Manilkara huberi* wood is primarily used in external construction, sleepers, and industrial flooring. While low-impact logging is performed to harvest these and other commercially valuable species in the Amazon. Reategui-Betancourt et al. (2024) emphasize that long-term forest dynamics have been affected by forest management, compromising species dynamics and timber production for future cycles. The authors suggest that the national forest management legislation should be revisited in the Brazilian Amazon to ensure long-term sustainability.

Non-timber commercial species analyzed with interest in oil extracted from seeds and trunks respectively, include *Carapa guianensis* and *Copaifera guianensis*. According to Meneguetti et al. (2019), the oil from these species shows potential for insecticidal, antiparasitic, anti-inflammatory, and healing products. Financial support from the Brazilian government and agencies to foster research in the Amazon region is needed. Sousa et al. (2021) demonstrated the socioeconomic significance of oil extraction from *Carapa guianensis* for Amazon communities, using manual extraction methods. *Bertholletia excelsa*, known as Brazil nuts, serves primarily the food sector, where nuts are consumed fresh, processed into food ingredients (Pinto et al., 2010), or used for oil extraction and cosmetic production, such as soaps and moisturizing creams (Natura, 2024). Studies underscore the socioeconomic importance of non-timber forest products (NTFPs) from this species in the Brazilian Amazon (Batista et al., 2019; Kainer et al., 2018; Silva; Paraense, 2019). Blue Timber Florestal (2023) notes that individuals of *Bertholletia excelsa* within Forest Management Units (FMUs) are utilized for NTFP extraction, providing income for collectors from local communities. This illustrates that forest concessions applying sustainable timber harvesting can forge partnerships with local communities for NTFP extraction, contributing to infrastructure development, utilizing individuals identified in the 100% forest inventory, processing, and accessing new market opportunities (Soares; Bezerra, 2021).

5. Conclusion

In the total area sampled 83 species were found considering a Minimum Diameter at Inventory of $\geq$ 40 cm. Among these, the 5 commercial timber species that stood out with the highest Importance Value Index (IVI) (*Chrysophyllum lucentifolium*, *Micropholis venulosa*, *Handroanthus serratifolius*, *Handroanthus impetiginosus*, *Manilkara huberi*) showed sufficient volume (m³/ha) and distribution for effective exploration planning.

The potential for exploiting species with non-timber commercial interest is also promising in the area, particularly for *Carapa guianensis* and *Bertholletia excelsa*, which ranked 1st and 9th, respectively, in terms of the highest IVI values. This highlights the opportunity for partnerships between the forest concession holder and surrounding communities for the extraction of these non-timber forest products.

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Author Statements

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- ✓ There is no evidence of plagiarism in this article.

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