



FLORAL COMPOSITION, POPULATION STRUCTURE, AND DYNAMICS OF A SECONDARY FOREST FRAGMENT IN THE EASTERN AMAZON, PARÁ, BRAZIL

Jesomi Jonatan da Costa Abreu¹
Maria de Lourdes Pinheiro Ruivo²
Helaine Cristine Gonçalves Pires³

ABSTRACT

Objective: This study aims to analyze the floristic composition, population structure, and temporal dynamics of a secondary forest fragment in São João de Pirabas, Pará, in order to understand its successional stage and the factors driving its regeneration.

Theoretical Framework: The research is grounded in studies on ecological succession, secondary forest dynamics, and remote sensing. Key contributions by Chazdon, Laurance, Poorter, and Almeida highlight natural regeneration patterns, floristic structure, and the use of NDVI for temporal assessment.

Method: The study combined forest inventory, phytosociological analysis, diameter distribution, and processing of Landsat images (2004, 2015, 2024). NDVI, structural parameters, Shannon diversity index, and Pielou's evenness were calculated to characterize the fragment.

Results and Discussion: The dominance of *Manilkara bidentata*, *Tapirira guianensis*, and *Symphonia globulifera* indicates an intermediate successional stage. The inverted "J" diameter distribution suggests active recruitment. NDVI declined after 2004, indicating recent disturbances. Moderate diversity reflects a transitional successional phase.

Research Implications: Findings support management, conservation, and ecological restoration strategies in Eastern Amazonia.

Originality/Value: The study integrates floristic, structural, and temporal analyses in an underexplored area, offering a robust diagnosis of secondary forest regeneration.

Keywords: Secondary Forest, Phytosociology, NDVI, Eastern Amazon, Ecological Succession.

COMPOSIÇÃO FLORÍSTICA, ESTRUTURA POPULACIONAL E DINÂMICA DE UM FRAGMENTO DE FLORESTA SECUNDÁRIA NA AMAZÔNIA ORIENTAL, PARÁ, BRASIL

RESUMO

Objetivo: O objetivo deste estudo é analisar a composição florística, a estrutura populacional e a dinâmica temporal de um fragmento de floresta secundária em São João de Pirabas, Pará, buscando compreender seu estágio sucessional e os fatores que influenciam sua regeneração.

Referencial Teórico: A pesquisa fundamenta-se em estudos sobre sucessão ecológica, dinâmica de florestas secundárias e sensoriamento remoto. Destacam-se contribuições de Chazdon, Laurance, Poorter e Almeida, que discutem regeneração natural, padrões florísticos e uso de índices de vegetação como o NDVI para avaliação temporal.

Método: A investigação combinou inventário florestal, análise fitossociológica, distribuição diamétrica e processamento de imagens Landsat (2004, 2015, 2024). Foram calculados NDVI, parâmetros estruturais, índice de Shannon e equabilidade de Pielou para caracterização ecológica do fragmento.

¹ Universidade Federal do Pará, Cuiabá, Mato Grosso, Brazil. E-mail: jonatanabreu1997@gmail.com

² Museu Paraense Emílio Goeldi, Belém, Pará, Brazil. E-mail: ruivo@museu-goeldi.br

³ Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: helaine.pires@ufra.edu.br



Resultados e Discussão: Observou-se dominância de *Manilkara bidentata*, *Tapirira guianensis* e *Symphonia globulifera*, padrão típico de florestas secundárias intermediárias. A distribuição diamétrica em “J” invertido indica forte recrutamento. O NDVI revelou queda após 2004, sugerindo perturbações recentes. A diversidade moderada reflete transição entre estágios sucessionais.

Implicações da Pesquisa: Os resultados auxiliam na compreensão da regeneração florestal na Amazônia Oriental, contribuindo para estratégias de manejo, conservação e restauração ecológica regional.

Originalidade/Valor: O estudo integra florística, estrutura e dinâmica temporal em área pouco investigada, oferecendo diagnóstico robusto de um fragmento secundário e ampliando o conhecimento sobre sucessão na paisagem amazônica.

Palavras-chave: Floresta Secundária, Fitosociologia, NDVI, Amazônia Oriental, Sucessão Ecológica.

COMPOSICIÓN FLORÍSTICA, ESTRUCTURA POBLACIONAL Y DINÁMICA DE UN FRAGMENTO DE BOSQUE SECUNDARIO EN LA AMAZONIA ORIENTAL, PARÁ, BRASIL

RESUMEN

Objetivo: Este estudio tiene como objetivo analizar la composición florística, la estructura poblacional y la dinámica temporal de un fragmento de bosque secundario en São João de Pirabas, Pará, para comprender su etapa sucesional y los factores que influyen en su regeneración.

Marco Teórico: La investigación se fundamenta en estudios sobre sucesión ecológica, dinámica de bosques secundarios y teledetección. Destacan las contribuciones de Chazdon, Laurance, Poorter y Almeida sobre regeneración natural, patrones florísticos y el uso del NDVI para evaluaciones temporales.

Método: El estudio combinó inventario forestal, análisis fitosociológico, distribución diamétrica y procesamiento de imágenes Landsat (2004, 2015, 2024). Se calcularon NDVI, parámetros estructurales, índice de Shannon y equidad de Pielou.

Resultados y Discusión: La dominancia de *Manilkara bidentata*, *Tapirira guianensis* y *Symphonia globulifera* indica una etapa sucesional intermedia. La distribución diamétrica en “J” invertida sugiere reclutamiento activo. El NDVI disminuyó después de 2004, señalando perturbaciones recientes. La diversidad moderada refleja una fase sucesional de transición.

Implicaciones de la investigación: Los resultados apoyan estrategias de manejo, conservación y restauración ecológica en la Amazonía Oriental.

Originalidad/Valor: El estudio integra análisis florísticos, estructurales y temporales en un área poco investigada, ofreciendo un diagnóstico sólido sobre la regeneración de bosques secundarios.

Palabras clave: Bosque Secundario, Fitosociología, NDVI, Amazonía Oriental, Sucesión Ecológica.

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1 INTRODUCTION

Tropical forests play a central role in maintaining global biodiversity and the functioning of terrestrial ecosystems, constituting one of the most complex environments in terms of floristic composition and ecological interactions (Martins *et al.*, 2022; Faithfull *et al.*,



2023). The Amazon, in particular, is home to a high diversity of plant species, whose distribution is related to environmental, historical, and anthropogenic factors (Ter Steege *et al.*, 2020). However, intense processes of deforestation, fragmentation, and logging have led to the replacement of primary forests by mosaics of secondary forests in different stages of succession (Silva *et al.*, 2021; Almeida *et al.*, 2023).

The study of secondary forests is fundamental to understanding natural regeneration processes and expanding knowledge about regional flora. Floristic and structural inventories allow the identification of patterns of diversity, dominance, and diametric distribution, in addition to providing input for comparative analyses at the local and regional scales (Carvalho *et al.*, 2019; Nunes *et al.*, 2022). These surveys are especially relevant in poorly studied areas of the Eastern Amazon, where secondary forest fragments represent an important part of the current landscape.

Several studies in the Amazon region have shown that the population structure of fragments undergoing regeneration exhibits characteristics typical of communities in succession, such as high density of individuals in smaller diameter classes and significant participation of early and late secondary species (Oliveira *et al.*, 2020; Castro *et al.*, 2021). Studies conducted in nearby municipalities, such as Bragança (Moraes *et al.*, 2018), Castanhal (Santos *et al.*, 2020), and Capanema (Rodrigues *et al.*, 2022), show that the floristic composition of these remnants varies depending on the history of land use, proximity to primary forest areas, and the intensity of anthropogenic disturbances. Such comparisons allow for the evaluation of floristic convergences and divergences between locations and assist in the characterization of forest succession on a regional scale.

In this context, the present study aimed to analyze the floristic composition, population structure, and temporal dynamics of a forest fragment in São João de Pirabas, northeastern Pará. We seek to answer the following questions: (a) what is the composition and diversity of tree species present in the fragment? (b) how is the population structure organized in terms of density, frequency, dominance, and diameter distribution? and (c) how does the temporal dynamics, assessed through remote sensing images, reflect the successional stage of the area? The investigation of these aspects contributes to the knowledge of Amazonian flora and to the understanding of regeneration processes in secondary forests in the region.



2 THEORETICAL REFERENCE

2.1 SECONDARY FORESTS IN THE AMAZON

Historically, the Eastern Amazon, especially the state of Pará, has undergone intense human occupation since the 1970s, with colonization programs, agricultural expansion, and highway construction, resulting in extensive mosaics of degraded and fragmented landscapes. Laurance *et al.* (2018) highlight that fragmentation promotes "ecological erosion," compromising the stability of ecosystems and profoundly altering regional forest dynamics. In this context, secondary forests emerge as essential formations to buffer the effects of degradation, reestablish ecological processes, and contribute to the structural recovery of the forest.

In addition to reoccupying degraded areas, secondary forests play a central role in mitigating climate change, as they accumulate carbon rapidly in their first decades of regeneration. Poorter *et al.* (2021) demonstrated that secondary forests can recover up to 122 Mg C ha⁻¹ in approximately 20 to 40 years, varying according to environmental conditions and the intensity of the initial disturbance. Thus, such formations are considered "natural carbon sinks," contributing substantially to global atmospheric emission reduction targets.

These forests are also essential for maintaining ecological connectivity in highly fragmented areas. Ferreira, Venticinque, and Almeida (2019) emphasize that secondary fragments function as corridors capable of connecting primary areas, promoting gene flow, seed dispersal, and fauna circulation. Connectivity is particularly important in the Eastern Amazon, where the landscape is densely fragmented, increasing the need for intermediate areas that sustain biodiversity.

From an ecological point of view, secondary forests have great structural plasticity and resilience. Studies show that even heavily degraded areas can regenerate when seeds are available, there is no ongoing disturbance, and environmental conditions are favorable (Silva; Nelson; Mesquita, 2020). Thus, their presence highlights the Amazon ecosystem's capacity to recover, although this recovery depends directly on anthropogenic and environmental factors.

Finally, the relevance of secondary forests goes beyond the ecological perspective: it involves socioeconomic and cultural dimensions. They offer timber and non-timber resources, such as fruits, fibers, and medicinal plants, which are essential for traditional communities. In addition, their presence reduces pressure on primary forests, allowing them to perform their ecological functions without suffering further degradation. Thus, the study of their floristic



composition, population structure, and temporal dynamics is fundamental to understanding the possible paths for Amazonian conservation.

2.2 FLORISTIC COMPOSITION AND POPULATION STRUCTURE

The floristic composition of Amazonian secondary forests reflects not only the diversity of species present, but also the history of land use and the intensity of previous disturbances. According to Chazdon (2014), floristic diversity is one of the central indicators of the successional trajectory, as it reveals the ecological complexity that is established after disturbances. In the early stages, a limited set of pioneer species is expected to be found, whose function is to stabilize the environment and prepare the substrate for more demanding species. However, as the canopy closes and competition for light increases, species from later ecological groups emerge, significantly altering the composition of the community.

Floristic diversity is also influenced by connectivity with primary forests. Studies show that fragments close to conserved forests tend to have greater richness of late and climax species due to the constant influx of diaspores brought in by fauna (Laurance *et al.*, 2018). Thus, the matrix surrounding the fragment plays a decisive role in the replacement of species and the maintenance of local diversity. For this reason, isolated fragments often exhibit lower diversity and a greater presence of generalist species.

Another relevant point in floristic analysis is the proportion of rare or low-abundance species. Finegan (2018) emphasizes that rare species serve as sensitive indicators of ecological integrity, as many depend on specific environmental conditions and low disturbance. Even if they are recorded in low density, their presence suggests that the fragment retains the ability to attract diaspores of structuring species typical of more mature forests.

In addition, floristic composition directly influences the functional structure of the forest. Larger tree species are responsible for increasing biomass and carbon storage, while smaller species contribute to greater horizontal diversity. Poorter *et al.* (2021) demonstrate that floristic diversity is correlated with the rate of structural recovery, since different species occupy complementary niches, accelerating succession and stabilizing the ecosystem.

The inverted J-shaped diameter distribution is considered the classic pattern of secondary forests and tropical forests in regeneration. This pattern, characterized by a high number of individuals in smaller diameter classes and few individuals in larger classes, indicates that there is effective and constant recruitment in the community (Almeida; Vieira,



2010). However, the reduced presence of large individuals suggests that the fragment is still far from the structural maturity typical of a primary forest.

Another relevant structural element is vertical stratification. Secondary forests in their early stages have poorly defined strata, with a predominance of individuals of similar height. As the forest matures, the upper canopy becomes more complex, intermediate strata emerge, and functional diversity increases (Chazdon, 2014). The presence of emergent trees is an important sign of structural advancement, as it indicates that some individuals have managed to reach higher levels of competition.

The spatial distribution pattern of species also reflects important ecological processes. In secondary forests, it is common to observe spatial aggregation of pioneer species and random distribution of late species. This aggregation is a consequence of the opportunistic behavior of pioneers and the high incident light in newly formed clearings (Vieira; Gardner; Ferreira, 2014).

Thus, population structure is central to understanding forest dynamics. Its metrics—density, basal area, diameter distribution, and IVI—are essential for interpreting the successional trajectory and assessing ecosystem resilience. When analyzed in conjunction with floristic composition and temporal dynamics, these indicators provide a robust diagnosis of the current state of the secondary forest.

2.3 TEMPORAL DYNAMICS

The temporal dynamics of a forest can be understood by observing structural and functional changes over the years. In this context, remote sensing has established itself as an indispensable tool for analyzing large territorial areas with a high level of temporal accuracy. According to Ferreira, Venticinque, and Almeida (2019), the use of satellite images is essential for monitoring forest fragments in regions that are difficult to access, such as the Eastern Amazon.

Among satellite-derived indices, the Normalized Difference Vegetation Index (NDVI) is widely used to assess vegetative vigor and leaf density. The NDVI ranges from -1 to 1, reflecting the difference between the absorption and reflectance of radiation in the red and near-infrared spectrum. In secondary forests, high values indicate canopy closure and biomass accumulation (Almeida; Vieira, 2010).

Temporal analysis of the NDVI allows for the detection of both advances and setbacks in regeneration. According to Silva, Nelson, and Mesquita (2020), abrupt drops in the NDVI may indicate recent disturbances, such as selective cutting, clearing of gaps, or severe weather



events. On the other hand, a gradual increase in the NDVI indicates structural advancement and progressive canopy closure.

NDVI is also sensitive to large-scale climatic phenomena, such as extreme droughts, El Niño, and seasonal changes in water availability. In years of prolonged drought, it is common to observe temporary reductions in NDVI due to leaf loss and water stress. Ferreira, Venticinque, and Almeida (2019) point out that secondary forests are more vulnerable to these fluctuations due to the higher proportion of fast-growing species and shallower root systems.

Another relevant application of NDVI is the identification of patterns of forest degradation that are not noticeable in field surveys. In many cases, the forest structure may appear stable, but NDVI reveals a gradual loss of leaf density associated with recurring disturbances. Martins, Silva, and Rodrigues (2020) demonstrate that temporal analysis is essential for diagnosing phenomena of "silent degradation," which are very common in the Eastern Amazon.

The combined use of NDVI with floristic and structural inventories provides an integrative approach to understanding the successional trajectory. According to Poorter *et al.* (2021), the synergy between field and remote sensing metrics improves diagnostic accuracy, especially in secondary forests with a complex history of disturbances.

In addition, NDVI assists in identifying priority areas for restoration and management. Fragments with persistently low NDVI may indicate ongoing degradation, requiring forest enrichment or anthropogenic impact containment actions. On the other hand, fragments with increasing NDVI demonstrate resilience and can serve as seed source areas for adjacent regions (Brancalion; Nunes; Rodrigues, 2018).

Thus, temporal analysis based on NDVI is essential for understanding the dynamics of secondary forests in the Eastern Amazon. When integrated with floristic and structural information, it provides a complete overview of the health of the fragment, allowing the identification of trends, disturbances, and potential future trajectories.

3 METHODOLOGY

3.1 CHARACTERIZATION OF THE STUDY AREA

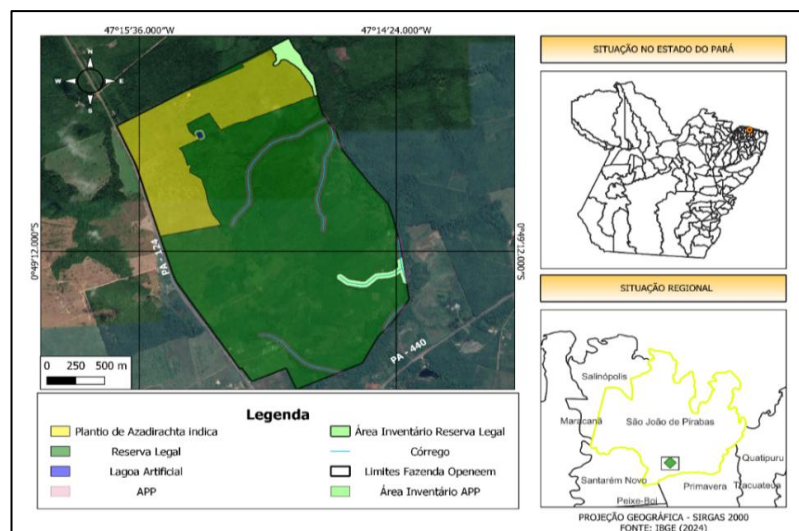
The study will be conducted in the area of the Openeem Farm, located on the banks of highways PA-124 and PA-324, in the municipality of São João de Pirabas, PA.



The municipality of São João de Pirabas is located in the central-northeastern region of the state of Pará and in the Salgado micro-region (Figure 1). The region is affected by a hot and humid tropical climate. According to the Köppen classification, it has an Aw climate with reduced temperature ranges and annual precipitation of around 2,100 mm. Of this rainfall, 90% was distributed in the first six months of the year.

Figure 1

Location map of the Openeem Farm, located in the municipality of São João de Pirabas - PA.



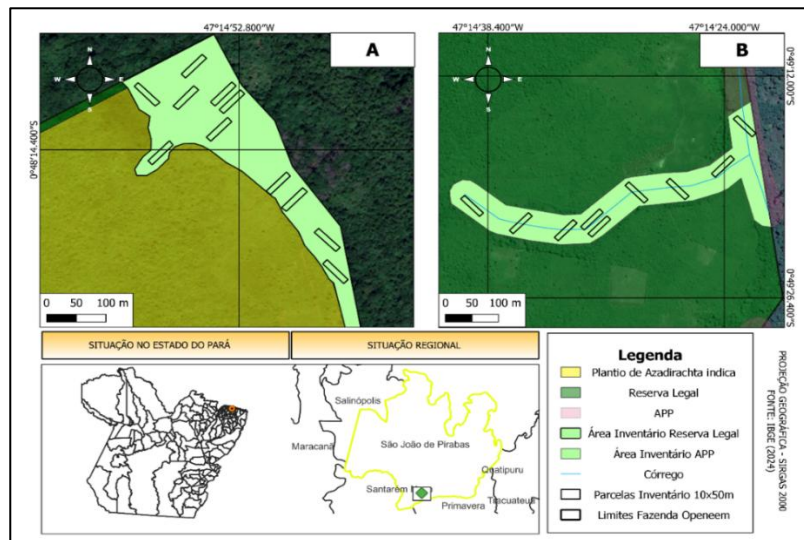
3.2 CHARACTERIZATION OF FOREST SPECIES

The main native species in the region were identified through a forest inventory carried out in partnership with taxonomists and botanical identifiers from the Emílio Goeldi Paraense y Museum. Twenty 10×50 m (1 ha) plots were randomly distributed (Figure 2). In each plot, the total height (h) and diameter at breast height (DBH) of trees with DBH > 10 cm were measured.



Figure 2

Map showing the location of the plots inventoried in the legal reserve (A) and permanent preservation area (B) in an advanced stage of ecological succession in the municipality of São João de Pirabas – PA.



In addition to the variables presented above, the floristic composition of the inventoried area was evaluated, with emphasis on the distribution of trees by botanical family, basal area distribution, and diameter distribution of the population, according to the equations in Table 1.

Table 1

Equations used to calculate horizontal structure parameters.

Variables	Equation
DBH	$DAP = CAP / \pi$
Cross-sectional area	$g = \frac{DAP^2 \times \pi}{40000}$
Basal Area	$G = g / \text{Área}$

DBH = diameter at breast height.

The same diameter classes were used to analyze the distribution of basal area and volume with a class range of 10 cm, as observed (Table 2).



Table 2

Diameter class interval.

Diameter range (cm)	Class
15 cm ≤ DBH < 24 cm	180
25 cm ≤ DBH < 34 cm	80
35 cm ≤ DBH < 44 cm	42
45 cm ≤ DBH < 54 cm	22
55 cm ≤ DBH < 64 cm	5
65 cm ≤ DBH < 74 cm	1
75 cm ≤ DBH ≥ 85 cm	1

DBH = diameter at breast height.

3.3 TIME SERIES ANALYSIS

The temporal analysis performed for the years 2004, 2015, and 2024 was carried out by obtaining images from the Landsat 5 TM satellite for 2004 and Landsat 8 OLI/TIRS for 2015 and 2024, acquired through the USGS Earth Explore platform.

The images were chosen for their low cloud cover (< 10%) and collected during the dry season (09/2004 – 08/2015 – 09/2024).

Arcmap version 10.8 (Esri, 2020) software was used to perform the pre-processing and composition of the bands, and Envi version 5.1 (Harris Geospatial, 2019) software was used to calculate the vegetation index.

The NDVI was calculated for each year (2004, 2015, 2024) using the near-infrared (NIR) and red (RED) bands, according to formula (1) (Rouse et al., 1974):

$$NDVI = \left(\frac{NIR-RED}{NIR+RED} \right) \quad (1)$$

where:

NDVI = normalized difference vegetation index

NIR = near-infrared bands

RED= red bands.



For Landsat 5 TM images: RED: Band 3 (0.63–0.69 μm) and NIR: Band 4 (0.76–0.90 μm); for Landsat 8 OLI: RED: Band 4 (0.64–0.67 μm) NIR: Band 5 (0.85–0.88 μm).

3.4 STATISTICAL ANALYSIS

The structural characterization of the forest fragment was performed based on the analysis of the diameter distribution of individuals, with the construction of histograms in diameter classes to verify the inverted J distribution pattern, typical of forests in regeneration. Descriptive statistics (mean, standard deviation, and coefficient of variation) were calculated for the dendrometric variables diameter at breast height (DBH) and total height (h) in order to assess the structural heterogeneity of the sampled population.

The phytosociological structure was determined based on the classic parameters of absolute and relative density, absolute and relative frequency, absolute and relative dominance, and calculation of the Importance Value Index (IVI), enabling the identification of the most representative species in the fragment. Floristic diversity was estimated using the Shannon-Weaver index (H'), widely used in tropical forest studies, and Pielou's evenness (J'), which quantifies the uniformity of the distribution of individuals among the recorded species, as shown in Table 3 (Curtis and McIntosh, 1950; Lamprecht, 1964; Brower and Zar, 1984).

Table 3

Equations used to calculate horizontal structure parameters and diversity index.

Parameter	Formula	Description
Absolute Abundance (aa)	$AA_i = N_i$	Total number of individuals of species i.
Relative Abundance (RA)	$RA_i = (N_i / N_{\text{total}}) \times 100$	Proportion of individuals of species i in relation to the total number of individuals.
Absolute Frequency (AF)	$AF_i = P_i / P_{\text{total}}$	Ratio between the number of plots with occurrence of species i and the total number of plots.
Relative Frequency (RF)	$RF_i = (AF_i / \sum AF) \times 100$	Frequency of species i in relation to the sum of the frequencies of all species.
Absolute Dominance (AD)	$AD_o = \sum (\pi \cdot DBH^2 / 4)$	Basal area occupied by individuals of species i (m^2/ha).
Relative Dominance (DoR)	$DoR_i = (DoA_i / \sum DoA) \times 100$	Relative share of species i in the total dominance of the community.
Coverage Value Index (CVI)	$CVI_i = (AR_i + RD_i)/2$	Representativeness of species i considering abundance and dominance.
Importance Value Index (IVI)	$IVI_i = (AR_i + FR_i + DoR_i)/3$	Ecological importance of species i considering abundance, frequency, and dominance.
Species Richness (S)	$S = \text{total number of species}$	Number of species recorded in the community.



Shannon-Weaver Index (H')	$H' = - \sum (p_i \ln p_i)$, where $p_i = N_i / N_{total}$	Diversity considering abundance and evenness.
Pielou's evenness (J')	$J' = H' / \ln(S)$	Uniformity of distribution of individuals among species.

In addition, species were grouped into ecological groups (pioneer, early secondary, late secondary, and climax), allowing for the assessment of the successional composition of the individuals inventoried.

Finally, a temporal analysis of the normalized difference vegetation index (NDVI) was performed using orbital images from 2004, 2015, and 2024. This approach allowed us to identify changes in vegetation density and vigor, as well as to infer possible disturbances and trends in forest succession in the studied fragment.

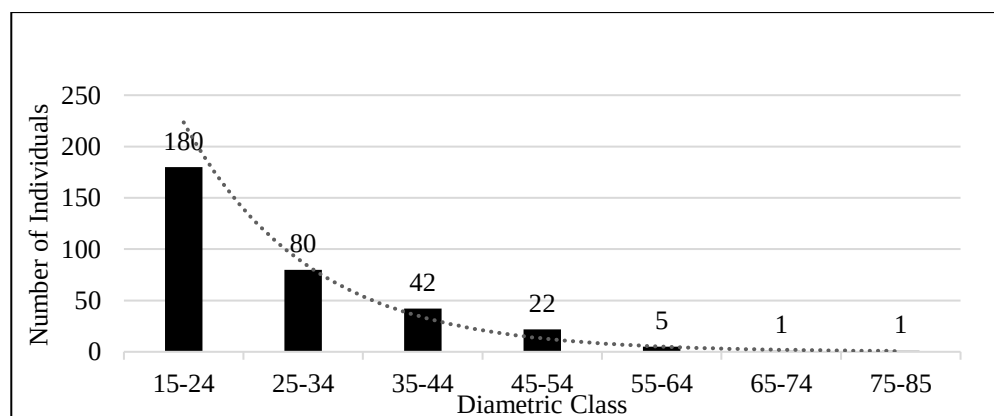
4 RESULTS AND DISCUSSIONS

4.1 DIAMETER DISTRIBUTION

The diameter distribution of the sampled population has an inverted J-shape, with a large number of individuals in the first diameter classes and a decrease in the last classes (Figure 3).

Figure 3

Diameter distribution of individuals sampled in the forest fragment inventoried in the municipality of São João de Pirabas – PA.



The inverted J-shaped diameter distribution suggests active forest dynamics, with a high density of young individuals and few individuals in higher diameter classes, which is typical of secondary forests (Lopes *et al.*, 2012). This indicates that, despite good recruitment, there is



still a gap in the presence of mature trees, reflecting a relatively short period of ecological recovery.

This distribution pattern is characteristic of vegetation in a state of succession, consisting of individuals belonging to different species, ages, diameter classes, diverse ecophysiological conditions, and low biodiversity; the trees are at various stages of regeneration (Lima and Leão, 2013).

The individuals collected in this study showed greater dispersion in DBH (10.88 cm) when compared to height (3.64 m), with a high coefficient of variation between the data, mainly in the DBH variable (Table 4).

The average height for the individuals inventoried is approximately 12 m. This value may suggest that the forest fragment analyzed presents a coexistence between species from different ecological groups in the forest succession stage.

The coefficient of variation of the data found in this study for the DBH variable indicates high structural heterogeneity, since there were individuals represented in several diameter classes, with the largest number of individuals concentrated in the smallest classes.

Table 4

Descriptive statistics for the variables diameter at breast height (DBH) and height (h) of individuals sampled in the forest fragment inventoried in the municipality of São João de Pirabas – PA.

Variable	Average	Minimum	Maximum	Standard deviation	CV (%)
DAP (cm)	22.49662	10.18592	89.12677	10.88783574	48.40
h (m)	11.99758	5	25	3.642608983	30.36

Source: Authors (2025).

4.2 PHYTOSOCIOLOGICAL STRUCTURE

Based on the forest inventory conducted, it was possible to count 32 tree species belonging to 32 genera and 25 families (Table 5). The *Fabaceae* family, with 6 species, and the *Apocynaceae* and *Clusiaceae* families, both with 2 species each, were the most representative, accounting for 31.25% of the total species sampled.

The most dominant species was *Manilkara bidentata*, which accounted for 29.04%, followed by *Tapirira guianensis* Aubl (14.66%) and *Symphonia globulifera* (13.11%).



Regarding the distribution of the number of individuals per species, a total of 9 species had only 1 individual each.

For the phytosociological structure, it was found that the species *Manilkara bidentata* was the most important in terms of forest cover, with an IVI of 19.79%, followed by the species *Tapirira guianensis* Aubl (15.83%) and *Symphonia globulifera* (11.26%).

The basal area (16.23 m²/ha) was lower than the average reported for primary forests in the region (30 m²/ha) (Almeida *et al.*, 2010), but consistent with areas in an intermediate stage of succession (20–40 years), as observed in similar fragments in Pará (Carvalho *et al.*, 2013).. Thus, it can be inferred that the BA variable analyzed corroborates the diametric, structural, and ecological data of a forest fragment in an intermediate stage of regeneration.

Table 5

Number of individuals, occurrence in plots, relative frequency, relative density, relative dominance, importance value, basal area, and ecological group of species inventoried in the municipality of São João de Pirabas – PA.

Scientific name	Family	AA	OP	FA	FRi	DRi	DoRi	IVI	IVC	AB	GE
<i>Aspidosperma desmanthum</i>	Apocynaceae	1	1	0.05	0.8	0.30	0.117	0.40	0.2099	0.02	C
<i>Bocageopsis multiflora</i> (Mart.)	Annonaceae	1	1	0.05	0.8	0.30	0.070	0.39	0.1864	0.01	C
<i>Bowdichia virgilioides</i> Kunth	Fabaceae	1	1	0.05	0.8	0.30	0.226	0.44	0.2644	0.04	P
<i>Buchenavia</i> sp	Combretaceae	8	6	0.3	4.8	2.41	2.077	3.09	2.2474	0.34	ST
<i>Calycophyllum spruceanum</i> .	Rubiaceae	2	1	0.05	0.8	0.60	2.020	1.14	1.3124	0.33	ST
<i>Carapa guianensis</i>	Meliaceae	3	2	0.1	1.6	0.90	1.260	1.25	1.0833	0.20	C
<i>Cecropia pachystachya</i>	Urticaceae	3	2	0.1	1.6	0.90	0.540	1.01	0.7232	0.09	P
<i>Croton matourensis</i>	Euphorbiaceae	13	3	0.15	2.4	3.92	1.518	2.61	2.7228	0.25	P
<i>Diospyros sericea</i> A.DC.	Ebenaceae	2	1	0.05	0.8	0.60	0.280	0.56	0.4422	0.05	C
<i>Emmotum fugifolium</i> Desv.	Icacinaceae	2	2	0.1	1.6	0.60	0.120	0.77	0.3621	0.02	SI
<i>Schomburgk's Enterolobium</i>	Fabaceae	16	7	0.35	5.6	4.83	3.980	4.80	4.4071	0.65	SI
<i>Eschweilera juruensis</i> R. Knuth.	Lecythidaceae	1	1	0.05	0.8	0.30	0.290	0.46	0.2964	0.05	C
<i>Goupia glabra</i>	Goupiaceae	1	1	0.05	0.8	0.30	0.240	0.44	0.2711	0.04	SI
<i>Inga alba</i> (Sw.) Willd	Fabaceae	13	9	0.45	7.2	3.92	1.320	4.14	2.6240	0.21	SI
<i>Manilkara bidentata</i>	Sapotaceae	66	13	0.65	10.4	19.9	29.04	19.7	24.491	4.71	C



<i>Minquartia guianensis</i> Aubl	Olacaceae	3	1	0.05	0.8	0.90	0.540	0.74	0.7234	0.09	C
<i>Nectandra rubra</i> (Mez) C. K. Allen	Lauraceae	1	1	0.05	0.8	0.30	0.117	0.40	0.2099	0.02	C
<i>Ormosia coutinhoi</i>	Fabaceae	51	8	0.4	6.4	15.4	10.16	10.6	12.786	1.65	ST
Water apple	Bombacaceae	3	3	0.15	2.4	0.90	0.491	1.26	0.698	0.08	P
<i>Parahancornia amapa</i>	Apocynaceae	5	3	0.15	2.4	1.51	1.907	1.93	1.708	0.31	C
<i>Parkia platycephala</i> Benth	Mimosaceae	2	1	0.05	0.8	0.60	1.475	0.96	1.040	0.24	SI
<i>Platonia insignis</i>	Clusiaceae	1	1	0.05	0.8	0.30	0.063	0.38	0.1828	0.01	C
<i>Pterocarpus santalinoides</i> DC	Fabaceae	2	2	0.1	1.6	0.60	0.594	0.93	0.599	0.10	P
<i>Pterodon emarginatus</i>	Fabaceae	7	6	0.3	4.8	2.11	1.99	2.96	2.054	0.32	P
<i>Sacoglottis guianensis</i> Benth.	Humiriaceae	2	2	0.1	1.6	0.60	0.479	0.89	0.541	0.08	ST
<i>Schizolobium amazonicum</i>	Fabaceae	2	2	0.1	1.6	0.60	0.280	0.82	0.442	0.05	P
Bitter simaroub	Simaroubaceae	2	2	0.1	1.6	0.60	0.376	0.86	0.490	0.06	P
<i>Spondias mombin</i>	Anacardiaceae	1	1	0.05	0.8	0.30	0.194	0.43	0.248	0.03	P
<i>Symphonia globulifera</i>	Clusiaceae	37	11	0.55	8.8	11.1	13.81	11.2	12.49	2.24	C
<i>Tapirira guianensis</i> Aubl	Anacardiaceae	61	18	0.9	14.4	18.4	14.66	15.8	16.54	2.38	ST
<i>Virola surinamensis</i>	Myristicaceae	17	11	0.55	8.8	5.13	9.595	7.84	7.36	1.56	ST
<i>Vochysia spp.</i>	Vochysiaceae	1	1	0.05	0.8	0.30	0.132	0.41	0.21	0.02	P
Total		331		6.25	100	100	100	100	100	16.23	

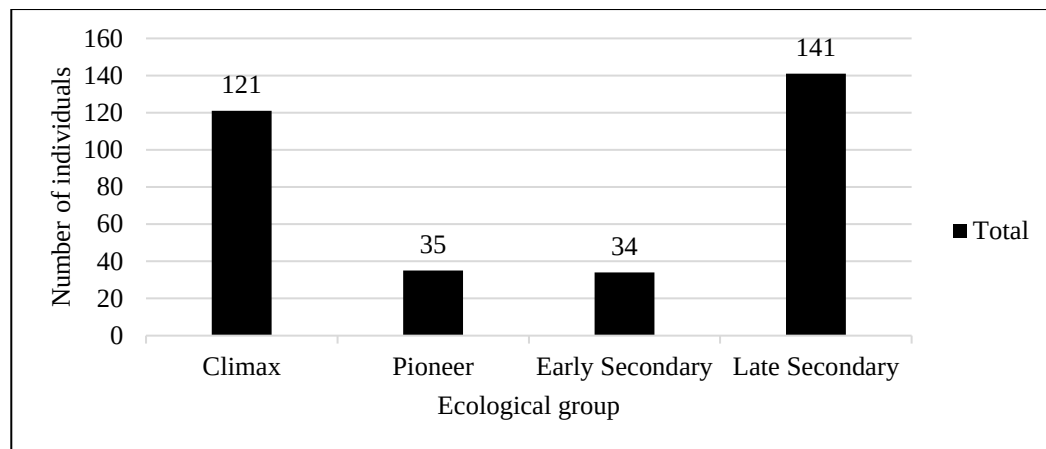
AA: Absolute abundance; OP: Occurrence in plots; FA: Absolute frequency; *FRi*: Relative frequency; *DRi*: Relative density; *DoRi*: Relative dominance; IVI: Importance value index; IVC: Coverage value index; AB: Basal area; EG: Ecological group; C: Climax; P: Pioneer; IS: Early secondary; LSS: Late secondary.

Figure 4 shows the number of individuals inventoried in this forest fragment and their respective ecological classification, demonstrating the broad dominance of late secondary species, with 141 individuals, and climax species, with 121 individuals.



Figure 4

Number of individuals per ecological group found in the forest fragment inventoried in the municipality of São João de Pirabas – PA.



The floristic composition observed in the studied fragment reflects a typical pattern of Amazonian secondary forests in an intermediate stage of regeneration, with a predominance of secondary and climax species associated with natural succession (Oliveira *et al.*, 2020; Castro *et al.*, 2021). The presence of *Manilkara bidentata*, *Symphonia globulifera*, and *Tapirira guianensis* among the species of greatest structural importance confirms trends already described in other surveys of the Eastern Amazon, indicating that these species play a functional role in the reorganization of the community after disturbances (Nunes *et al.*, 2022; Rodrigues *et al.*, 2023).

The importance of key species such as *Manilkara bidentata* with high cover value (IVC=24.49%) highlights their role in structuring the community, providing resources for fauna and facilitating natural regeneration (Chazdon *et al.*, 2009). However, floristic homogenization, evidenced by the dominance of three species, reduces the fragment's potential to harbor rare biodiversity (Martins *et al.*, 2020).

In this sense, in terms of phytosociological structure, the dominance of a few families in the results found is characteristic of secondary tropical forests (Souza *et al.*, 2013). This pattern corroborates the literature, in which fast-growing and light-tolerant species are present in environments with regenerating soils and greater luminosity (Chazdon *et al.*, 2009).

In studies of forest fragments conducted by Martins *et al.* (2020) in the city of Bragança, PA, the predominance of pioneer and early secondary species was identified, which may be indicative of greater pressure from human actions on the fragment.



Carvalho *et al.* (2016), studying forest fragments in the city of Castanhal, PA, observed that the increase in climax species was only predominant after 40 years of regeneration. In this sense, it can be inferred that the forest fragment in this study is at a higher successional stage than the forest fragment studied by Martins *et al.* (2020), as it has more individuals from the late secondary and climax ecological groups.

4.3 DIVERSITY INDEX

The Shannon-Weaver diversity index, widely used for Amazonian tropical forests, considers values between 3.83 and 5.85 to be high for the diversity of any type of vegetation (Knight, 1975, apud Dionísio *et al.*, 2016). In the present study, the value found for H' was 2.53 (Table 6).

Table 6

Number of individuals and diversity of species inventoried in a forest fragment in the municipality of São João de Pirabas – PA.

Common Name	Scientific Name	Ni	pi	ln pi	pi * ln pi
Amapá	<i>Parahancornia amapa</i>	5	0.015106	-4.19268	0.063334
Anani	<i>Symphonia globulifera</i>	37	0.111782	-2.1912	0.244938
Andiroba	<i>Carapa guianensis</i>	3	0.009063	-4.70351	0.04263
Aquariquara	<i>Miquartia guianensis Aubl</i>	3	0.009063	-4.70351	0.04263
Araracanga	<i>Aspidosperma desmanthum</i>	1	0.003021	-5.80212	0.017529
Bacuri	<i>Platonia insignis</i>	1	0.003021	-5.80212	0.017529
Buiucu	<i>Ormosia coutinhoi</i>	51	0.154079	-1.87029	0.288172
Cupiúba	<i>Goupia glabra</i>	1	0.003021	-5.80212	0.017529
Embaúba	<i>Cecropia pachystachya</i>	3	0.009063	-4.70351	0.04263
Black Envira	<i>Bocageopsis multiflora (Mart.)</i>	1	0.003021	-5.80212	0.017529
Monkey Slide	<i>Calycophyllum spruceanum.</i>	2	0.006042	-5.10897	0.03087
Fava	<i>Parkia platycephala Benth</i>	2	0.006042	-5.10897	0.03087
Red Inga	<i>Inga alba (Sw.) Willd</i>	13	0.039275	-3.23717	0.12714
Red laurel	<i>Nectandra rubra (Mez) C. K. Allen</i>	1	0.003021	-5.80212	0.017529
Macaqueira	<i>Diospyros sericea A.DC.</i>	2	0.006042	-5.10897	0.03087
Mamorana	<i>Water apple</i>	3	0.009063	-4.70351	0.04263
Maparajuba	<i>Manilkara bidentata</i>	66	0.199396	-1.61246	0.321518
Maravuvuia	<i>Croton matourensis</i>	13	0.039275	-3.23717	0.12714
Maraxibé	<i>Emmotum fugifolium Desv.</i>	2	0.006042	-5.10897	0.03087
Marupá	<i>Simarouba amara</i>	2	0.006042	-5.10897	0.03087
Matamata	<i>Eschweilera juruensis R. Knuth.</i>	1	0.003021	-5.80212	0.017529
Mututi	<i>Pterocarpus santalinoides DC</i>	2	0.006042	-5.10897	0.03087
Paricá Aranha	<i>Amazonian spider</i>	2	0.006042	-5.10897	0.03087
Paricarana	<i>Bowdichia virgilioides Kunth</i>	1	0.003021	-5.80212	0.017529
Quaruba	<i>Vochysia spp.</i>	1	0.003021	-5.80212	0.017529
Sucupira	<i>Pterodon emarginatus</i>	7	0.021148	-3.85621	0.081551
Yellow sucupira	<i>Enterolobium schomburgkii</i>	16	0.048338	-3.02953	0.146443
Tanimbuca	<i>Buchenavia sp</i>	8	0.024169	-3.72268	0.089974



Taperebá	<i>Spondias mombin</i>	1	0.003021	-5.80212	0.017529
Tatapiririca	<i>Tapirira guianensis</i> Aubl	61	0.18429	-1.69124	0.31168
Ucuuba	<i>Virola surinamensis</i>	17	0.05136	-2.96891	0.152482
Uxirana	<i>Sacoglottis guianensis</i> Benth.	2	0.006042	-5.10897	0.03087
Total	33	331	1	-143.514	2.52961

NI= number of individuals; PI= relative frequency of species; LN= natural logarithm.

The Pielou index quantifies the uniformity of the distribution of individuals among existing species, on a scale from 0 (minimum uniformity) to 1 (maximum uniformity).

Thus, the diversity indices found in this study, 2.53 for Shannon-Weaver (H') and 0.73 for Pielou's evenness (J), indicate moderately high diversity at a reasonable level of evenness (Table 7).

Table 7

Floristic diversity index considering individuals with DBH > 10 cm of the species inventoried in a forest fragment in the municipality of São João de Pirabas – PA.

Parameter	Forest
Species richness (S)	33
Shannon-Weaver index (H')	2.5
Pielou's J Equivalence Index	0.73

The diversity indices recorded in this study ($H'=2.53$) and evenness ($J=0.73$) are within the range observed for Amazonian secondary forests (Carvalho *et al.*, 2019; Almeida *et al.*, 2023). The simultaneous presence of pioneer and late secondary species indicates a transition between successional phases, which reinforces the importance of considering the history of land use in the area and its connectivity with more conserved forest remnants. This floristic heterogeneity was also evident in Capanema (Rodrigues *et al.*, 2022), where nearby fragments had different compositions depending on the intensity of past disturbances.

The values found for the Shannon-Weaver and Pielou indices are in agreement with those found by Chaves *et al.* (2014) and Silva *et al.* (2018) for secondary forests in the Amazon in an intermediate stage of ecological succession.

4.4 VEGETATION INDEX

The massive presence of late secondary and climax individuals raises the question of the intensity of anthropic action in the forest fragment studied. Therefore, a temporal analysis was performed to estimate the vegetation index of the forest fragment.

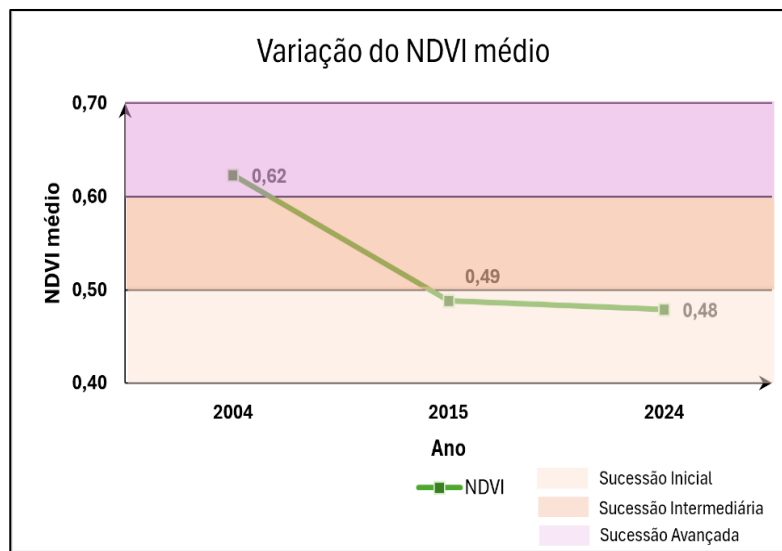


The NDVI (Normalized Difference Vegetation Index) ranges from -1 to 1 and indicates vegetation vigor and density: values above 0.6 generally represent healthy and dense vegetation; values between 0.5 and 0.6 indicate sparser vegetation in an intermediate stage of succession; values below 0.5 indicate vegetation in the early stages of succession.

Figure 5 shows a comparison between the average NDVI calculated for the years 2004 (0.62), 2015 (0.49), and 2024 (0.48) for the forest fragment under study. It can be observed that in 2004, the vegetation showed signs of advanced forest succession. However, this index fell for the years 2015 and 2024, suggesting the presence of disturbance in the vegetation.

Figure 5

Temporal evaluation of the average NDVI for the years 2004, 2015, and 2024 of the forest fragment inventoried in the municipality of São João de Pirabas – PA.



NDVI = Normalized Difference Vegetation Index.

The temporal analysis using NDVI showed fluctuations in vegetation cover density over the two decades evaluated, signaling recent disturbances in the fragment. This behavior reinforces the need to consider environmental and anthropic variables in understanding succession dynamics (Silva *et al.*, 2021). Similar studies conducted in the Bragantina region have shown that fluctuations in NDVI may be associated with both subsistence agricultural practices and climatic events that affect natural regeneration (Ferreira *et al.*, 2022).

When comparing the results of the temporal analysis for the last 20 years with those found by Carvalho *et al.* (2016), the average NDVI for the years 2015 and 2024 confirms that the forest fragment is in an early stage of forest succession, very close to the intermediate stage.



Another factor that may contribute to the massive presence of late secondary and climax species is the size of the sampled area, proximity to preserved forests, and low ecological isolation (Viera *et al.*, 2013).

A comparison of the variables measured in this study—floristic composition, phytosociological structure, and diversity—with those reported by the aforementioned authors confirms that the floristic and functional structure of the fragment studied is characteristic of a secondary forest at a stage of succession close to the intermediate stage.

In general, the results confirm that secondary forests in the Eastern Amazon share similar structural and floristic patterns, although they have particularities determined by the intensity of local disturbances and connectivity with adjacent forest areas. In this sense, the São João de Pirabas fragment expands the available knowledge for the region, providing evidence of the ecological relevance of secondary remnants as components of the current landscape.

5 CONCLUSION

The forest fragment analyzed in São João de Pirabas has a floristic composition and population structure compatible with secondary forests in an intermediate stage of succession in the Eastern Amazon. The predominance of secondary and climax species, combined with the inverted J-shaped diameter pattern, confirms the occurrence of continuous recruitment and the maintenance of regenerative processes.

Regional comparisons indicate that the patterns observed are consistent with those described in other municipalities in the region, such as Bragança, Castanhal, and Capanema, reinforcing that secondary fragments, even when subjected to different histories of use, can converge in similar floristic and structural trajectories.

Temporal analysis via NDVI showed fluctuations in vegetation cover density, suggesting that succession dynamics are influenced by recent disturbances, but that there is a tendency for community reorganization and stabilization.

Thus, this study expands knowledge about the flora and structure of secondary forests in northeastern Pará, contributing to the characterization of ecological succession in the Amazon region and highlighting the importance of secondary remnants for understanding forest diversity and dynamics on a regional scale.



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