

Dynamics and Structure of the Natural Regenerative Layer in a Floodplain Forest in the District of Arapixuna, Santarém, Pará

Juliana Sousa da Sousa Silva

julianass844@gmail.com

Universidade Federal do Oeste do Para - Campus Tapajos: Universidade Federal do Oeste do Para
<https://orcid.org/0000-0003-4055-3307>

José Mauro Sousa de Moura

Universidade Federal do Oeste do Para

Adelaine Michela e Silva Figueira

Universidade Federal do Oeste do Para

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Additional Declarations:

Data availability

The datasets generated during and/or analysed during the current study are available from 20 the corresponding author on reasonable request.

Abstract

This study analyzed the floristic composition, structure, and dynamics of the natural woody regenerative stratum in a floodplain forest in Arapixuna, Santarém-PA. Two 10 × 50 m plots were demarcated to identify plant species, classify life forms, and group regenerating woody plants (50 cm to 3 m in height; DBH < 10 cm) into size categories. Vertical and horizontal structures, density, relative frequency, total natural regeneration, and diversity indices were calculated. In 2018, 236 individuals were recorded across 10 families, 11 genera, and 7 species. By 2021, this number dropped significantly to 65 individuals (8 families and 5 species), representing a 72% mortality rate after three flood cycles. Due to identification challenges, many individuals were classified only to the family level. Fabaceae, Lecythidaceae, and Combretaceae were the most representative families. *Schizolobium amazonicum* Huber ex Ducke stood out in both periods, demonstrating—along with *Gustavia augusta* L., *Ouratea* sp., and *Cassia leiandra* Benth—great ecological importance and key morphophysiological adaptations to water stress. These findings contribute to understanding the role of the regenerative stratum in biogeochemical cycles and carbon fixation, supporting the management and conservation of standing floodplain forests.

Keywords: Amazonian wetlands; floristic composition; mortality rate; phytosociology; successional stage; water stress.

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INTRODUCTION

The vast area occupied by the diverse vegetation formations of the Amazon region is indicative of the region's importance in controlling climate change, potentially contributing both to the emission of greenhouse gases into the atmosphere and to the capture of carbon from the atmosphere through the growth of tree cover (Bezerra De Souza et al. 2013). Along the Amazon River and its major tributaries, the floodplains, subject to long-duration, monomodal flood pulses, cover an area of approximately 760,000 km² (Assis et al. 2017). The floodplains extend for a distance of approximately 5,000 km by the Solimões River - Amazon, starting at the foot of the Andes, going to Marajó Island, and by its white-water tributaries (Melack and Hess 2011; Junk et al. 2011; Junk et al. 2020).

In the Amazon region, among the various vegetation formations classified as floodplains, wetlands, or floodplains, várzea forests stand out because they are quite dynamic, changing vegetation

cover, landscape morphology, human population density, and the type of use of natural resources (Peixoto et al. 2009). The main characteristic that causes various changes in várzea forests is the amplitude of the flood pulse, which can be high or low, depending on the seasonality and geomorphology of the region (Wittmann and Junk 2002). The condition of rising and falling river levels generates the following periods: flood, high water, low water, or drought. Furthermore, várzea forests have the greatest floristic richness among floodplain forests, even sharing a large number of species with upland areas (Junk et al. 2011, 2014). This richness of the floodplain forests is a result of the highly fertile soils with a high cation exchange capacity (Assis and Wittmann 2011). The rivers that flood the areas transport a large amount of suspended sediments that are deposited on the soil surface and renew its nutritional state after each flood (Junk et al. 1989; Assis et al. 2017).

Many species found in floodplain forests have economic potential and are considered a source of income for riverside communities, such as timber plants and Fruit trees, however, are being decimated due to disordered exploitation and lack of management procedures (Carim 2004). Natural and anthropogenic processes and the use of natural field formations for cattle raising generate a worrying problem, since the floodplain is an ecosystem that is difficult to recover and fragile when modified by human action (Junk 1997; Felsemburgh 2019).

Following these disturbances, regardless of the responsible factor and its intensity, the restoration or recovery of forest formations depends on the interaction of natural processes of re-establishment of the forest ecosystem, known as natural regeneration (NR). This process is part of the forest growth cycle and refers to the initial phases of its establishment and development (Carvalho 1982; Gama et al. 2002).

According to Norden et al. (2009), current research on the relationships of tree communities in a given ecosystem is mostly related to the adult forest stratum; therefore, little is known about seedlings and plants in the regenerative stratum. To understand the dynamics and structure of a community, it is important to highlight the ecological relationships that exist between the different tree strata within the forest community (Chazdon et al. 2010; Moreira and Carvalho 2018).

In floodplain areas, regeneration is influenced by the flood pulse, which is a strong limiting factor for the successful establishment of species, both for plants in the regenerative stratum and for plants in the upper stages of the successional line, as well as for seed dispersal, germination, seedling establishment, and the structure and composition of a forest stand (Nilsson et al. 2010; González et al. 2010; Gee et al. 2014).

Success is restricted to species that have morphophysiological mechanisms capable of tolerating the seasonality of flooding (Gama et al. 2005). These mechanisms include reduced growth and optimized use of energy reserves (Worbes 1997; Parolin 2001; Ferreira et al. 2009), hydrochoric and ichthyochoric dispersal strategies (Lopez 2001), and adventitious roots (Parolin 2001). Due to the demands and the existence of few highly flood-tolerant species, a high degree of endemism is observed in floodplain areas (Wittmann et al. 2006).

Flooding represents a high level of water stress (due to excess) in floodplain forests for plants (Visser et al. 2003; Parolin and Wittmann 2010), therefore plants have developed adaptation mechanisms to tolerate and survive in this environment (Lopes and Piedade 2015). In this way, plants are able to maintain and adjust the phenological and physiological processes that involve both their leaf and fruit production, as well as cambial activity (Schöngart et al. 2002).

Based on the study of natural regeneration, it is possible to make predictions about the behavior and future development of the forest (Carvalho 1982; Gama et al. 2002). This is because information is obtained on autecology, successional stage, effects of the type of forest exploitation, as well as other information relevant to possible interventions (Higuchi et al. 1985; Gama et al. 2002).

The Amazon biome, within the current scenario, is threatened by several disturbances. Among these disturbances are agricultural expansion and climate variability. Authors such as Lovejoy and Nobre (2018) highlight and warn about the deforestation rates in the Amazon, which have already reached the critical limit of 20%, beyond which the hydrological cycle may be irreversibly compromised, no longer allowing the existence of the tropical forest. Cattle ranching is one of the main causes of changes in land cover, as it leads to the removal of vegetation cover to establish farms (Fearnside 2005).

Deforestation generates negative effects on biodiversity and the atmosphere, consequently disrupting the ecological balance of the forest and causing changes in temperature and the hydrological cycle (Davidson et al. 2012). The removal of vegetation can intensify erosion processes, thus increasing water turbidity and consequently making it impossible for submerged plant species to survive (Junk et al. 2020).

Climate variability also interferes with the ecological balance of the Amazon rainforest. According to data from the Intergovernmental Panel on Climate Change (IPCC 2022), increases in temperature and average sea level are predicted worldwide in the coming decades, with an increase in the frequency of

extreme drought and rainfall events. Activities carried out by humans since the 19th century, such as the industrial revolution and greenhouse gas (GHG) emissions from burning fossil fuels, wildfires, and deforestation, are the main factors that generate variations in the climate.

Such climate changes caused by human actions generate significant impacts on the biodiversity of wetlands, especially because they alter the hydrology and hydrochemistry of the waters, increasing the duration and frequency of flooding, soil erosion, evapotranspiration, and the propensity for fire. Furthermore, consecutive years of drought or extreme floods can result in the replacement of vulnerable species with those more tolerant to the new conditions (Piedade et al. 2013). In this way, there is a loss of biodiversity, impacting not only ecosystems but, above all, traditional peoples.

It is need Understanding the dynamics and characteristics of floodplain forests is crucial, as they possess unique attributes. such as high degree of endemism, species adapted to the flood pulse, nutrient-rich soil and high natural contributions of methane (CH₄) emissions to the atmosphere, a potent GHG (Junk et al. 2020).

Within the communities' vegetables occurring in floodplains, the stratum Regenerative change is a topic that is rarely discussed and studied., but it composes and influences the dynamics of forest succession. According to Wittmann et al. (2007), the regeneration behavior in most floodplain trees is still unknown, and there is no information on the content of tree seedlings in total forest biomass and net primary production (NPP).

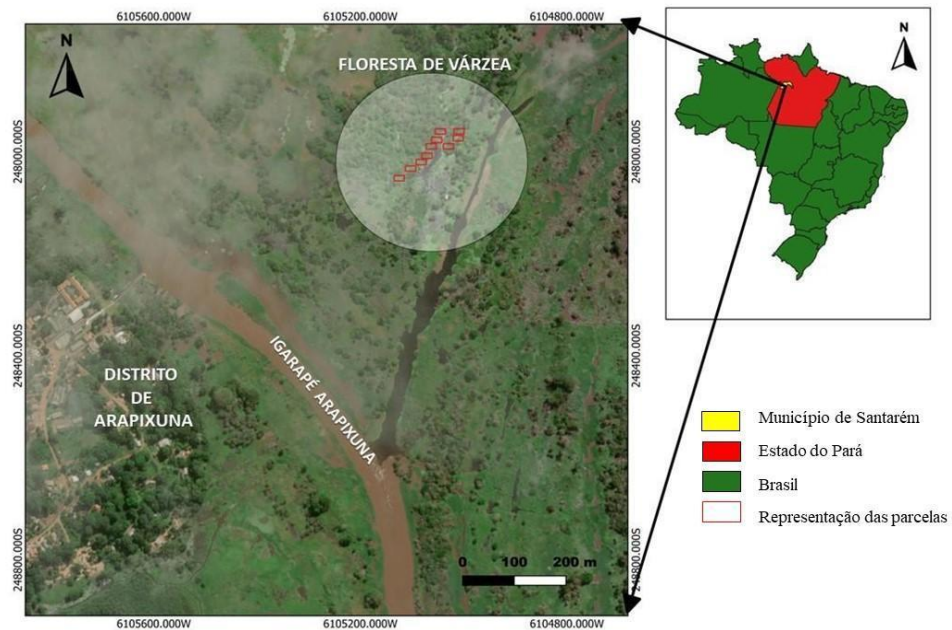
The regenerative stratum is the initial survival phase of plant species that are part of the forest and are most vulnerable to ecosystem changes (Gama et al. 2002). Therefore, there is a need to learn more about natural regeneration and the various aspects that constitute the environment, investigating abiotic aspects. on Hydrology, climate, temperature, and insolation. Biotic aspects. about Composition, structure, dynamics, and quantification of forest biomass. In this way, it is possible to understand its role in the ecology of future ecosystems and its role in the world, especially in biogeochemical cycles and in carbon emission and fixation.

This study aimed to analyze the floristic composition, structure, and dynamics of the natural woody regenerative stratum of the floodplain forest, describing the floristic composition of the plants in the woody regenerative stratum; evaluating the vertical and horizontal structure of natural regeneration; analyzing the mortality and persistence rates of regenerating woody species; and assessing the effect of flooding.

Material and methods

The studied floodplain forest is located in Brazil, in a region called the Arapixuna district, adjacent to the channel that connects the Amazon River to the Tapajós River (Igarapé do Arapixuna - Lat. 02°13'49"S; Long. 054°50'55"W (Figure 1)). The region is bathed by white water from the Amazon River, which has a large load of suspended material, resulting in extremely nutrient-rich soils, and also presents vegetation with characteristics determined by the river's flood pulse.

Fig. 1 Location map of the study area in the Arapixuna district, Santarém, PA. In the upper right corner, the 10 plots (P1 to P10) are shown in red.



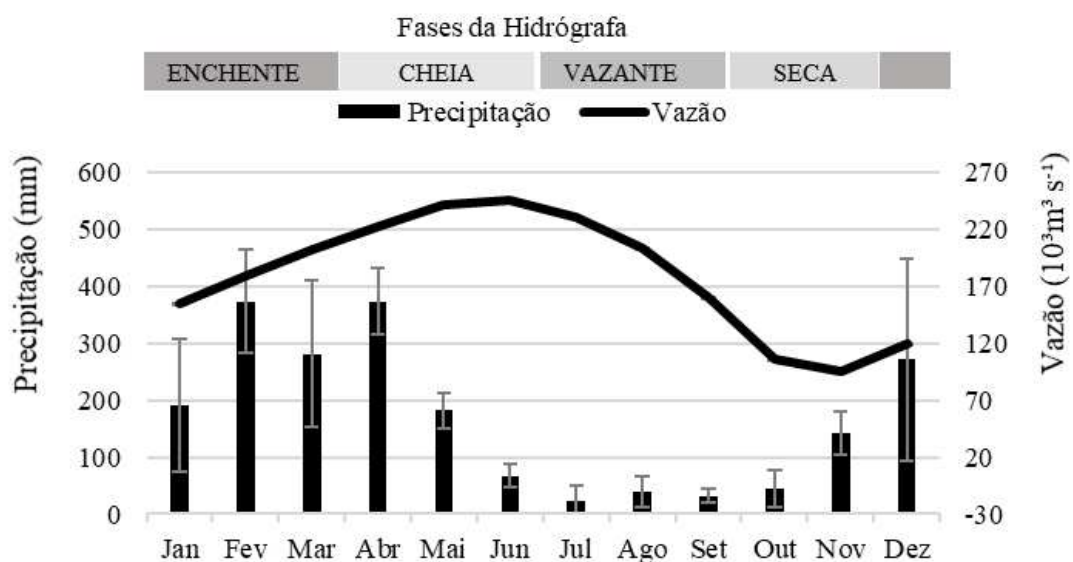
The research site is categorized as an area of predictable, high-amplitude, long-duration unimodal pulse and classified as lowland floodplain forest following the proposals of Junk et al. (2011). The distribution of plots in this site was carried out only in the highest part of the region, where the flooding time is shorter and they are parallel to the Arapixuna stream channel. This distribution of plots occurred in the respective years: 2018 and 2021. The data collection process was repeated.

This area has bodies of water on all sides, and in the north of the plots there is a permanently flooded lake approximately 1 km away. To the east and south, the research the research is close at hand

which connects the Amazon River to the Arapixuna stream, and to the west by the Arapixuna stream. This area is 2.6 km from the Amazon River (to the east).

The dry season occurs between October and November (Figure 2), and the flooding begins in December. According to data available from the municipality of Óbidos on the INMET (National Institute of Meteorology) and ANA (National Water Agency) websites, it is possible to verify that a flood pulse causes the area to be flooded between February and September, meaning that the vegetation can be submerged for a period of 7-8 months. In the heaviest month, the water level at the study site reaches approximately 3 meters in height.

Fig. 2 Monthly accumulated rainfall and flow of the Amazon River between 2018 and 2020 in the municipality of Óbidos, Pará. Source: INMET, 2020; ANA, 2020.



Climate

The climate type of the region is Am (tropical rainy climate) according to the Köppen classification. (Chambers et al. 2004; Alvares et al. 2013). It is characterized by two distinct climatological seasons during the year, defined by monthly rainfall; however, the average annual temperature is 26°C, with an average relative humidity of 85%. The rainy season comprises the months with precipitation above 200 mm, beginning in December, while the dry season has approximately 100 mm of rainfall per month.

Soil

Due to the constant processes of erosion and sedimentation along the main and secondary channels of the Amazon rivers, their alluvial geological formations are marked by small-scale depressions and elevations, which provides diverse habitats in these areas and consequently generates a great biodiversity of the floodplains (Wittmann et al. 2004). Many of the sediment The water carried by the white-water rivers during the flood season originates from the Andes, which is why the floodplain soils are quite rich in nutrients (Junk et al. 2011).

The high fertility of the floodplain soils is due to the nutrients brought by the floodwaters, providing conditions for agriculture (commercial and subsistence) and extensive livestock farming in the natural fields (Canto 2007). According to information from EMBRAPA, the soils of 86% of the floodplain areas of Santarém, PA, are classified as Fluvisols and about 6% are Haplic Gleysols. There is still no specific pedology for Arapixuna in the literature.

According to Junk et al. (2011), floodplain soils are much more fertile because they originate from solid particles suspended in the Amazon River, which is rich in montmorillonite, a substance with a high ion exchange capacity that releases potassium upon decomposition. Due to this, important products bioeconomics Crops such as pumpkin (*Cucurbita* sp. L.), rice (*Oryza sativa* L.), corn (*Zea mays* L.), and cassava (*Manihot esculenta* Crantz) are planted for short-cycle harvesting in lowland areas near riverbeds (Machado et al. 2019). In general Floodplain soils are heterogeneous, as they present high nutrient availability with intermediate levels of K, P, Ca, Mg, Zn, Cu, Mn, and Fe, in addition to high variability in chemical and physical properties as a result of differences in sediment discharges from tributaries of the Amazon River basin. Although floodplain soils have high fertility, they also exhibit high acidity and high toxic levels of exchangeable Al, which can affect root growth, plant growth, iron absorption, and phosphate availability (Gaspar et al. 2023).

Data collection

Analysis of Natural Regeneration, Growth, and Mortality

The floodplain forest in the Arapixuna district has a forest inventory of its tree population, with a diameter at breast height (DBH) greater than 10 cm, which was previously performed by Machado (2019). For the lift mentation the regeneration analysis was installed back in 2018 two plots (P1 and P2) of 10 m x 50 m, totaling 0.1 ha of area. The following collection schedule was followed: in 2018, activities consisted of conducting an inventory, analyzing natural regeneration, and calculating the diversity index. Subsequently, in 2021, field efforts focused on analyzing natural regeneration and verifying specimen mortality.

Therefore, they were selected the Individuals with a circumference at breast height (CBH) less than or equal to 31.4 cm were considered (this measurement was chosen as a parameter because above this value there is already a tree inventory classified as the adult stratum of this forest). For individuals shorter than 1.30 m, where measurement at breast height is not possible, measurements were taken with circumferences close to the ground (CIRC). The individuals were identified with aluminum tags containing each individual's number and attached with nylon thread. Following the methodology of Gama et al. (2002), the information was recorded like the common name known by field assistants (community residents), excessive tortuosity or presence of branching (in the case of bifurcated trees below 1.30 m from the ground, they were Plates with the same numbering were added, differing only in the trunks and branches. they were (circumference and total height measurements taken).

Diversity Index

According to De França et al., (2016) and Felfili & Rezende (2003), for calculating the diversity of natural regeneration in relation to flooding, the Shannon index (H') was used for data referring to 2018 and 2021, also called Shannon-Weaver or Shannon-Wiener, and Pielou's evenness (J') according to Muller-Dombois & Ellenberg (1974), Brower & Zar (1984). The data were processed and the result was obtained using the FITOPAC 2.1 program.

To analyze the normality of the data, the Shapiro-Wilk test with independent samples was used. The data did not present a normal distribution; therefore, the non-parametric Mann-Whitney test for comparison of means was performed. The analyses were performed using the Jamovi 2.3 program.

Assessment of the floristic composition and vertical and horizontal structure of the regenerative stratum

To measure the height of individuals up to 3.0 m, a pocket tape measure was used. Phytosociological parameters were estimated using the FITOPAC 2.1 program. The parameters for analyzing the horizontal structure were: overdensity (D), frequency (F), dominance (Do) in their absolute values (DA, FA, and DoA, respectively) and relative values (DR, FR, and DoR, respectively), as well as the importance value index (IVI), which represents the sum of the values of DR, FR, and DoR, were analyzed to evaluate the horizontal structure of natural regeneration as described by Curtis & McIntosh (1951). The parameters used to analyze the vertical structure were the Size Class divided into four categories: CT1 class: $0.5 \text{ m} \leq h < 1.5 \text{ m}$; CT2: $1.5 \text{ m} \leq h < 3.0 \text{ m}$; CT3: $h \geq 3.0 \text{ m}$ and $\text{DBH} < 5.0 \text{ cm}$ and CT4: $5.0 \text{ cm} \leq \text{DBH} \leq 10.0 \text{ cm}$ as described by Gama et al. (2022) and adapted for this study area.

These phytosociological parameters, obtained from data collected in the field in 2018 and 2021, serve to analyze the horizontal and vertical structure of the natural regeneration of this floodplain forest area and to evaluate the growth of the individuals that make up this community and that remained after three flood cycles. To assess the mortality rate, the inventory carried out between 2018 and 2021 was compared. To assess the percentage of survival and mortality, the inventory carried out in different years was compared. The analysis of survival and mortality data will be performed using Microsoft Excel 2019.

Botanical identification

This study complements the project already developed in the floodplain forest area, which already contains inventory data of trees in the arboreal stratum above 10 cm in diameter. Most of the sampled species had their botanical material collected and underwent herbarium preparation. Subsequently, they were identified to family, genus, and species by specialists from the Herbarium linked to the Federal University of Western Pará (HSTM – Fátima Meckedece), and some species were defined together with bibliographic reviews found on the website - floradobrasil.jbrj.gov.br - and by field observations described by Medeiros (2019). These species of the arboreal stratum identified in the floodplain forest of the Arapixuna District, Santarém-PA, served as a basis for identifying the regenerative stratum, since this does

not have flowering. However, the difficulty in identifying regenerating species resulted in a larger number of individuals being identified only at the family level.

RESULTS

Floristic Composition and Horizontal Structure

In the 2018 inventory, 236 individuals were recorded in an area of 0.1 ha, distributed among 10 families, 11 genera, and 7 identified species. The families with the greatest representation were Fabaceae (72 individuals) and Lecythidaceae (16 individuals) (Table 1). In terms of horizontal structure, the species with the highest absolute and relative density were *Schizolobium amazonicum*, *Cassia leiandra*, and *Buchenavia* sp. The Importance Value Index (IVI) was led by unknown individuals, followed by *S. amazonicum* (43.22) and *Buchenavia* sp. (36.08) (Table 2). In the 2021 survey, there was a significant reduction to 65 individuals, distributed among 8 families and 5 species (Table 3). The Fabaceae family maintained the highest representation (15 individuals). *Schizolobium amazonicum* showed the highest absolute density, while the highest IVI was recorded for the group of unknown species (94.41) and, again, for *S. amazonicum* (45.07).

Table 1. Floristic composition of regenerating species with DBH ≥ 10 cm from forest fragments in the floodplain of the Arapixuna District in 2018.

Family	Species	Number of Individuals	Reference
Araceae	<i>Montrichardia linifera</i> (Arruda) Schott	7	floradobrasil.jbrj.gov.br
Bignoniaceae	Unknown 4	1	
Chrysobalanaceae	<i>Couepiasp.</i>	8	floradobrasil.jbrj.gov.br
Combretaceae	<i>Buchenavia</i> sp.	20	floradobrasil.jbrj.gov.br
Unknown 1	Unknown 1	90	-
Unknown 2	Unknown 2	6	-
Unknown 3	Unknown 3	2	
Fabaceae	<i>Cassia leiandra</i> Benth.	21	Lorenzi, 2009. floradobrasil.jbrj.gov.br
	<i>Schizolobium amazonicum</i> Huber ex Ducke	51	Santos Rosa, 2006. floradobrasil.jbrj.gov.br
Lamiaceae	<i>Vitex cymosa</i> Bertero ex Spreng.	3	Fehlauer, 2012; floradobrasil.jbrj.gov.br.
Lecythidaceae	<i>Gustavia Augusta</i> L.	16	Lorenzi, 2009; floradobrasil.jbrj.gov.br
Myrtaceae	<i>Eugenia</i> sp.	3	-
	<i>Psidium cattleianum</i> Sabine	3	-
Ochnaceae	<i>Ouratea</i> sp.	4	-
Salicaceae	<i>Laetia corymbulosa</i> Spruce ex Benth.	1	-
Grand total	-	236	-

Table 2. Horizontal Structure of the Floodplain Forest in 2018. Phytosociological parameters of the sampled species ordered by IVI. Where N = number of individuals, DA = absolute density, DR = relative density, FA = absolute frequency, FR = frequency.

Popular Name	Species	Family	FROTHE	DR	FA	FR	DoA	Pain	IVI
Aningá	<i>Montrichardia linifera</i> (Arruda) Schott	<i>Araceae</i>	70	2.97	50	5.56	1.81	18.33	26.85
Description	Description	Description	1000	42.37	100	11.11	2.97	30.02	83.50
Cuiarana	<i>Buchenavia</i> sp. Eichler	<i>Combretaceae</i>	200	8.47	100	11.11	1.63	16.49	36.08
Jenipaporana	<i>Gustavia Augusta</i> L. <i>Cassia</i>	<i>Lecythidaceae</i>	160	6.78	100	11.11	0.46	4.63	22.52
Mari	<i>Leiandra</i> Benth. <i>Laetia</i>	<i>Fabaceae</i>	210	8.90	100	11.11	0.26	2.60	22.61
Meracuiara	<i>corymbulosa</i> Spruce ex Benth.	<i>Salicaceae</i>	10	0.42	50	5.56	0.00	0.01	5.99
Murucirana	<i>Mabea fistulifera</i> Mart.	<i>Euphorbiaceae</i>	20	0.85	50	5.56	0.40	4.00	10.40
Pajurázinho	<i>Couepia</i> sp. Aubl.	<i>Chrysobalanaceae</i>	80	3.39	100	11.11	0.23	2.31	16.81
Paricá	<i>Schizolobium amazonicum</i> Huber ex Ducke	<i>Fabaceae</i>	510	21.61	100	11.11	1.04	10.50	43.22
Jijum Pepper	<i>Ouratea</i> sp. Aubl.	<i>Ochnaceae</i>	40	1.69	50	5.56	1.09	11.03	18.28
Socoró	<i>Eugenia</i> sp. L.	<i>Myrtaceae</i>	30	1.27	50	5.56	0.00	0.01	6.84
Tarumã	<i>Vitex cymosa</i> Bertero ex Spreng.	<i>Lamiaceae</i>	30	1.27	50	5.56	0.01	0.06	6.89

Table 3. Horizontal Structure of the Floodplain Forest in 2021. Phytosociological parameters of the sampled species ordered by IVI. Where N = number of individuals, DA = absolute density, DR = relative density, FA = absolute frequency, FR = frequency.

Popular Name	Species	Family	FR OM TH E	DR	FA N	FR	DoA	Pain	IVI
Aningá	<i>Montrichardia linifera</i> (Arruda) Schott	<i>Araceae</i>	30	4.62	50	9.09	0.18	27.31	41.01
Description	Description	Description	340	52.31	100	18,18	0.16	23.92	94.41
Cuiarana	<i>Buchenavia</i> sp. Eichler	<i>Combretaceae</i>	50	7.69	50	9.09	0.12	18.79	35.58
Jenipaporana	<i>Gustavia Augusta</i> L.	<i>Lecythidaceae</i>	30	4.62	100	18,18	0.04	6.05	28.84
Mari	<i>Cassia Leiandra Benth.</i>	<i>Fabaceae</i>	40	6.15	50	9.09	0.01	1.84	17.09
Murucirana	<i>Mabea fistulifera</i> Mart.	<i>Euphorbiaceae</i>	10	0.42	50	5.56	0.00	0.19	9.09
Pajurázinho	<i>Couepiasp.</i> Aubl.	<i>Chrysobalanaceae</i>	10	1.54	50	9.09	0.00	0.19	10.82
Paricá	<i>Schizolobium amazonicum</i> Huber ex Ducke	<i>Fabaceae</i>	11	16.92	100	18,18	0.07	9.97	45.07
Jijum Pepper	<i>Ouratea</i> sp. Aubl.	<i>Ochnaceae</i>	40	6.15	50	9,099	0.08	11.93	27.18

Mortality and Dynamics

Between 2018 and 2021, a mortality rate of 72% was observed in the total number of individuals. Species such as *Laetia corymbulosa*, *Eugenia* sp., and *Vitex cymosa* showed 100% mortality after three flood cycles. In contrast, *Ouratea* sp. recorded no losses, demonstrating success in floodable environments, while *Mabea fistulifera* had a 50% reduction (Table 4).

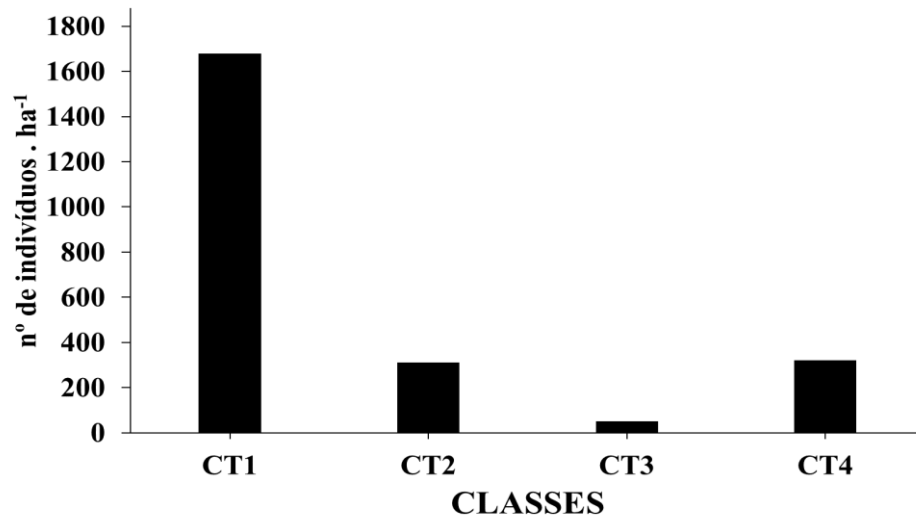
Table 4. Comparison between the number of individuals of each species observed in 2018 and 2021 and the percentage of mortality.

Species	Number of individuals observed in 2018	Number of individuals observed in 2021	Difference	Mortality (%)
<i>Montrichardia linifera</i> (Arruda) Schott	7	3	4	57.1
Unknown 1	3	0	3	100.0
<i>Buchenaviasp.</i> eichler	20	5	15	75.0
Unknown 2	6	5	1	16.7
Unknown 3	90	28	62	68.9
Unknown 4	1	0	1	100.0
<i>Gustavia augusta</i> L.	16	3	13	81.3
<i>Cassia leiandra</i> Benth.	21	4	17	81.0
<i>Laetia corymbulosa</i> Spruce ex Benth.	1	0	1	100.0
<i>Mabea fistulifera</i> Mart.	2	1	1	50.0
<i>Couepia</i> sp. Aubl.	8	1	7	87.5
<i>Schizolobium amazonicum</i> Huber ex Ducke	51	11	40	78.4
<i>Ouratea</i> sp. Aubl.	4	4	0	0.00
<i>Eugenia</i> sp. L.	3	0	3	100.0
<i>Vitex cymosa</i> Bertero ex Spreng	3	0	3	100.0
Total	236	65	171	

Vertical Structure and Total Natural Regeneration (TNR)

The diameter distribution of the forest approximated the "inverted-J" model, with a higher concentration of individuals in the smaller size classes. The CT1 class ($0.4 \text{ m} \leq h < 1.5 \text{ m}$) stood out with the highest average number of individuals per hectare. When analyzing the Total Natural Regeneration (TNR), it was found that 7 species are present in all three height classes, with *Schizolobium amazonicum* (TNR of 38.04%), *Gustavia augusta* (16.45%) and *Ouratea* sp. (9.52%) being the most prominent (Figure 3).

Fig. 3 Distribution of individuals (ha⁻¹) in relation to size class (CT1: 0.5 m ≤ h < 1.5 m; CT2: 1.5 m ≤ h < 3.0 m; CT3: h ≥ 3.0 m and DBH < 5.0 cm and CT4: 5.0 cm ≤ DBH ≤ 10.0 cm) in the floodplain forest in the year 2018.



Diversity Indices

The Shannon-Weaver diversity index (H') was higher in 2018 (1.7) compared to 2021 (1.5). Pielou's evenness (J') ranged from 0.5 to 0.7 in the respective years, indicating an area of low richness and low diversity (Table 5).

Table 5. Shannon and Weaver diversity index (H') and evenness (J') of regenerating tree species.

Year	Quantity (Numbers)			Diversity Indices	
	Individuals	Family	Species	(H')	(J')
2018	236	10	7	1.7	0.7
2021	65	8	5	1.5	0.7

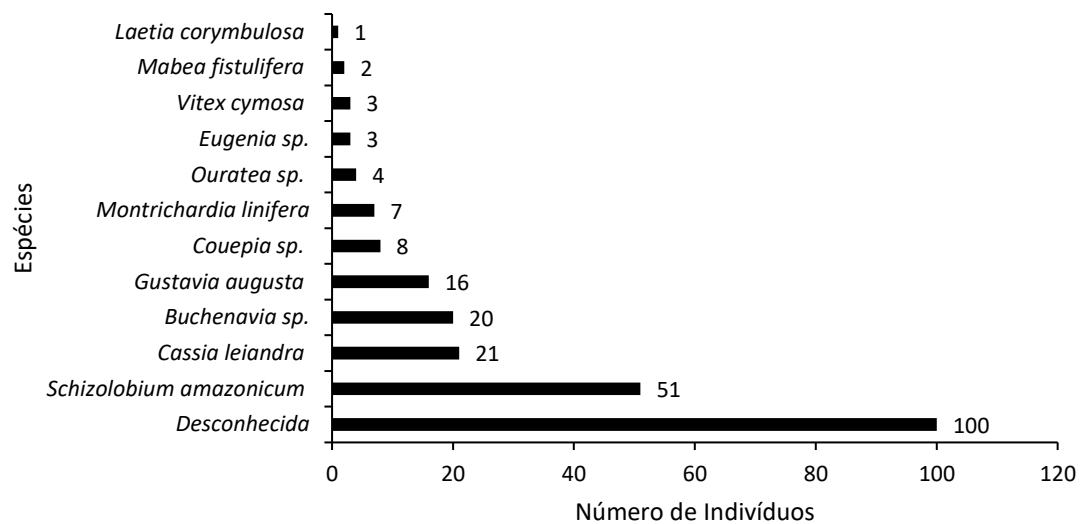
DISCUSSION

Succession Dynamics and Resilience

The predominance of individuals in the lower height classes (inverted J-shape) suggests that the forest, despite stress from human activities and flood pulses, invests in the development of natural

regeneration to ensure the survival of future generations (Figure 4). The high mortality observed in certain species reflects the difficulty of establishing themselves in environments of periodic stress.

Fig. 4 Distribution of individuals by species in the floodplain forest plots of the Arapixuna District, Santarém, PA.



Strategies of the Dominant Species

Schizolobium amazonicum The success of Paricá (*S. amazonicum*) in the area is attributed to its rapid growth and adaptability to diverse edaphoclimatic conditions (Pereira et al. 1982; Ducke 1949; Rondon 2000; Rosa 2006; Ohashi, Yared, Farias Neto 2010). Strategies such as abundant anemochorous dispersal, seeds with a resistant exocarp (which maintain germination potential for up to 2 years), and tolerance to solar radiation explain its dominance in both floodplains and secondary forests of terra firme.

Establishment Potential and Future of the Forest

Species that occur in all three height classes of natural regeneration, such as *S. amazonicum* and *Gustavia augusta*, are considered the most suitable to compose the future structure of the forest. The abundance of *G. augusta* is relevant because it is one of the most important floodplain species, with resistant seeds dispersed by fish (ichthyochory) in waterlogged soils.

Convergence between Strata and Diversity

A significant similarity was observed between the regenerative stratum and the adult tree stratum (DBH > 10 cm), with the same species (*C. leiandra*, *S. amazonicum*, *V. cymosa*, and *G. augusta*) showing

high importance indices at both levels. This indicates that the regenerative stratum serves as a predictive tool for the characteristics of the adult forest. However, the low diversity found ($H' = 1.7$) compared to other floodplain areas, such as in Afuá-PA ($H' = 3.05$), reinforces the condition of ecological fragility or stress in the studied area.

CONCLUSIONS

The natural regeneration of the Arapixuna floodplain forest demonstrates The capacity for self-renewal is evident, despite the high individual mortality imposed by the environment. The prominence of *Schizolobium amazonicum* and *Gustavia augusta* suggests that these species will be the main components of the future canopy. The similarity between the young and adult strata allows the regeneration inventory to be used as a predictive tool for the management and conservation of this ecosystem. Preservation of low-density species is recommended to avoid further biodiversity loss in an area that already has low floristic richness.

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Author Contributions

Authors' contributions: Conceptualization and field sampling: JSS, JMSM, AMSF; Formal analysis and data curation: JSS, JMSM; Writing – original draft preparation: JSS; Writing – review and editing: JMSM, AMSF; Funding acquisition and supervision: JMSM, AMSF. All authors read and approved the final manuscript.

Declarations / Conflict of Interest

Conflict of Interest: The authors declare that they have no conflict of interest.

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