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Biomass and carbon balance in a dry tropical forest area in northeast Brazil

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Abstract: Forest ecosystems play an important role in mitigating the concentration increase of carbon dioxide (CO_2) in the atmosphere through carbon sequestration by plants and its storage in biomass and soil. The objective was to determine the aerial biomass carbon stock in a dry tropical forest in Brazil. It was developed between 2012 to 2015, in an area with an advanced regeneration stage (50 years) in the semi-arid region of Pernambuco and it was used 40 permanent plots (400 m^2) distant 80 m apart, with 50 m from the border, totaling 1.6 ha of the area to sample the shrubby-arboreal component, where all individuals with circumference at breast height (1.30 m of the soil) equal or greater than 6 cm were identified, measured and labeled in 2012 and remeasured in 2015. It was calculated the biomass and carbon stocks through developed equations available in the literature. The results showed that the total biomass and carbon stock in the first year was 27.97 e 12.92 $Mg.ha^{-1}$ while in 2015 it was 18.49 and 8.39 $Mg.ha^{-1}$ respectively. The results showed a biomass and carbon stock reduction of more than 30% in the period evaluated, even this, the area manages to present values within the expected pattern for the region, assuring the importance of sustainable forest management of these native/natural vegetation areas.

Key words: phytomass, productivity, savannah, semiarid.

INTRODUCTION

Studies on forest dynamics in Tropical Dry Forests (TDF) are of fundamental importance in designing management and conservation goals (Álvarez-Yépiz et al. 2018, Araújo Filho et al. 2018, Marengo et al. 2018) since there is a gap between studies of this magnitude when compared to moist tropical forests (Portillo-Quintero & Sánchez-Azofeifa 2010), mainly motivated by an interest in the Amazon region and Atlantic rain forest.

Forest ecosystems represent a viable alternative to mitigate the concentration increase of carbon dioxide (CO_2) in the atmosphere through carbon fixation by plants and its storage in biomass and soil, but this information is still scarce (Gatto et al. 2011); this is especially relevant for the Caatinga phytogeographic domain, which is one of the TDF formations in Brazil (Santos et al. 2011, Dryflor 2016, Pereira Júnior et al. 2016, Bastin et al. 2017).

There are four options in the forest area to mitigate the effects of global climate change: forest management, to reduce deforestation, and promote afforestation and reforestation. In the short term, the benefits of mitigation through avoiding deforestation are greater than the benefits of reforestation and afforestation (Ipcc 2007), and therefore the preservation of forest vegetation by reducing deforestation rates is the main strategy to increase atmospheric carbon uptake rates (Bastin et al. 2017, Wang et al. 2017, Nobre 2010, Shepherd 2009).

Forest ecosystems cover large parts of the Earth's surface and play an important role in the terrestrial carbon cycle (Lorenz & Lal 2010), being considered by Pan et al. (2011) as large atmospheric carbon sinks. Mature tropical forests are responsible for storing 471 ± 93 tons of carbon (sum of living biomass above and below ground, dead wood, litter, and soil), which represents more than 50% of the carbon stock estimated for all forest ecosystems. The methods of managing an area will have a direct influence on the vegetation carbon stocks, as suggested by authors such as Kauffman et al. (2009) and Don et al. (2011). Fixed carbon estimates in forest biomass can generally be obtained by multiplying the biomass value found by the carbon content (Dallagnol et al. 2011). This carbon content value is being used in the great majority of works, independently of the forest type, and is approximately 50% of the of the determined biomass weight (Keith et al. 2014, Xu et al. 2016, Behera et al. 2017), constituting an average of the data obtained in several works.

It is observed (from research) that this value is not always ideal and may cause overestimation or underestimation in carbon stock (Dallagnol et al. 2011, Watzlawick et al. 2014, Silva et al. 2015). From this perspective, the main objective of this work was to determine the biomass and carbon stock balance of a dry tropical forest over a 3-year period in an area in an advanced stage of regeneration in the semi-arid region of Northeast Brazil. The results will help us to understand the vegetation role in the carbon stock and consequently contribute to studies on the global carbon cycle, which are important for decision-making on management and conservation activities of TDF in the semi-arid region.

MATERIALS AND METHODS

Sampling areas and forest inventory

The study area is located at the Fazenda Itapemirim in the municipality of Floresta in the semi-arid region of Pernambuco State, Brazil. The farm has 5,695.65 ha and is situated at 8°30'49" South Latitude and 37°57'44" West Longitude. A forest area with vegetation was used in an advanced stage of regeneration with approximately 50 years of preservation. The region's climate is BS'h type according to the Köppen Climate Classification, which equates to a hot semi-arid climate. The total annual precipitation is between 100 and 600 mm. The mean annual air temperature in the semi-arid region is 26°C (Embrapa 2000). The rainy periods are concentrated from January to May, with the rainy months being March and April; the monthly accumulations of the last 15 years can be observed in Figure 1. The vegetation can be classified as Shrub Savanna-steppe - Caatinga (IBGE 2012), and the soil of the region is classified as Chromic Luvisol, characterized by being shallow and usually presenting an abrupt change in its texture (Embrapa 2011). There is also the presence of freely grazing cattle in this study area.

The study area is in the *Depressão Sertaneja Meridional* ecoregion, a region among the most impacted by human action and with few protected areas in terms of number, total area or protection category, but still having extensive areas with the possibility of recovery (Velloso et al. 2002). The study history shows establishment and monitoring since 2008 of 40 (20 x 20 m) plots (400 m²) 80 m apart, with 50 m from the edge, thus totaling 1.6 ha of sampled area.

The plots were installed in 2008 and all shrubs and tree individuals with CBH (circumference at breast height - 1.30 m) ≥ 6 cm were identified and labeled on their CBH, aiming

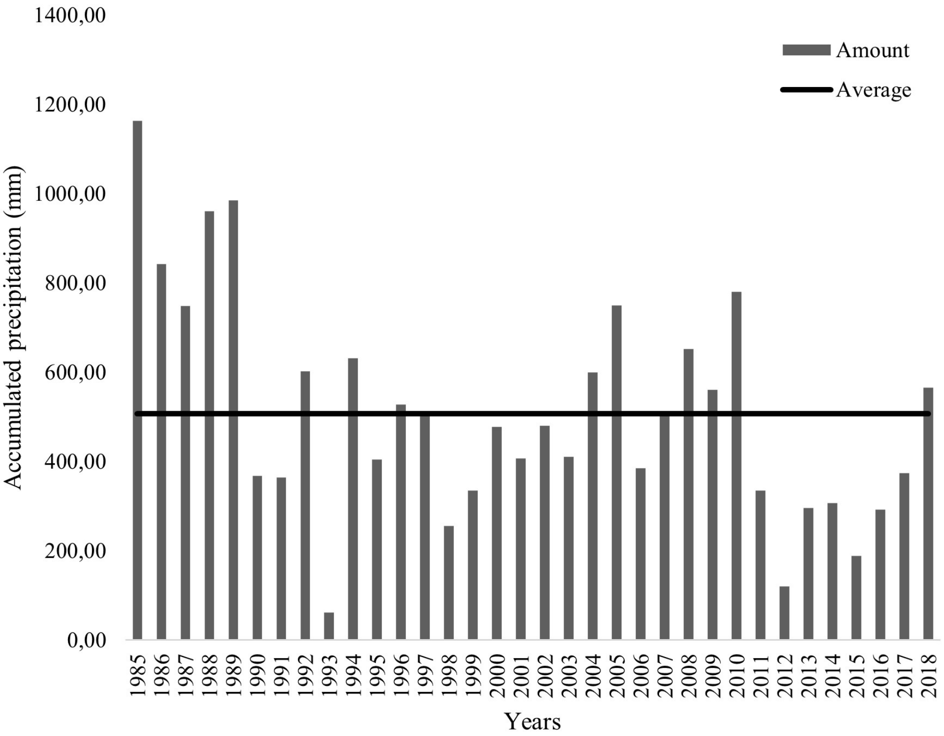

Figure 1. **Monthly accumulations (mm) of the last 16 years in the municipality of Floresta, Pernambuco, Brazil. Source: APAC (2017).**

to standardize the measurement site. For trees with more than one stem, only those with the intersections below the CBH were considered as individuals. The CBH and height measurements of the individuals that were within the inclusion range for this study were carried out in the 2012 and 2015 inventories, and follow the nomenclatures and pattern suggested by the Angiosperm Phylogeny Group IV (APG IV 2016).

The reason we chose to work with these time intervals is due to the Caatinga's response time to extreme drought between 2012 and 2015; a previous period (2008-2013), a second later interval (2013-2018) and a total of ten years, thus being able to verify the vegetation response of each area according to its usage histories in facing the drought effects.

Estimation and balance of carbon stock in vegetation

The equations developed by Dalla Lana et al. (2018) were used to estimate the biomass stock in the vegetation. Equations were used for eight Caatinga species and a general equation was used for the other species (Table I). These equations were specifically developed for the species in the study area, thus making their results more accurate.

The tree carbon stock was estimated by the individual's total dry biomass product by its estimated average carbon percentage, as shown in Table I. The results were expressed in megagram per hectare ($Mg.ha^{-1}$). Changes in carbon stocks between 2012 and 2015 were calculated by the equation:

$$\Delta C\ (t) = (Ct_{2015} - Ct_{2012})/\Delta t$$

Where: ΔC is the variation of the carbon stock in the area; Ct_{2012} is the C stock in the year 2012; Ct_{2015} is the C stock in the year 2015; and Δt is the time interval in years.

The mortality rates of this dry tropical forest were determined using the function implied by Primack et al. (1985) and explained

Table I. Equations for estimating the dry biomass stock and their respective carbon conversion factor for species in a dry tropical forest area, Floresta, Pernambuco, Brazil.

Species	Equations	CF Carbon
Anadenanthera colubrina var. cebil (Griseb.) Altschul	$\widehat{DB}=48.7255*[1-\exp(-0.1435*DBH)]^{2.4096}$	0.464
Aspidosperma pyrifolium Mart.	$\widehat{DB}==0.7858*(DBH^2*H)^{0.4550}$	0.464
Bauhinia cheilantha (Bong.) Steud.	$\widehat{DB}==0.0669*(DBH^{2.2115})*(H^{0.8155})$	0.464
Cnidoscolus quercifolius Pohl	$\widehat{DB}==0.6064*(DBH^{1.4216})$	0.464
Croton heliotropiifolius Kunth	$\widehat{DB}==0.1868*(DBH^{1.2764})*(H^{0.9401})$	0.459
Mimosa ophthalmocentra Mart. ex Benth.	$\ln\widehat{DB}==1.1118+1.7371*\ln DBH-0.9536*\ln H$	0.464
Mimosa tenuiflora (Willd.) Poir.	$\widehat{DB}==0.5084*(DBH^{1.7121})$	0.464
Cenostigma bracteosum (Tul.) Gagnon & G.P. Lewis	$\widehat{DB}==6.6205+0.0341*(DBH^2*H)$	0.449
All species	$\ln\widehat{DB}=-1.2884+1.6102*\ln(DBH)+0.4343*\ln(H)$	0.461

$\widehat{DB}$ = estimate of total dry biomass above ground (kg); DBH = diameter at 1.30 m above the ground (cm) and H = total height (m); CF = conversion factor.
Source: Dalla Lana et al. (2018).

by Sheil et al. (1995) for the annual mortality rate calculation. This function considers that mortality logarithmically decreases over time:

$$m = 1 - (N_1/N_0)^{(1/t)}$$

where m = mortality per year, N_0 = number of live trees at the initial inventory, N_1 = number of trees that survived until the second inventory, and t = number of years between the first and second inventory.

Variance Analysis (ANOVA) and later the Tukey test for means comparison were used to verify possible differences in the carbon stock between the evaluated inventories. A statistical analysis using a completely randomized design with a factorial arrangement (two factors – the year with two levels and species with eight levels) was performed using the Statistical Package for the Social Sciences (SPSS) program for Windows (version 20). A significance level of 5% was adopted for all analyzes.

RESULTS

Forest inventory and mortality rate

A total of 5531 individuals (3457 ind.ha^{-1}) were found in the sampled area of 1.6 ha with a basal area of 8.78 m^2 (5.49 m^2.ha^{-1}) in the first year of evaluation, while and in the second year of evaluation, 1398 individuals (874 ind.ha^{-1}) in a basal area of 6.15 m^2 (3.84 m^2.ha^{-1}) were found in the second year of evaluation, distributed in 7 families, 21 genera and 23 species. This shows that the species with the highest absolute density changed from the first to the second inventory (Table II) and that the mortality rate for the area in the evaluated period was 25%.

The mortality rate of trees varied considerably among species: 13% to 94% of losses occurred between 2012 and 2015 (Table II). This notably was the reflection period of the strong droughts which hit the Northeastern region of Brazil after 2010, meaning that there were relatively drier (Fig. 1) and consequently hotter years.

The ten species with the highest density in the area over the first year of evaluation still continued among the greater density species in the second year of evaluation even though they

Table II. List of species found in this study for 2012 and 2015 in a dry tropical forest area, Floresta, Pernambuco, Brazil.

Scientific Name	Family	2012		2015		m
		BA	AD	BA	AD	
Poincianella bracteosa (Tul.) L. P. Queiroz	Fabaceae	4.4690	2005.00	3.1570	502.50	0.25
Myracrodum urundeuva (Allemão) Engl.	Anacardiaceae	0.7130	101.88	0.6630	40.63	0.40
Cnidoscolus quercifolius Pohl	Euphorbiaceae	0.6410	94.38	0.6710	33.13	0.35
Aspidosperma pyrifolium Mart.	Apocynaceae	0.5540	297.50	0.4830	55.63	0.19
Mimosa ophthalmocentra Mart. ex Benth.	Fabaceae	0.5420	397.50	0.1630	61.25	0.15
Anadenanthera colubrina var. cebil (Griseb.) Altschul	Fabaceae	0.4300	80.63	0.1610	34.38	0.43
Commiphora leptophloeos (Mart.) J. B. Gillett	Burseraceae	0.3680	24.38	0.4120	10.63	0.44
Mimosa tenuiflora (Willd.) Poir.	Fabaceae	0.3550	71.88	0.0650	11.25	0.16
Sapium glandulosum (L.) Morong	Euphorbiaceae	0.1180	10.00	0.0220	3.13	0.31
Manihot glaziovii Muell. Arg.	Euphorbiaceae	0.1180	30.00	0.0380	9.38	0.31
Bauhinia cheilanta (Bong) Steud.	Fabaceae	0.0980	118.13	0.0310	30.00	0.25
Piptadenia stipulacea (Benth) Ducke	Fabaceae	0.0930	50.63	0.0450	13.13	0.26
Spondias tuberosa Arruda	Anacardiaceae	0.0720	4.38	0.0750	0.63	0.14
Croton heliotropiifolius Kunth	Euphorbiaceae	0.0690	93.75	0.0310	21.25	0.23
Schinopsis brasiliensis Engl.	Anacardiaceae	0.0650	12.50	0.0710	7.50	0.60
Jatropha mollissima Muell. Arg.	Euphorbiaceae	0.0300	31.88	0.0330	30.00	0.94
Libidibia ferrea (Mart. Tul.) L. P. Queiroz	Fabaceae	0.0120	2.50	0.0140	1.88	0.75
Combretum glaucocarpum Mart.	Combretaceae	0.0100	14.38	0.0050	3.75	0.26
Cnidoscolus bahianus (Ule) Pax & K. Hoffm.	Euphorbiaceae	0.0100	5.00	0.0020	0.63	0.13
Cynophalla flexuosa (L.) J. Presl.	Capparaceae	0.0080	2.50	0.0060	0.63	0.25
Erythrostemon calycina (Benth.) L. P. Queiroz	Fabaceae	0.0030	3.13	0.0010	0.63	0.20
Senna spectabilis var. excelsa (Schrad.) Irwin & Barneby	Fabaceae	0.0020	3.13	0.0010	0.63	0.20
Neocalyptrocalyx longifolium (Pohl) Baill.	Euphorbiaceae	0.0010	1.88	0.0010	1.25	0.67
	Total	8.7800	3456.88	6.1530	873.75	0.25

M = mortality rate, BA = basal area ($m^2.ha^{-1}$), AD = absolute density ($ind.ha^{-1}$).

presented the highest mortality rates among the species found, thus demonstrating that there is a marked hegemony over the other species.

Carbon stock estimation and balance in vegetation

There was a significant difference in the biomass stock variance analysis ($p < 0.01$) and the degrees of freedom showed a significant effect of the following factors: year, species, as well as their interaction (Table III).

The results showed that the total biomass stock in the first year was 27.97 $Mg.ha^{-1}$ (12.92 $Mg.ha^{-1}$ of carbon), while in 2015 it was 18.49 $Mg.ha^{-1}$ (8.39 $Mg.ha^{-1}$ of carbon), with a reduction of 33.89% and 35% of the biomass and carbon stock in the evaluated period, respectively. The eight species selected corresponded to 89.86% and 87.08% of the study area total biomass stock in the first and second year, respectively.

The *Myracrodruon urundeuva* species appears in the fourth position of the greatest absolute density in the study area for the

Table III. Variance analysis of the biomass stock (kg) of the eight species between 2012 and 2015 for a dry tropical forest area in the city of Floresta, Pernambuco, Brazil.

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	21709259.196	15	1447283.946	70.813	70.813**
Year	198757.998	1	198757.998	9.725	9.725**
Species	20657272.805	7	2951038.972	144.390	144.390**
Year * Species	675428.167	7	96489.738	4.721	4.721**
Error	7868633.220	385	20438.008		
Corrected Total	29577892.417	400			

**** Significant at 99% probability.**

two years evaluated (Table II), but it was not included in the analyses because it is a species that was listed on the official list of Brazilian Flora threatened with extinction, therefore its cutting is prohibited (BRASIL 2008). Although there is a newly updated list upon which the species is no longer included on it (BRASIL 2014), the Northeast states continue to treat it as threatened with extinction according to the 2008 law.

C. *bracteosum* was the most outstanding species in the two evaluated periods, accounting for 64.91% and 69.4% of biomass stocks in 2012 and 2015, respectively. It was followed by *M. tenuiflora* (10.04%) in the year 2012, and by *A. pyrifolium* (5.9%) in the year 2015.

There was a significant difference in the biomass stocks between the two evaluated inventories only for the *C. bracteosum* and *M. ophthalmocentra* species, indicating that there was a superiority of these stocks in the year 2012, whereas there was no significant variation in biomass stocks over the studied period for the other species (Table IV).

When comparing the species in each of the evaluated inventories, the biomass stocks of the *C. bracteosum* and *M. ophthalmocentra* species statistically differed among themselves and among the other species in 2012; while only the biomass stock of *C. bracteosum* differed statistically from the other species in the year 2015 (Table IV).

DISCUSSION

Biomass and carbon stocks are expected to increase over time, and this fact is linked to the forest age, as mature forests, regardless of forest type, have a higher carbon storage capacity than in forests undergoing a growth process (Joshi & Dhyani 2019, Chazdon 2014). However, this premise was not observed in this Caatinga area.

The reduction of biomass and carbon stocks in the area can be explained by the high mortality rate in the period, which may be mainly related to the low rainfall levels occurring in it (among other factors), which was always below the average (Fig. 1). This constitutes a factor present in numerous studies on the resilience of dry tropical forests surveyed by Álvarez-Yépiz et al. (2018) and Marengo et al. (2018). In studying the effects of the interannual variation of precipitation on the regenerative community dynamics using a successional chronosequence, Martínez-Ramos et al. (2018) found that there was a limitation in regeneration in drier years (severe droughts), inducing high rates of mortality and loss of species.

The limitation in the vegetation re-establishment due to reduced water availability

Table IV. **Mean biomass stock (kg) and the standard deviation of the eight species between 2012 and 2015 for a dry tropical forest area in the city of Floresta, Pernambuco, Brazil.**

	Year	
Species	**2012**	**2015**
A. colubrina	59.26±29.18Ac	32.02±31.97Ab
A. pyrifolium	79.59±28.04Ac	75.74±29.81Ab
B. cheilantha	10.54±28.04Ac	4.14±31.97Ab
C. quercifolius	51.40±28.04Ac	56.23±29.18Ab
C. heliotropiifolius	14.14±33.70Ac	8.34±36.91Ab
M. tenuiflora	72.50±33.70Ac	25.36±45.21Ab
M. ophthalmocentra	115.19±22.89Ab	41.68±25.27Bb
C. bracteosum	726.00±22.60Aa	505.88±22.60Ba

Values followed by the same lowercase letter in the column and uppercase letter in the lines do not statistically differ from each other by the Tukey test at 5% probability.

was observed in some other studies which show biological processes being affected by this limiting factor; the natural regeneration of woody species (Jimenez-Rodríguez et al. 2018), primary productivity (Bhaskar et al. 2018, Parker et al. 2018), as well as the repercussions on forest dynamic processes (Mason-Romo et al. 2018, Renton et al. 2018). The species which can establish themselves also have the death/elimination tendency of the tree stem to minimize the individuals' energy demand and water consumption against prolonged periods of drought (Fontes 2012, Pérez-Harguindeguy et al. 2013), which is present in numerous studies on the resilience of tropical dry forests by Álvarez-Yépiz et al. (2018).

Studies have shown that average mortality rates in undisturbed tropical dry forests can vary widely. Martínez-Ramos et al. (2018) found average annual mortality rates of 10% yr^{-1} for a dry forest in Mexico, while Suresh et al. (2010) found rates of 6.9 ± 4.6% yr^{-1} for a dry forest in India, which are generally lower values than those found in this work. In studies conducted in caatinga areas in Brazil, the authors found a mortality rate ranging from 1.41 (Barreto 2013) to 2.77% yr^{-1} (Carvalho & Felfili 2011).

The results confirm the dynamic pattern of the studied community and may mainly be related to the intense area exploitation in the period prior to the study, as well as to the frequent and intense goat and cattle grazing in the area, which according to Rogério et al. (2016) give preference to the tree leaves and shrubs, and ends up negatively influencing the growth of the species, as well as impoverishing and reducing the size of the plants. For Schulz et al. (2016), grazing has a negative impact on carbon stocks in Caatinga forest ecosystems, which are fundamental to ecosystem resilience and soil fertility in these sites. Another important factor is the extensive droughts which have occurred in the region over the last years and have affected community development (Álvarez-Yépiz et al. 2018). According to Lopes & Schiavini (2007), lower mortality rates are characteristic of more stable forests, without major disturbances and with numerically constant populations in a dynamic equilibrium, which is not a characteristic of the area under study.

The total biomass found is within the expected range reported by Sampaio (2010) when describing the characteristics and potentialities of the Caatinga, who state that the biomass in vegetation with a more limited size due to less favorable conditions and anthropization varies from 20 to 80 Mg ha^{-1}. Values within this range were reported by Menezes et al. (2012), who showed that the estimated average inventories of above-ground biomass can vary between 30 to 50 t.ha^{-1}; this was based on a broad literature review, but the authors warn that it is not possible to make a better approximation because direct measurements are almost non-existent for this type of vegetation, and that indirect estimates have very high spatial variability.

The values obtained in this study are within those which have already been observed in the area, thus showing that the stocks have remained constant with only a few changes. This is corroborated by the examples of Alves et al. (2017), who found accumulated values of 29.6 $Mg.ha^{-1}$, and by Dalla Lana et al. (2018) with values between 27.08 $Mg.ha^{-1}$ and 30.98 $Mg.ha^{-1}$, both in shoot biomass studies. As noted by Bhaskar et al. (2018) and Álvarez-Yépiz et al. (2018), the area's usage occupation history certainly influences the resilience capacity of each site, thus affecting its successional pattern and the establishment of biomass and carbon stocks later on. For this reason, there are studies which point out quite superior stocks. Brand et al. (2015) found 164 $Mg.ha^{-1}$ of shoot biomass in characterizing the vegetation of a well-conserved Caatinga area located in the south of the Piauí state destined to a sustainable forest management plan aiming to use it for firewood in generating energy. Furthermore, when studying a chronosequence to verify that both open and dense Caatinga forests presented good carbon stocks, Costa et al. (2014) found values close to 60 $Mg.ha^{-1}$ of shoot biomass for the mature Caatinga areas with no recent disturbance history. Even with these differences in the values obtained by these studies, the values of biomass and carbon stock found in this study are within the expected range for the Caatinga from 2 to 160 $Mg.ha^{-1}$ (Sampaio & Freitas 2008).

The variation in carbon stock from 12.92 $Mg.ha^{-1}$ (2012) to 8.39 $Mg.ha^{-1}$ (2015) has a direct relationship with the biomass values, which was also lower than the values found in the literature. Chaturvedi et al. (2011) found 87 $Mg.ha^{-1}$ in studying the density and accumulation of carbon in dry tropical forest trees in India constituting a much higher value than the one found in this work. Pereira Júnior et al. (2016) determined a carbon stock of 19.27 $Mg.ha^{-1}$ in quantifying the carbon stock in the shrubby-tree component of a tropical dry forest fragment with 30 years of regeneration in Ceará State, Brazil.

The *C. bracteosum*, *M. tenuiflora* and *A. pyrifolium* species were more representative for the biomass and carbon stocks of the evaluated area. Alves et al. (2017), Araújo & Silva (2010), Souza et al. (2012), Ferraz et al. (2014) and Lima et al. (2018) also found these dominant species in different studies in Caatinga areas in Northeast Brazil. *C. bracteosum* is a typical Caatinga species and a good colonizer of degraded areas due to its high capacity of sprouting even when in adverse situations (Queiroz 2009). Thus, it is common to observe a higher density of *C. bracteosum* individuals (Galindo et al. 2008), and according to Sampaio (1996), it is the species which most frequently appears at the top of the Caatinga study lists, and one of the greater species of economic importance for the region.

CONCLUSION

- There was a reduction of approximately 30% in biomass and carbon stocks in this area during the three years of evaluation;

- There was a reduction in terms of absolute density;

- There was a high mortality rate which was not compensated by the individuals who entered it;

- Even with the reduction of the biomass and carbon stocks, the area manages to present values within the expected pattern for the region, assuring the importance of sustainable forest management of these native/natural vegetation areas.

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