

DYNAMICS OF WOODY SPECIES IN DRY TROPICAL FOREST (CAATINGA), BRAZIL

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Resumo

Dinâmica de espécies lenhosas em floresta tropical seca (caatinga), Brasil. Estudar as mudanças estruturais e florísticas das florestas tropicais secas é fundamental para fomentar as estratégias de conservação, preservação e manejo florestal sustentável. Objetivou-se analisar a dinâmica de espécies lenhosas em floresta tropical seca com histórico de uso. Em 2008, foram instaladas 40 parcelas permanentes e mensurados os indivíduos lenhosos com circunferência a 1,30 m do Solo, Circunferência acima do Peito (CAP) \geq 6 cm. Em 2012, levantaram-se os indivíduos remanescentes, os ingressos e computada a mortalidade. Conforme ocasião, para cada espécie foram estimados: densidade, frequência e dominância absolutas, valor de importância, ingresso, mortalidade, crescimentos brutos e líquidos e o índice de Shannon. A composição e a diversidade florística permaneceram inalteradas. Após quatro anos, houveram poucas diferenças estruturais entre as espécies, que em sua maioria o crescimento em área basal foi positivo e para algumas o ingresso superou a mortalidade. Durante 24 anos a área florestal analisada, quando comparada a outras áreas de Caatinga sem histórico de perturbação, não atingiu o seu estoque inicial de área basal.

Palavras-chave: crescimento; semiárido; variação temporal.

Abstract

Studying selected floristic changes in dry forests is fundamental to foster conservation and sustainability strategies. Objective: to analyze the occurrence of woody species in a tropical forest with a history of use. In 2008, 40 permanent plots were installed and wood with a circumference of 1.30 m at a breast height (CAP) \geq 6 cm were measured. In 2012, newly established individuals (those that did not meet the size requirements in 2008 but did in 2012) and mortality of the remaining individuals were analyzed by computer. Where applicable, the density, frequency, and absolute dominance, importance value, newly established individuals, mortality, and gross growth for each species, along with the Shannon index were estimated. The floristic composition and diversity remain unchanged. After four years, there were few differences between species, while in most cases the growth in the basal area was positive and sometimes the number of newly established individuals exceeded the mortality. After 24 years of logging, the analyzed forest area did not reach its initial basal area stock when compared to other areas of the Caatinga that do not have a history of disturbance.

Keywords: growth; semiarid; temporal variation.

INTRODUCTION

Studies on structural and floristic changes in anthropized areas over time are fundamental for continually monitoring the growth, recruitment, mortality, and presence of new individuals in plant communities, as they help in the construction of strategies aimed at optimizing productivity, preservation and/or conservation of forest massifs.

Thus, studying the local vegetation requires consideration of its initial and future stocks, productive potential, growth dynamics, and recovery and resilience, which then facilitates the actions of sustainable management plans. This is especially important in dry tropical forests, where logging activities are more intense due to the high demand of energy for industrial purposes, as well as for local agriculture and livestock.

In addition to the recurring anthropic pressure in dry forests in Brazil, climatic phenomena such as periods of drought, evapotranspiration, El Niño, and La Niña also severely affect structural and floristic changes in the Caatinga, with the relevance of monitoring the dynamics in forest communities, however, there is a scarcity of work developed on this theme in recent years in this biome (SILVA *et al.*, 2019; OLIVEIRA *et al.*, 2020).

The objective of the current study was to answer the following question: is four years enough to observe changes in the dynamics of dry tropical forest communities?

Thus, to answer the objective, we analyzed the dynamics of woody species in a dry tropical forest (Caatinga) in the secondary succession stage after 24 years of logging in the municipality of Floresta-PE, Brazil.

MATERIAL AND METHODS

Study Location

The research was carried out in an area belonging to Empresa Agrimex SA. The area was logged in 1988 but there is no current knowledge regarding the intensity of logging (on average, in m³). There was also extensive grazing by goats over an area of about 50 ha in the municipality of Floresta-PE (the mesoregion of São Francisco and microregion of Sertão de Itaparica, 8°30'37"S and 37°59'07"W), approximately 433.4 km from Recife.

The vegetation is characterized as Savanna-Estépica Arborizada - caatinga (IBGE, 2012). The climate is classified as BSh according to the Köppen classification, which is a tropical semi-arid climate with summer rains between November and April. The average annual precipitation between 2008 and 2012 was 488.48 mm (APAC, 2020).

Data Collection and Analysis

Sampling and data collection took place in 40 permanent plots of 20 x 20 m that were systematically distributed in 2008. These plots were situated 80 m apart and 50 m away from the edges, and were georeferenced. In 2012, the remaining woody individuals in the plots were re-measured following the same measurement procedure adopted in 2008, including bifurcations. Trees with a circumference of 1.30 m at a breast height (CAP) ≥ 6 cm were measured. Dead individuals (those that were alive and measured in 2008 but dead in 2012) were also counted and newly established individuals (those that were not measured in 2008 due to their small size but met the size requirement in 2012, with a CAP ≥ 6 cm) were scored and measured.

Estimates of the parameters of the horizontal distribution or phytosociological analysis (density, frequency, dominance, coverage values [VC], and importance values [VI]), Shannon's diversity index, and Pielou's equability indices were calculated and confidence limits were estimated through the Jackknife procedure (P = 95%, gl = 39).

For the analysis of the dynamics of the community and its species, the mortality and newly established individual rates, and gross and net growth (including and excluding newly established individuals and annual and periodic increments in diameter and basal area) were estimated. Recruitment and mortality rates were calculated for the community and by species using Equations 1 and 2.

$$TI = \left[1 - \left(1 - \frac{N_r}{N_f} \right)^{\frac{1}{t}} \right] \cdot 100 \quad (1) \quad TM = \left[1 - \left(1 - \frac{N_m}{N_i} \right)^{\frac{1}{t}} \right] \cdot 100 \quad (2)$$

where TI = recruitment rate (% year⁻¹); t = time elapsed between measurements (years); N_f = final count of living trees (per ha); N_r = number of newly established individuals with CAP ≥ 6 cm recorded (per ha); TM = mortality rate (% year⁻¹); N_i = initial number of trees (per ha); N_m = number of individuals killed (per ha).

For the net growth, the difference between the initial basal area (2008) and the final one (2012) was considered, not accounting for losses or deaths. As for the gross growth, the basal area of lost or dead individuals was included. Equations 3, 4, 5 and 6 were used to calculate gross and net growth.

$$Cb_i = G_f - (G_i - M) \quad (3) \quad Cb = Cb_i - I \quad (4) \quad Cl_i = Cb_i - M \quad (5) \quad Cl = Cb - M \quad (6)$$

where G_f = basal area (m² ha⁻¹) in 2012; G_i = basal area (m² ha⁻¹) in 2008; I = new individuals in basal area (m² ha⁻¹); M = basal area mortality (m² ha⁻¹), from 2008 to 2012; Cb_i = gross growth in basal area (m² ha⁻¹), from 2008 to 2012, including newly established individuals; Cb = gross growth in basal area (m² ha⁻¹), from 2008 to 2012, excluding newly established individuals; Cl_i = net growth in basal area (m² ha⁻¹), from 2008 to 2012, including newly established individuals; Cl = net growth in basal area (m² ha⁻¹), from 2008 to 2012, excluding newly established individuals. The periodic and annual periodic increments in the diameter and basal area were obtained according to Equations 7 and 8:

$$IPAd = \frac{(\bar{D}_{2012} - \bar{D}_{2008})}{P} \quad (7) \quad IPAG = \frac{(G_{2012} - G_{2008})}{P} \quad (8)$$

where: \overline{D}_{2008} = mean DAP (diameter at chest height) in 2008 (cm), \overline{D}_{2012} = mean DAP in 2012, $P = 4$ years, G_{2008} = basal area in 2008, and G_{2012} = basal area in 2012.

Then, the net and gross growth were calculated. For the net growth, the difference between the initial basal area (first measurement) and the final basal area (2012) were used, with losses or deaths disregarded, while for the gross growth, lost or dead individuals were also considered, as shown in the equations below:

$$Gb_i = G_f - (G_i - M) \quad (9) \quad Gb_e = (G_f - I) - (G_i - M) \quad (10) \quad GL_i = G_f - G \quad (11) \quad GL_e = (G_f - I) - G_i \quad (12)$$

Where: Gb = gross growth in basal area ($m^2 ha^{-1}$) between 2008 and 2012, excluding newly established individuals; Gb_i = growth in basal area ($m^2 ha^{-1}$) between 2008 and 2012, including newly established individuals; G_f = basal area ($m^2 ha^{-1}$) in 2012; G_i = basal area ($m^2 ha^{-1}$) in 2008; GL = net growth in basal area ($m^2 ha^{-1}$) between 2008 and 2012, excluding newly established individuals; GL_i = net growth in basal area ($m^2 ha^{-1}$) between 2008 and 2012, including newly established individuals; I = newly established individuals into the basal area ($m^2 ha^{-1}$) during the period from 2008 to 2012; M = basal area mortality ($m^2 ha^{-1}$) from 2008 to 2012.

RESULTS

Changes in the richness and abundance of woody species

There was no change in the floristic composition of the area for the years 2008 and 2012 at the level of family, genus, or species. The same nine families were sampled, with 19 genera and 23 species distributed across these, and 94% of the sampled individuals belonging to Fabaceae (66%, 65%), Euphorbiaceae (22%, 17%) and Combretaceae (6%, 12%), for 2008 and 2012 respectively.

The number of individuals only increased by 52 after four years in the study community. However, when interspecifically analyzing the change in the abundance of the 23 species, only six remained unchanged and 15 showed a decrease in 2012, particularly *Poincianella bracteosa* (Tul.) L. P. Queiroz, *Jatropha mollissima* Muell. Arg., and *J. mutabilis* (Pohl) Baill., with a reduction of 30, 17, and 14 individuals, respectively. Only *Thiloua glaucocarpa* (Mart.) Eichl (77) and *Pityrocarpa moniliformis* (Benth.) Luckow & Jobson (64) showed significant increases.

Regarding the richness and diversity of the forest community, these remained practically unchanged according to Shannon's diversity and Pielou's equability (Table 1).

Table 1- Richness and diversity of the forest community between 2008 and 2012 in an experimental area in the municipality of Floresta.

Tabela 1- Riqueza e diversidade da comunidade florestal entre 2008 e 2012 em área experimental no município de Floresta.

H' 2008	J' 2008	H' 2012	J' 2012
2.05 nats ind ⁻¹	0.65	2.00 nats ind ⁻¹	0.64
0.0016	0.0062	0.0888	0.3553

H': Shannon index; J': Pielou's equability index.

Although the four years were not enough to detect major changes in the floristics, richness, and diversity of the area, the vegetation showed a good recovery in terms of number of species and families, thus requiring a further assessment of the forest dynamics in the area.

Structural changes

In 2008, 780 individuals ha^{-1} were counted in the survey area, while 813 individuals ha^{-1} were counted in 2012. The absolute dominance (DoA) of the tree community showed a gain of 64.7% and most woody species increased their basal areas, with the exception of *Bauhinia cheilanta* (Bong.) Steud. and *Lippia microphylla* Cham., which showed a slight decrease (Table 2).

Table 2 - Estimation of the parameters of the horizontal distribution of woody species in 2008 and 2012 at an experimental area at a farm Itapemirim, Floresta.

Tabela 2 - Estimativa dos parâmetros da distribuição horizontal das espécies lenhosas, de 2008 e 2012, realizado em área experimental na fazenda Itapemirim, Floresta.

Species	AB		DA		DR		FA		FR		DoA		DoR		VC (%)		VI (%)	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
<i>Poincianella b.</i>	1.48	2.36	355.6	401.8	46.5	42.3	97.5	97.5	22.4	22.4	0.93	1.47	53.9	53.6	48.2	49.9	39.6	40.8
	8	6	3	8	6	6	0	0	1	1	0	9	1	3	4	9	3	0
<i>Mimosa o.</i>	0.38	0.58	63.75	76.25	7.63	8.80	42.5	42.5	9.77	9.77	0.24	0.36	14.1	13.1	10.8	10.9	10.5	10.5
	9	1					0	0			3	3	1	6	7	8	0	8
<i>Pityrocarpa m.</i>	0.08	0.26	128.1	100.6	15.3	11.6	17.5	17.5	4.02	4.02	0.05	0.16	3.21	5.90	9.27	8.75	7.52	7.18
	9	0	3	3	3	1	0	0			5	3						
<i>Thiloa g.</i>	0.00	0.04	60.63	51.88	7.26	5.98	37.5	37.5	8.62	8.62	0.00	0.02	0.04	0.95	3.65	3.47	5.31	5.18
	1	2					0	0			1	6						
<i>Cnidoscopus p.</i>	0.20	0.33	13.13	13.75	1.57	1.59	30.0	30.0	6.90	6.90	0.12	0.20	7.43	7.59	4.50	4.59	5.30	5.36
	5	5					0	0			8	9						
<i>Jatropha mutabilis</i>	0.08	0.10	38.13	38.13	4.56	4.40	25.0	25.0	5.75	5.75	0.05	0.06	3.04	2.38	3.80	3.39	4.45	4.18
	4	5					0	0			3	6						
<i>Myracrodruon u.</i>	0.09	0.15	17.50	17.50	2.09	2.02	30.0	30.0	6.90	6.90	0.05	0.09	3.42	3.48	2.75	2.75	4.14	4.13
	4	3					0	0			9	6						
<i>Croton b.</i>	0.06	0.07	54.38	58.75	6.51	6.78	12.5	12.5	2.87	2.87	0.03	0.04	2.24	1.66	4.37	4.22	3.87	3.77
	2	3					0	0			9	6						
<i>Jatropha molíssima</i>	0.03	0.04	28.13	28.13	3.37	3.2	22.5	22.5	5.17	5.17	0.02	0.02	1.27	0.90	2.32	2.07	3.27	3.11
	5	0					0	0			2	5						
<i>Mimosa t.</i>	0.12	0.17	5.00	5.00	0.60	0.58	7.50	7.50	1.72	1.72	0.07	0.10	4.45	3.94	2.53	2.26	2.26	2.08
	3	4									7	9						
<i>Aspidosperma p.</i>	0.02	0.03	9.38	9.38	1.12	1.08	20.0	20.0	4.60	4.60	0.01	0.02	0.96	0.82	1.04	0.95	2.23	2.17
	6	6					0	0			7	3						
<i>Schinopsis b.</i>	0.05	0.07	5.63	5.63	0.67	0.65	15.0	15.0	3.45	3.45	0.03	0.04	1.80	1.58	1.24	1.12	1.97	1.89
	0	0					0	0			1	4						
<i>Cnidoscopus b.</i>	0.05	0.08	21.25	23.75	2.54	2.74	5.00	5.00	1.15	1.15	0.03	0.05	1.97	1.92	2.26	2.33	1.89	1.94
	4	5									4	3						
<i>Manihot g.</i>	0.01	0.02	4.38	4.38	0.52	0.50	10.0	10.0	2.30	2.30	0.00	0.01	0.51	0.55	0.52	0.53	1.11	1.12
	4	4									9	5						
<i>Croton r.</i>	0.00	0.00	6.25	6.25	0.75	0.72	10.0	10.0	2.30	2.30	0.00	0.00	0.26	0.17	0.50	0.45	1.10	1.06
	7	7									4	5						
<i>Senna s.</i>	0.00	0.00	2.50	2.50	0.30	0.29	10.0	10.0	2.30	2.30	0.00	0.00	0.18	0.13	0.24	0.21	0.93	0.91
	5	6									3	4						
<i>Commiphora l.</i>	0.00	0.01	2.50	2.50	0.30	0.29	10.0	10.0	2.30	2.30	0.00	0.00	0.10	0.28	0.20	0.28	0.90	0.95
	3	2									2	8						
<i>Piptadenia s.</i>	0.00	0.01	3.75	3.75	0.45	0.43	7.50	7.50	1.72	1.72	0.00	0.00	0.23	0.31	0.34	0.37	0.80	0.82
	6	4									4	8						
<i>Bauhinia c.</i>	0.00	0.00	3.13	3.75	0.37	0.43	7.50	7.50	1.72	1.72	0.00	0.00	0.08	0.04	0.23	0.23	0.73	0.73
	2	2									1	1						
<i>Anadenanthera c.</i>	0.00	0.01	3.75	4.38	0.45	0.50	5.00	5.00	1.15	1.15	0.00	0.00	0.33	0.27	0.39	0.38	0.64	0.64
	9	2									6	7						
<i>Lippia m.</i>	0.00	0.00	3.75	3.75	0.45	0.43	5.00	5.00	1.15	1.15	0.00	0.00	0.15	0.09	0.30	0.26	0.58	0.56
	4	4									3	2						
<i>Cordia l.</i>	0.00	0.00	1.88	1.88	0.22	0.22	5.00	5.00	1.15	1.15	0.00	0.00	0.12	0.11	0.17	0.16	0.50	0.49
	3	5									2	3						
<i>Erythroxylum sp.</i>	0.00	0.00	3.13	3.13	0.37	0.36	2.50	2.50	0.57	0.57	0.00	0.00	0.18	0.15	0.28	0.26	0.38	0.36
	5	7									3	4						
Total	2.76	4.41	836	867	100	100	435	435	100	100	1.73	2.76	100	100	100	100	100	100

I = 2008; II = 2012; AB = basal area/ha; DA = absolute density; DR = relative density; FA = absolute frequency; FR = relative frequency; DoA = absolute dominance; DoR = relative dominance; VC = percentage coverage value; VI = percentage importance value. *Poincianella b.* = *Poincianella bracteosa* (Tul.) L, P, Queiroz; *Mimosa o.* = *Mimosa ophthalmocentra* Mart, Ex Benth; *Pityrocarpa m.* = *Pityrocarpa moniliformis* (Benth.) Luckow & Jobson; *Thiloa g.* = *Thiloa glaucocarpa* (Mart.) Eichl; *Cnidoscopus p.* = *Cnidoscopus phyllacanthus* (Mull, Arg.) Pax & K, Hoffm; *Jatropha mutabilis* = *Jatropha mutabilis* (Pohl) Baill; *Myracrodruon u.* = *Myracrodruon urundeuva* (Engl.) Fr, All; *Croton b.* = *Croton blanchetianus* Baill; *Jatropha molíssima* = *Jatropha molíssima* Muell, Arg; *Mimosa t.* = *Mimosa tenuiflora* (Willd.) Poir; *Aspidosperma p.* = *Aspidosperma pyriformis* Mart; *Schinopsis b.* = *Schinopsis brasiliensis* Engl; *Cnidoscopus b.* = *Cnidoscopus bahianus* (Ule) Pax & K. Hoffm; *Manihot g.* = *Manihot glaziovii* Muell, Arg; *Croton r.* = *Croton rhamnifolius* Kunth; *Senna s.* = *Senna spectabilis* var. *excelsa* (Schad.) H.S, Irwin & Barneby; *Commiphora l.* = *Commiphora leptophloeos* (Mart.) J. B, Gillett; *Piptadenia s.* = *Piptadenia stipulacea* (Benth.) Ducke; *Bauhinia c.* = *Bauhinia cheilanta* (Bong), Steud.; *Anadenanthera c.* = *Anadenanthera colubrina* var. *cebil* (Griseb.) Altschul; *Lippia m.* = *Lippia microphylla* Cham; *Cordia l.* = *Cordia leucocephala* Moric,

The distribution of tree species by sample units based on the values of absolute frequency (FA) remained unchanged. It was also verified that the five species with the largest VI were the same in 2008 and 2012 and held 70% of the VI in both periods; they were (in decreasing order): *Poincianella bracteosa* (Tul.) L. P. Queiroz, *Mimosa ophthalmocentra* Mart. Ex Benth., *Pityrocarpa moniliformis* (Benth.) Luckow & Jobson, *T. glaucocarpa* (Mart.) Eichl, and *Cnidoscolus phyllacanthus* (Mull. Arg.) Pax & K. Hoffm. These five species are pioneer species, with similar adaptive characteristics and rusticity, and are opportunistic, becoming established in disturbed environments.

Regarding density, *Pityrocarpa moniliformis* and *T. glaucocarpa* were responsible for the increase of 32 individuals ha^{-1} , as they were the only species to increase abundance, dominance, and VI. *Poincianella bracteosa* showed higher values than the other species for all horizontal structure parameters. Structural changes of *Myracrodruon urundeuva* (Engl.) Fr. All., *Mimosa tenuiflora* (Willd.) Poir., and *Commiphora leptophloeos* (Mart.) J. B. Gillett, however small, were signs of the successional advance of vegetation.

Diametric Distribution

The density and dominance percentages of the tree community and the five species with the highest VI are shown in Figure 1 (A to F). When analyzing the diametric distribution of the community, it was noted that only the first class had higher percentages in 2008 (70% of the density and 40% of dominance) than 2012 (40% and 20% of the density and dominance, respectively), but in the other classes the density and dominance were lower in 2008.

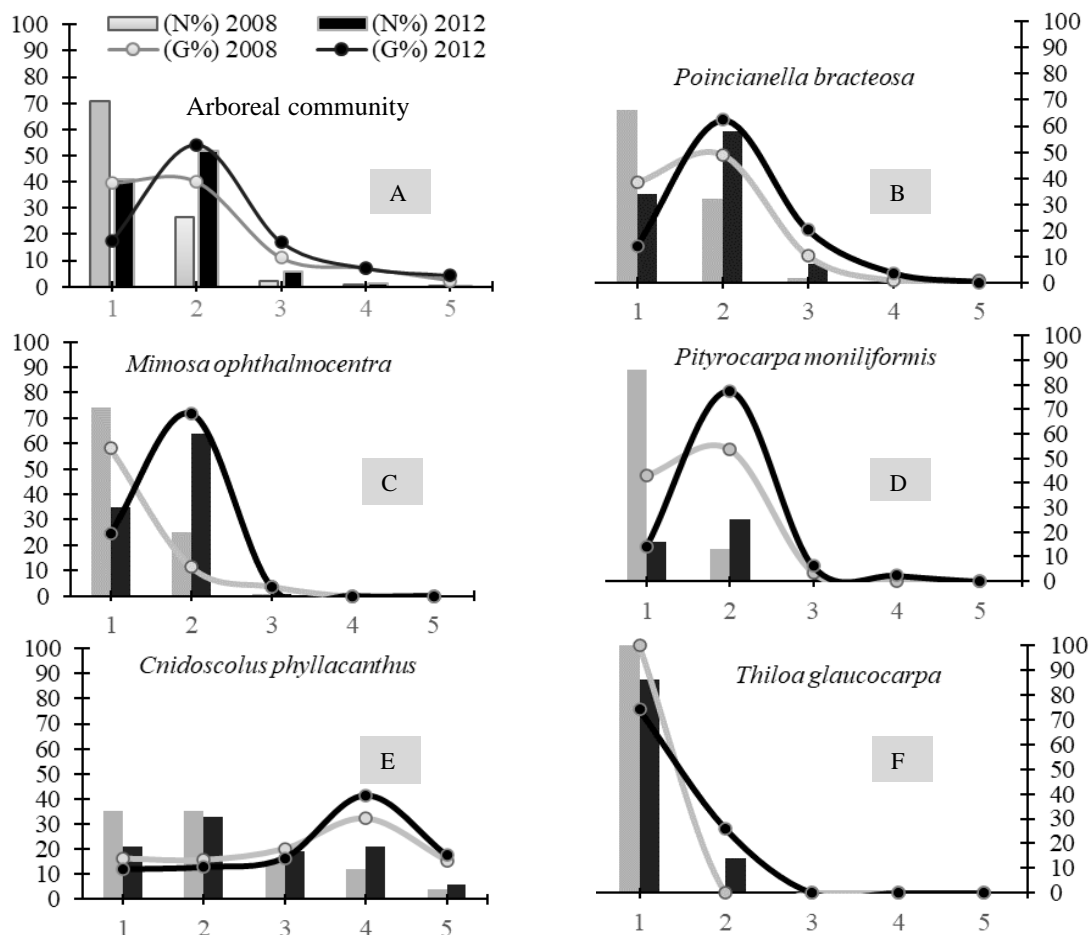


Figure 1. Percentage representation of the number of individuals (N%) and basal area (G%) sampled in 1.6 ha of forest, Floresta-PE, for (A) the arboreal community and (B-F) five species of with a higher VI by diameter class (Class 1: ≤ 3 ; Class 2: $3 \geq 6$; Class 3: $6 \geq 9$; Class 4: $9 \geq 12$; Class 5: $12 \leq$) in 2008 and 2012.

Figura 1. Representação percentual do número de indivíduos N% e área basal G% amostrados em 1,6 ha para a comunidade arbórea e as cinco espécies de maior VI por classe diamétrica (Classe 1: ≤ 3 ; Classe 2: $3 \geq 6$; Classe 3: $6 \geq 9$; Classe 4: $9 \geq 12$; Classe 5: $12 \leq$), em 2008 e 2012, Floresta-PE.

There was an increase in the spatial occupation of the study area, mainly in the basal area; however, it was possible to observe that, unlike in the first census (2008), there were signs of a marked imbalance in the tree community in the second census (2012), as it did not have an exponential curve in the form of an inverted "J" in its diametric distribution, with lower percentages of density in the first class compared to the second. This indicated that the community was altered, incurring possible losses in restocking from natural regeneration and class changes of individuals who previously occupied the first class diametric and moved to the second (Figure 1A). The low representativeness of individuals in the second sense, referring to the first diametric class, may have been caused by the severe drought that caused the mortality of smaller individuals, such as *Poincianella bracteosa* and *Jatropha mutabilis*, which may compromise forest restoration and the perpetuation of local vegetation in the long run.

Of the five species with the highest VI, only *T. glaucocarpa* showed density and dominance in the first class for both surveys, indicating its high occupancy power in the forest community (Figures 1F), while the diametric distributions of the other four did not show this (Figure 1B, 1C, 1D, and 1E). *Poincianella bracteosa* was the species that was most similar to the overall arboreal community in terms of its diametric distribution, as it had higher percentages of density, abundance, and frequency, with almost 40% of the VI, in both surveys (Figure 1B).

Periodic and annual periodic increment estimates

The average annual increment, considering all sampled trees and regardless of species over the four-year period, was 0.37 cm year⁻¹ in diameter, whereas the basal area a value corresponding to 0.26 m² ha⁻¹ was obtained per year (Table 3).

Table 3. Periodic increment and annual periodic increment in diameter (cm year⁻¹) and basal area (m² ha⁻¹ year⁻¹) for each species for the period of 2008–2012.

Tabela 3. Incremento periódico e Incremento periódico anual em diâmetro (cm/ano) e área basal (m²/ha/ano), por espécie para o período de 2008-2012.

Species	IPA(G)	IP(G)	IPA(DAP)	IP(DAP)
<i>Commiphora leptophloeos</i>	0.0015	0.0059	0.3716	1.4864
<i>Thiloa glaucocarpa</i>	0.0063	0.0253	0.3152	1.2606
<i>Pityrocarpa moniliformis</i>	0.0268	0.1073	0.2742	1.0968
<i>Cnidocolus phyllacanthus</i>	0.0203	0.0812	0.2264	0.9058
<i>Myracrodruon urundeuva</i>	0.0092	0.0370	0.2139	0.8555
<i>Mimosa tenuiflora</i>	0.0079	0.0317	0.1969	0.7875
<i>Piptadenia stipulacea</i>	0.0011	0.0045	0.1626	0.6504
<i>Schinopsis brasiliensis</i>	0.0031	0.0126	0.1447	0.5789
<i>Poincianella bracteosa</i>	0.1372	0.5488	0.1071	0.4284
<i>Mimosa ophthalmocentra</i>	0.0299	0.1197	0.0939	0.3757
<i>Manihot glaziovii</i>	0.0016	0.0062	0.0888	0.3553
<i>Cnidocolus bahianus</i>	0.0047	0.0189	0.0838	0.3353
<i>Erythroxylum</i> sp.	0.0003	0.0012	0.0691	0.2763
<i>Aspidosperma pyrifolium</i>	0.0015	0.0060	0.0545	0.2182
<i>Cordia leucocephala</i>	0.0002	0.0010	0.0497	0.1989
<i>Jatropha mollissima</i>	0.0007	0.0029	0.0393	0.1572
<i>Senna spectabilis</i>	0.0001	0.0006	0.0348	0.1393
<i>Croton blanchetianus</i>	0.0018	0.0072	0.0099	0.0395
<i>Jatropha mutabilis</i>	0.0033	0.0132	0.0096	0.0384
<i>Anadenanthera colubrina</i>	0.0004	0.0016	0.0062	0.0249
<i>Croton rhannifolius</i>	0.0000	0.0002	0.0029	0.0117
<i>Bauhinia cheilanta</i>	-0.0001	-0.0002	-0.0870	-0.3482
<i>Lippia microphylla</i>	-0.0001	-0.0002	-0.1212	-0.4849
Total	0.2581	1.0325	2.2559	9.0237

IPA (G) = annual periodic increase in basal area; IP (G) = periodic increase in basal area; IPA (DAP) = periodic annual increment in diameter; IP (DAP) = periodic increment in diameter.

Bauhinia cheilanta and *L. microphylla* showed negative values in their annual periodic increments, with Silva *et al.* (2019) finding similar result for *B. cheilanta*. The species that presented the largest increments in the basal area were the five with the highest VI, along with *Myracrodruon urundeuva*, which was also found in the study by Silva *et al.* (2019), and *Mimosa tenuiflora*. Regarding the increments in diameter, *Commiphora leptophloeos*, *T. glaucocarpa*, and *Pityrocarpa moniliformis* showed the largest values.

Most species showed positive periodic annual increments in diameter and basal area, probably due to the high mortality rate. This may be related to the effect of grazing goats, a situation observed during field surveys, which may have made recruitment and establishment even more difficult in the area.

The average annual increment in diameter was 0.10 cm year⁻¹ for all species, but the average values for some individuals species were above this, i.e., *Commiphora leptophloeos* (0.37 cm year⁻¹), *T. glaucocarpa* (0.32 cm year⁻¹), *Pityrocarpa moniliformis* (0.27 cm year⁻¹), *Cnidoscopus phyllacanthus* (0.23 cm year⁻¹), *Myracrodruon urundeuva* (0.21 cm year⁻¹), and *Mimosa tenuiflora* (0.20 cm year⁻¹). This indicated that these were more efficient in their survival strategies in the presence of water stress. The other species, in spite of the considerable gains in their basal area and diameter, did not increase as much prominence in these parameters due to mortality, which led to the emergence of newly established individuals with smaller diameters, modifying their structure in terms of the basal area and increasing the initial stock of woody individuals that existed in 2008. Overall, the basal area of the community increased by 64.7% in four years, equivalent to 1.033 m² ha⁻¹.

Mortality, newly established individuals, and gross and net growth rates

Newly established individual values (new trees meeting the size class requirements in 2012) were much higher than mortality for *Pityrocarpa moniliformis* and *T. glaucocarpa*, and the reverse was found for *Poincianella bracteosa*, *J. molissima*, *J. mutabilis*, *Mimosa ophthalmocentra*, *Croton blanchetianus*, and *Cnidoscopus phyllacanthus*. Even so, most species, showed gains in terms of basal area, indicating that the forest area is in the process of recovery. As for gross and net growth, these were higher when newly established individuals were included (Table 4). The highest net growth (CI_i) occurred for *Poincianella bracteosa*, *Mimosa ophthalmocentra*, and *Pityrocarpa moniliformis*.

Table 4 - Mortality rate, new individual establishment, and growth of tree species in an area of Caatinga Floresta-PE.

Tabela 4 - Taxa de mortalidade, ingresso e crescimento das espécies em uma área de Caatinga, Floresta-PE.

Species	M	I	% year ⁻¹				(m ² ha ⁻¹)			
			TM	TI	ABM	ABI	Cb _i	Cb	CI _i	CI
<i>Poincianella bracteosa</i>	21	2	0.94	0.09	0.0463	0.0012	0.5953	0.5940	0.5490	0.5477
<i>Mimosa ophthalmocentra</i>	5	3	1.26	0.78	0.0154	0.0029	0.1350	0.1322	0.1196	0.1167
<i>Pityrocarpa moniliformis</i>	8	48	1.63	7.02	0.0103	0.0930	0.1175	0.0245	0.1072	0.0142
<i>Cnidoscopus phyllacanthus</i>	2	0	2.47	0.00	0.0015	0.0000	0.0827	0.0827	0.0812	0.0812
<i>Myracrodruon urundeuva</i>	0	0	0.00	0.00	0.0000	0.0000	0.0369	0.0369	0.0369	0.0369
<i>Mimosa tenuiflora</i>	0	0	0.00	0.00	0.0000	0.0000	0.0318	0.0318	0.0318	0.0318
<i>Thiloa glaucocarpa</i>	1	49	0.32	9.00	0.0008	0.0261	0.0261	0.0000	0.0253	0.0008
<i>Cnidoscopus bahianus</i>	1	0	0.74	0.00	0.0018	0.0000	0.0203	0.0203	0.0185	0.0185
<i>Jatropha mutabilis</i>	9	0	3.91	0.00	0.0051	0.0000	0.0183	0.0183	0.0132	0.0132
<i>Schinopsis brasiliensis</i>	1	0	2.90	0.00	0.0005	0.0000	0.0131	0.0131	0.0126	0.0126
<i>Croton blanchetianus</i>	4	0	1.06	0.00	0.0039	0.0000	0.0110	0.0110	0.0071	0.0071
<i>Jatropha mollissima</i>	11	0	6.77	0.00	0.0066	0.0000	0.0095	0.0095	0.0029	0.0029
<i>Manihot glaziovii</i>	1	0	3.78	0.00	0.0008	0.0000	0.0070	0.0070	0.0062	0.0062
<i>Aspidosperma pyriformis</i>	1	0	1.71	0.00	0.0002	0.0000	0.0063	0.0063	0.0060	0.0060
<i>Commiphora leptophloeos</i>	0	1	0.00	5.43	0.0000	0.0014	0.0059	0.0045	0.0059	0.0045
<i>Piptadenia stipulacea</i>	0	0	0.00	0.00	0.0000	0.0000	0.0045	0.0045	0.0045	0.0045
<i>Anadenanthera colubrina</i>	1	0	3.78	0.00	0.0011	0.0000	0.0027	0.0027	0.0016	0.0016
<i>Erythroxylum</i> sp.	0	0	0.00	0.00	0.0000	0.0000	0.0012	0.0012	0.0012	0.0012
<i>Cordia leucocephala</i>	1	0	9.64	0.00	0.0002	0.0000	0.0011	0.0011	0.0010	0.0010
<i>Croton rhamnifolius</i>	1	0	2.60	0.00	0.0007	0.0000	0.0009	0.0009	0.0002	0.0002
<i>Lippia microphylla</i>	3	0	15.91	0.00	0.0011	0.0000	0.0009	0.0009	0.0002	0.0002
<i>Senna spectabilis</i>	0	0	0.00	0.00	0.0000	0.0000	0.0006	0.0006	0.0006	0.0006
<i>Bauhinia cheilanta</i>	1	0	4.46	0.00	0.0005	0.0000	0.0001	0.0001	0.0004	0.0004
General	72	103	2.77	0.97	0.0968	0.1246	1.1287	1.0041	1.0319	0.9088

M = number of individuals killed (N ha⁻¹); I = newly established individuals (N ha⁻¹); TM = mortality rates; TI = newly established individual establishment rate; ABM = basal area of dead individuals; ABI = basal area of newly established individuals; Cb = gross growth; CI = net growth; Cb_i = gross growth including newly established individuals; CI_i = net growth including newly established individuals.

DISCUSSION

Changes in the richness and abundance of woody species

Some studies carried out in the Caatinga and Cerrado have listed at least one of the three most representative families of this study (Fabaceae, Euphorbiaceae, and Combretaceae) as those with the greatest number of species and abundance present in the area (MARINHO *et al.*, 2019; SILVA *et al.*, 2019; OLIVEIRA *et al.*, 2020).

The diversity of Fabaceae along gradients of tropical seasonality, mainly in the Dry Tropical Forest (FTS), is due to its high succulence as fodder for animals, which increases its dispersion, in addition to the fact that the majority of species in this family have rapid growth due to their high levels of nitrogen and carbon fixation, which in turn helps to fertilize the surrounding soil (OLIVEIRA-FILHO *et al.*, 2013).

In other studies of the Caatinga, the Shannon diversity index and Pielou's equability index in areas with vegetation in an advanced stage of natural regeneration (ALVES *et al.*, 2017; SILVA *et al.*, 2020), an area with selective logging and grazing by animals (OLIVEIRA *et al.*, 2020), and even transitional environments with the Cerrado (ANDRADE *et al.*, 2019) were higher than the results obtained in the current study.

Structural changes

The significant increase in *T. glaucocarpa* may be associated with its low palatability and high capacity for intoxication, with a characteristic feature of causing edema in goats and cattle, especially during the rainy season (REIS *et al.*, 2020).

The species *Poincianella bracteosa* can be found among the species with the highest VI in Caatinga areas that are in the initial stages of ecological succession, as can be evidenced in a study developed by Lima and Coelho (2018); however, *Mimosa tenuiflora* can be found in secondary succession areas (Bezerra; Pereira, 2017).

Diametric Distribution

Some studies carried out in the Caatinga (LIMA; COELHO, 2018; SILVA *et al.*, 2019) demonstrated the distribution of inverted J-shaped diametric distributions, with the majority of the individuals concentrated in the first diameter classes and a sharp drop in the following classes. In a study developed by Silva *et al.* (2019), the inverted J-shape indicated a positive balance between recruitment and mortality, and was characteristic of autoregenerative populations. This was not observed in the current study; that is, the area needs specific interventions, such as restoration directed through human intervention, for effective restoration to occur, otherwise this forest fragment may cease to exist in the near future.

Periodic and annual periodic increment estimates

The average annual increment in diameter ($0.10 \text{ cm year}^{-1}$) was close to half of that observed in other studies carried out in FTS (SWAINE *et al.*, 1990; CASTRO MARÍN *et al.*, 2005; CARVAJAL-VANEGAS; CALVO-ALVARADO, 2013). Cavalcanti *et al.* (2009) showed that population dynamics (regarding the average annual periodic increase in diameter) were species-specific, with some species responding positively and others negatively, which indicates possible difficulties for tree establishment.

Although the basal area of the evaluated community increased to 64.7% in four years (equivalent to $1.033 \text{ m}^2 \text{ ha}^{-1}$), it was still lower than the value found by Silva *et al.* (2020) in a study carried out in the south of Piauí, where the basal area oscillated between 3.567 and $3.294 \text{ m}^2 \text{ ha}^{-1}$. Other studies carried out in FTS estimated that it would take more than 30–40 years for areas with a high degree of anthropization to match the level of ecological succession of areas in better condition, demonstrating how slow the succession process is (LEBRIJA-TREJOS *et al.*, 2011; CABRAL *et al.*, 2013).

Mortality, new individual establishment, and gross and net growth rates

In dry forests, mortality rates are between 0.9% (SWAINE *et al.*, 1990) and $4.9\% \text{ year}^{-1}$ (SURESH *et al.*, 2010), which was consistent with the value of the current study ($2.77\% \text{ year}^{-1}$). These rates are similar to the values found in Cerrado areas (2.64% and $3.36\% \text{ year}^{-1}$) by Oliveira *et al.* (2014) and in a dry forest area with an intermediate stage of succession in Mexico ($2.64\% \text{ year}^{-1}$) (CARVAJAL-VANEGAS; CALVO-ALVARADO, 2013). However, when comparing these values, it is important to note that different methodologies were used in calculating this rate, with some authors using logarithmic models while others did not.

The new individual establishment rate of $0.97\% \text{ year}^{-1}$ was lower than other values derived for FTS, which were: $2.5\% \text{ year}^{-1}$ (CASTRO MARÍN *et al.*, 2005), $2.30\% \text{ year}^{-1}$ (CAVALCANTI *et al.*, 2009), $4.8\% \text{ year}^{-1}$ (CARVAJAL-VANEGAS; CALVO-ALVARADO, 2013), and 1.76% and $1.97\% \text{ year}^{-1}$ (OLIVEIRA *et al.*, 2014). The fact the new individual establishment rate was lower than the mortality rate can be explained by severe periods of low rainfall, edge effects, and a higher density of young individuals.

Water is a limiting factor for areas in initial successional stages, favoring the emergence of more robust and tolerant species. However, as succession progresses, shading becomes a protagonist, protecting emerging species with a low stress tolerance to water deficiency (PATERNO *et al.*, 2016).

According to APAC (2020), rainfall between the years 2011 (342.2 mm) and 2012 (135.2 mm) for the municipality was lower than in 2009 (549.75 mm) and 2010 (765.3 mm), which may have contributed to, in part, a higher mortality rate due to severe drought in the region, or facilitated the increase in mortality of younger individuals.

Suresh *et al.* (2010), in a 19-year study on dry forest dynamics in India, also found that mortality increased when there was a drought period. This corroborated with Maza-Villalobos *et al.* (2013), who attributed the increase in mortality rates to the years when El Niño occurred. Thus, the authors argued that succession is delayed during the drought periods as it modifies the system's resilience, which is not only influenced by the amount of rain that falls at a certain time of the year, but also by previous drought and rain events.

The rate of new individual establishment and the small gains in gross and net growth are associated with the adaptive characteristics of woody species and years with higher precipitation, allowing trees to store water and store carbohydrates for their establishment and development through increasing in their basal area.

A study carried out by Cavalcanti *et al.* (2009) revealed that there were dynamics in the time intervals between the surveys carried out for the prediction of dynamics in Caatinga areas, a factor that interfered with the processes of mortality, recruitment, and growth of Caatinga forest species.

CONCLUSION

The following conclusions were drawn from the present study:

- Within four years there were visible and important structural changes in the forest community, mainly in relation to the abundance and dominance of species.
- Extensive periods of drought and grazing have negatively influenced the succession process of the forest community, resulting in high mortality rates and low values of growth and periodic increases compared to other dry tropical forest communities.
- This environment needs periodic monitoring in order to monitor resilience and gradual forest succession until homeostasis is achieved.

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