



## TEMPORAL RHYTHMS OF DRY TROPICAL FOREST REGENERATION UNDER EXPLORATION OF GRANITE-GNAISSE MINING IN A SEMI-ARID AREA

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### ABSTRACT

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This research aims to identify and analyze the level of regeneration of Caatinga vegetation in different stages, under the impact of granite-gneiss mining in a semi-arid region in Northeast Brazil. To carry out the floristic and phytosociological survey, four areas of vegetation cover were selected in different stages of regeneration: 20 years (closed bush shrubland); 15 years (open bush shrub); 10 years (sub-shrub Caatinga); 50 years (reference area with shrubby Caatinga). The species records of the four sampled areas were compared using the Jaccard and Sorensen similarity index. For the phytosociological analysis, the parameters of Basal Area, Absolute and Relative Density, Absolute and Relative Dominance and Coverage Value of the species were calculated. The floristic survey registered 5,494 individuals belonging to 14 families and 34 species. It was found that Euphorbiaceae and Fabaceae were the families that contributed with the largest number of species in the tree and shrub components. The species in the areas where there was exploitation 20 and 15 years ago showed a regeneration process close to that registered in the preservation area for 50 years. However, with respect to wealth, the 20-year area showed the greatest abundance. From the results it was possible to know the process of regeneration of the pioneer and secondary successional species in the Caatinga, contributing to the preservation of the species and the recovery of degraded areas in the semi-arid region of Paraiba.

**Contribution/Originality:** The exploitation of granites and gneisses has a high economic impact in the state of Paraiba. There are extensive areas under environmental impact and biological loss due to the removal of vegetation. We characterize the rate of regeneration of Caatinga vegetation with a history of exploitation of these rocks.

## 1. INTRODUCTION

The Caatinga biome is inserted in the semi-arid domain, and occupies an area of approximately 1,128,697 km<sup>2</sup> [1]. The area is located under the subequatorial latitudes, has a predominantly Tropical Hot Dry climate and corresponds to 11% of the Brazilian territory, occupying 86.44% of the State of Paraíba, with coverage corresponding to 194 municipalities [2, 3]. The native flora of the Caatinga biome is composed of small woody and herbaceous species, usually with thorns and succulents, with a predominance of families: Euphorbiaceae, Anacardiaceae, Fabaceae, Cactaceae and Bromeliaceae [4-6]. This vegetation presents degradation processes, such as deforestation, which alter floristics and natural regeneration. However, the elimination of vegetation cover causes serious environmental problems in the Northeastern Semi-arid, among which the reduction of biodiversity and soil degradation, mainly by mining, stand out [7-9].

The mineral resources extracted in Brazil are governed by the provisions of the law. In the Brazilian Environmental Legislation, CONAMA Resolution 001/86 defines the enterprises subject to Environmental Licensing and among them is mining. This resolution makes licensing mandatory for any mining activity. And in the State Constitution of the State of Paraíba, Chapter IV, "On the Protection of the Environment and Soil", it is ensured in Art. 227 that "the environment is of the common use of the people and essential to the quality of life, being a duty the State, defend it and preserve it for present and future generations. In this context, the natural regeneration of Caatinga vegetation refers to the initial stages of plant establishment and development. This regeneration is associated with the conservation and preservation of forest formation, both for integral protection and sustainable use [9-11].

In this sense, the objective of this work was to identify and analyze the level of regeneration of Caatinga vegetation in different stages, on the impact of mining in Cariri Paraibano, through the floristic composition and structure of the vegetation, in an area located in the Semi-arid region of the State.

## 2. MATERIALS AND METHODS

The study was carried out in a granite and gneiss mining area in the municipality of Soledade, in the state of Paraíba. This area is located under the coordinates 07°03'26 "S and 36° 21' 46 "W, with an altitude of 521 meters [12] Figure 1.

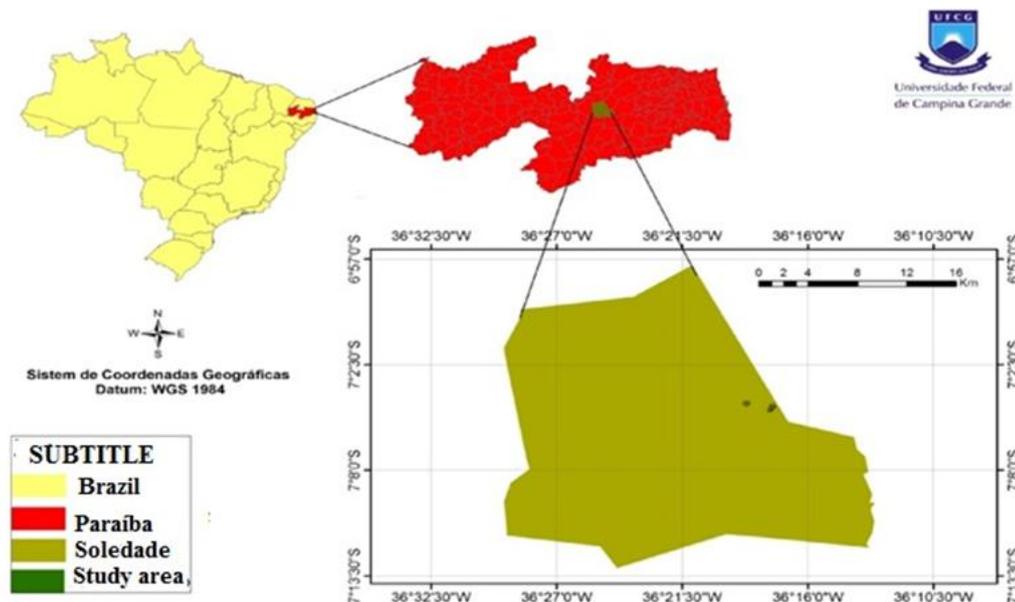


Figura-1. Localização das áreas de estudo no município de Soledade -PB.

Source: MARQUES, 2020.

The area is inserted in the geoenvironmental unit of the Borborema Plateau, under the Alto Pajeú Terrain, in the Cariris Velhos Range, composed of mesoproterozoic sedimentary volcanic meta sequences and narrow neoproterozoic bands [12-14]. According to the Köppen classification (1918), the climate of the study area is predominant of the BSh - Hot and Dry Tropical Climate type. The average annual temperature in the region is 25° C, and the relative humidity is approximately 65% [15].

Geologically there are outcrops of granitic and gneissic rocks in this area, with intrusions of quartz. Luvisolo soils predominate, but eutrophic, underdeveloped, shallow or very shallow Neossols and outcrops of rocks in the Crystalline Complex are also common (Gneisses and Granites are the most common), in the form of large slabs or disaggregated blocks [14, 16]. The study area is inserted in the domains of the Paraíba River hydrographic basin, in the sub-basin of the Taperoá river. The water courses have an intermittent flow regime and the dendritic drainage pattern [3]. The predominant biome is Caatinga, which is characterized by an intertropical xeromorphic domain and is classified by Romariz [17] a complex formation.

This survey was carried out in the years 2017, from the dry period (October to December) to 2018, in the rainy period (April to June). For the floristic survey, four areas of vegetation cover of the Caatinga biome were selected, in different stages of regeneration. The first, an area with preserved vegetation for an average of 50 years, located under the coordinates 07°04'34.8" S, 36°18'42.3" W, presenting a forest with arboreal-shrubby physiognomy Figure 2.

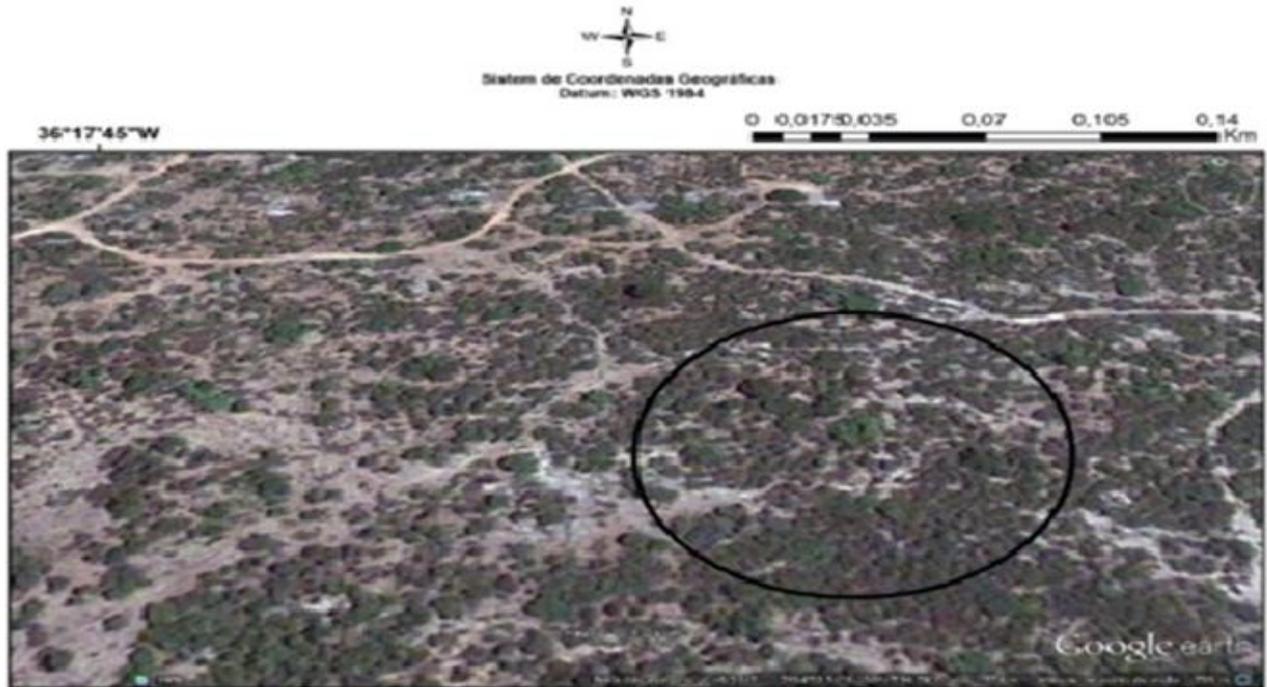
## Regeneration of Caatinga vegetation in Soledade-PB



**Figure-2.** Reference area explored 50 years ago. Source: made from images of Google Earth, 2014 and the Database of the Executive Agency of Water Management of the State of Paraíba-AESA/PB. Source: MARQUES, 2020.

The second, an area under regeneration, in which mineral exploration took place 20 years ago, (07°04'52,8" S, 36°17'34,6" W) showing an open shrubby Caatinga physiognomy Figure 3.

## Regeneration of Caatinga vegetation in Soledade-PB

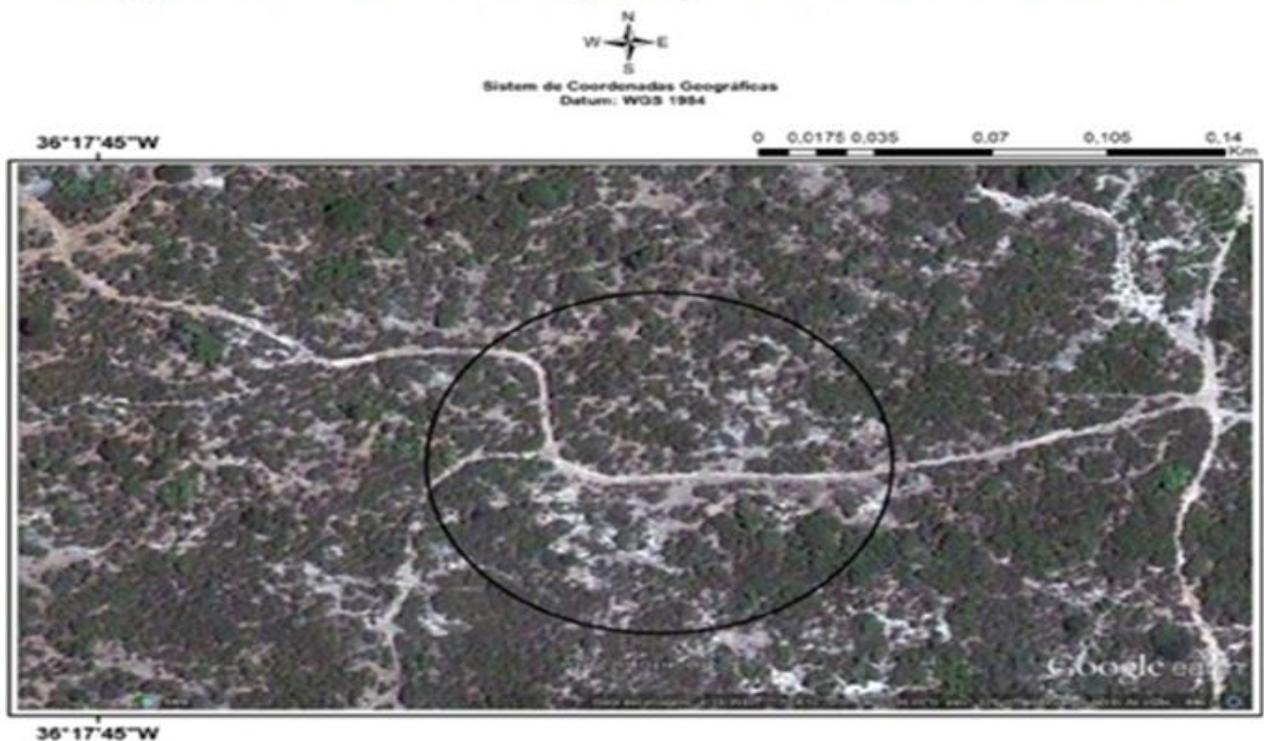


**Figure-3.** Mining area explored 20 years ago. Source: made from images of Google Earth, 2014 and the Database of the Executive Agency of Water Management of the State of Paraíba-AESA/PB.

Source: MARQUES, 2020.

The third, an area with 15-year exploration ( $07^{\circ}04'52.8''$  S and  $36^{\circ}17'40.4''$  W) that presents an open shrubland Caatinga physiognomy [Figure 4](#).

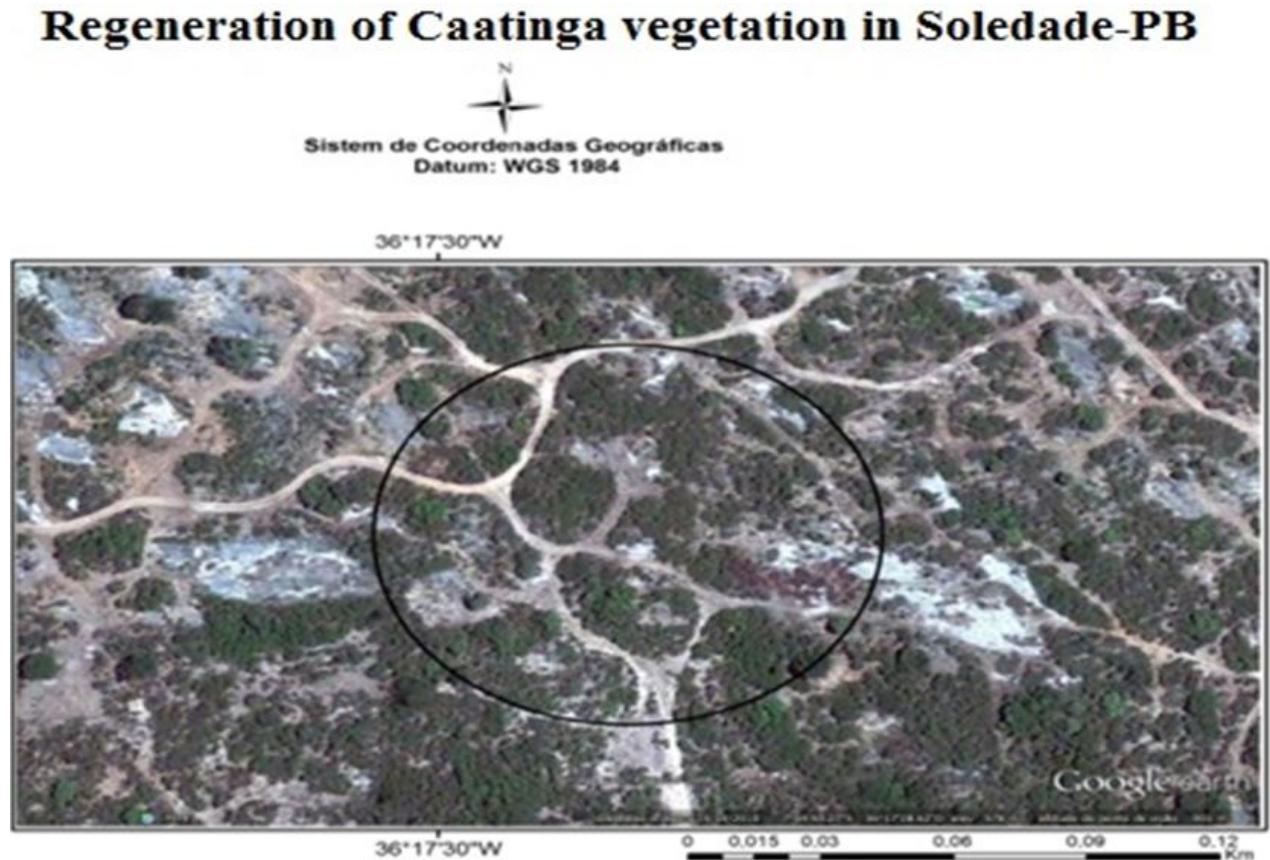
## Regeneration of Caatinga vegetation in Soledade-PB



**Figure-4.** Mining area explored 15 years ago. Source: made from images of Google Earth, 2014 and the Database of the Executive Agency of Water Management of the State of Paraíba-AESA/PB.

Source: MARQUES, 2020.

The fourth area with 10-year mineral exploration ( $07^{\circ}04'44.3''$  S,  $36^{\circ}17'29.7''$  W), shows a physiognomy of Caatinga sub-shrub [Figure 5](#).



**Figure-5.** Mining area explored 10 years ago. Source: made from images of Google Earth, 2014 and the Database of the Executive Agency of Water Management of the State of Paraíba-AESA/PB. Source: MARQUES, 2020.

In these areas, woody plant species (trees, shrubs and sub-shrubs) were collected. Each plot was made inside each granite-gneiss exploration crater. The plots comprise an area of 10m x 20m, totaling twenty five plots. All woody individuals were measured, with diameters at ground level (base) - (DNS)  $\geq 10$  cm, diameter at Chest-DAP level  $\geq 5$  cm, and measured at 1m in height [18, 19]. The specimens were pressed and sent for drying in an oven at  $50^{\circ}$  C, for approximately 72 hours, afterwards they were identified taxonomically, at the levels of family, genus and species.

The choice of areas follows the criteria of geographical coverage of points obtained in the GPS (Global Positioning System). In each plot four points were defined, and the area with the most preserved vegetation cover, that is, 50 years old, was compared to the other areas with mining impact. From these points obtained in the GPS, maps of the location of the areas included in this study were built in the municipality. For this purpose, data from AESA (Executive Agency for Water Management of the State of Paraíba) and Google Earth were used, in addition to the ArcGis software (for the construction of maps).

The ecological indexes of the areas were performed using the software Primer 6.0, and the floristic similarity was made by the Jaccard and Sorensen similarity index. The floristic data were organized in the Microsoft Excel 2010 software titled as a binary matrix of presence and absence of species, and from there the data were run in the Primer 6.0 software. The Sorensen index considers the number of common species in relation to the total of species [20]. Meanwhile, the Jaccard index ranges from 0 to 1, with the value 1 being the maximum similarity. These methods are basically used in abundance data with presence and absence of species [21, 22].

**Table-1.** Floristic listing of the species found in the five natural regeneration areas of the Caatinga vegetation, under the exploitation of Ornamental Granite-Gneissic Stones in Agreste Paraibano.

Families	Species	50 years	20 years	15 years	10 years	Lifestyle
Anacardiaceae	<i>Myracrodruon urundeuva</i> Allemão	X				Tree
	<i>Schinopsis brasiliensis</i> Engl.	X				Tree
Apocynaceae	<i>Aspidosperma pyriforme</i> Mart.	X	X			Tree
Asteraceae	<i>Centratherum punctatum</i> Cass.	X				Tree
Cordiaceae	<i>Varronia leucocephala</i> (Moric.) J.S. Mill.			X		Sub-bush
Burseraceae	<i>Commiphora leptophloeos</i> (Mart.) J.B. Gillett	X				Tree
Cactaceae	<i>Cereus jamacaru</i> DC.	X				Tree
	<i>Pilosocereus gounellei</i> f.a.c. weber) byles&g.d. rowley	X	X	X		Bush
	<i>Tacinga palmadora</i> (britton& rose) x n. p. taylor&stuppy)		X	X	X	Bush
Capparaceae	<i>Cynophalla flexuosa</i> (L.) J. Presl	X				Bush
Celastraceae	<i>Maytenus rigida</i> Mart.	X				Tree
Combretaceae	<i>Combretum leprosum</i> Mart.	X			X	Bush
Euphorbiaceae	<i>Sapium glandulosum</i> (L.) Morong	X				Tree
	<i>Maniho tpseudoglaziovii</i> Pax& K. Hoffm.	X				Tree
	<i>Jatropha molissima</i> (Pohl) Baill.	X	X	X	X	Bush
	<i>Jatropha ribifolia</i> (Pohl) Baill.	X	X	X	X	Sub-bush
	<i>Croton heliotropiifolius</i> Kunth	X	X	X		Bush
	<i>Croton sonderianus</i> Müll. Arg.	X	X	X	X	Bush
	<i>Crotons parsiflorus</i> Morong	X				Tree
Fabaceae	<i>Anadenanthera colubrina</i> (Vell.) Brenan	X				Tree
	<i>Bauhinia cheilantha</i> (Bong.) Steud.	X				Tree
	<i>Mimosa acutistipula</i> (Mart.) Benth.	X				Tree
	<i>Cenostigma nordestinum</i> Gagnon & G.P. Lewis	X	X	X		Tree
	<i>Senna martiana</i> (Benth.) H.S. Irwin & Barneby	X				Tree
	<i>Senna rizzinii</i> H.S. Irwin &Barneby		X			Bush
	<i>Senna spectabilis</i> (DC.) H.S. Irwin &Barneby			X	X	Bush
Loasaceae	<i>Aosa rupestris</i> (Hook.) Weigend					Sub-bush
Malvaceae	<i>Herissantia tiubae</i> (K. Schum.) Brizicky					Sub-bush
	<i>Melochia tomentosa</i> L.					Sub-bush
	<i>Sida cordifolia</i> L.	X		X	X	Sub-bush
Oxalidaceae	<i>Oxalis frutescens</i> Ruiz & Pav. ex G. Don		X	X	X	Sub-bush
	<i>Nicotiana glauca</i> L.	X		X		Bush
Verbenaceae	<i>Lantana camara</i> L.					Sub-bush
	<i>Lippia gratissima</i> (Gillies&Hook.) L.D. Benson					Sub-bush
<b>Total</b>		<b>3555</b>	<b>1109</b>	<b>368</b>	<b>462</b>	<b>5494</b>

Source: Elaborated from data collected in the field, 2014.

To verify the difference between the means of the DAP, Base and Height parameters, generalized linear models (GLM's) were made for the type of poissonian distribution, as well as plots representing the above variables were

plotted, according to the four objective areas of the study. All analyzes were performed using the R software. Finally, the phytosociological parameters of Basal Area (ABi), Absolute Density (AD), Relative Density (DR), Absolute Dominance (DoA), Relative Dominance (Pain) and Coverage Value (VC) of the species were calculated, according to the Moreira [4] and Pereira, et al. [6] method.

### 3. RESULTS AND DISCUSSION

Through the floristic survey in the four vegetation areas of Caatinga, 5,494 individuals belonging to 14 botanical families and 34 species were registered, considering trees, shrubs and sub-shrubs (Table 1). From the data obtained and observed in Table 1, the richness and diversity at each sample point was analyzed.

A number of 24 species were recorded in the preserved area, referring to the age of 50, in a total of 3,555 individuals. The families Anacardiaceae, Burseraceae, Capparaceae and Celastraceae were registered only in this area, due to their representatives having an arboreal habit, thus composing the physiognomy of the Caatinga tree, which according to Fernandes [23]; Andrade, et al. [24]; Souza, et al. [7]; Batista, et al. [25] in their studies corroborate this information. The families that presented the highest number of species were: Euphorbiaceae, Fabaceae and Cactaceae, this was also confirmed by several authors when studying the richness and diversity of the Caatinga [8, 26, 27].

Lima, et al. [27] studying the semi-arid region of Paraíba, found that the species *Myracrodruon urundeuwa* and *Commiphora leptophloeos* are more frequent, found in more protected areas, and are rarely recorded in heavily anthropized areas, such as areas with mineral exploration. In the 20-year mineral impact regeneration area, 1,109 individuals belonging to 10 species were registered. Among the most abundant and dominant were the families: Cactaceae, Euphorbiaceae and Fabaceae. In the 15-year sample area, 368 individuals were registered, distributed in 12 species, of which all had a shrub and sub-shrub habit (with the exception of the *Cenostigma nordestinum* species), as representatives of the families Cactaceae and Euphorbiaceae. In the 10-year area, the number of individuals found was 462 in 8 species, all of them showing sub-shrub and shrubby habit. The family that showed the greatest number of species was Euphorbiaceae, with emphasis on the species *Jatropha molissima*, because this species is predominant in degraded areas. Gomes, et al. [8]; Sabino, et al. [28]; Rito, et al. [29]; Costa, et al. [30] found that Euphorbiaceae and Malvaceae present greater abundance among shrub and sub-shrub individuals.

Euphorbiaceae and Fabaceae went to families, which contributed with the largest number of species in the Caatinga, both in the tree component, as in the shrub, with Euphorbiaceae being the most representative. This was also found in research by other authors in studies in the Caatinga [28, 31-34] Based on Jaccard's floristic similarity index Figure 6 it was found that the two most similar and closest floristically areas were to the bushes of 20 and 15 years of mineral exploration with the most preserved (50 years).

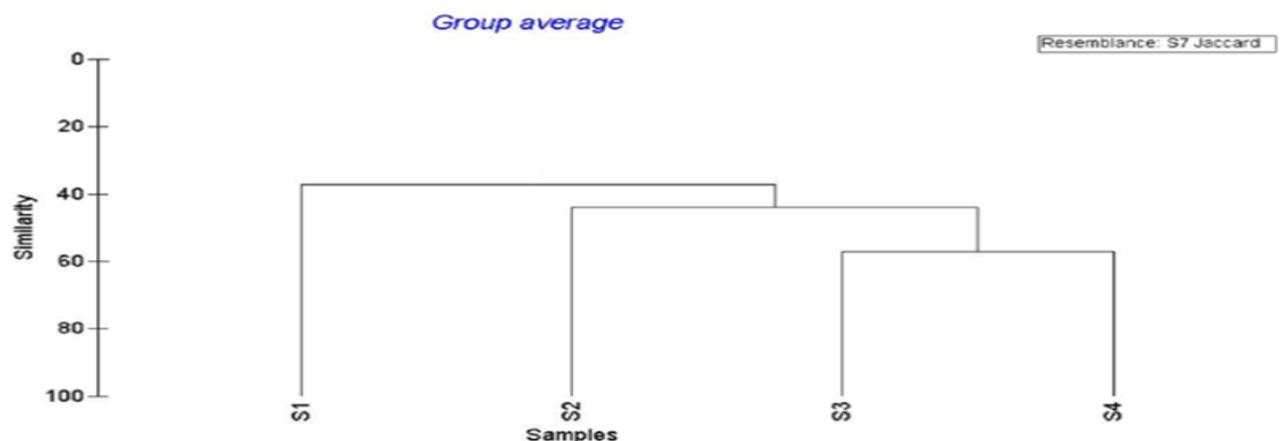
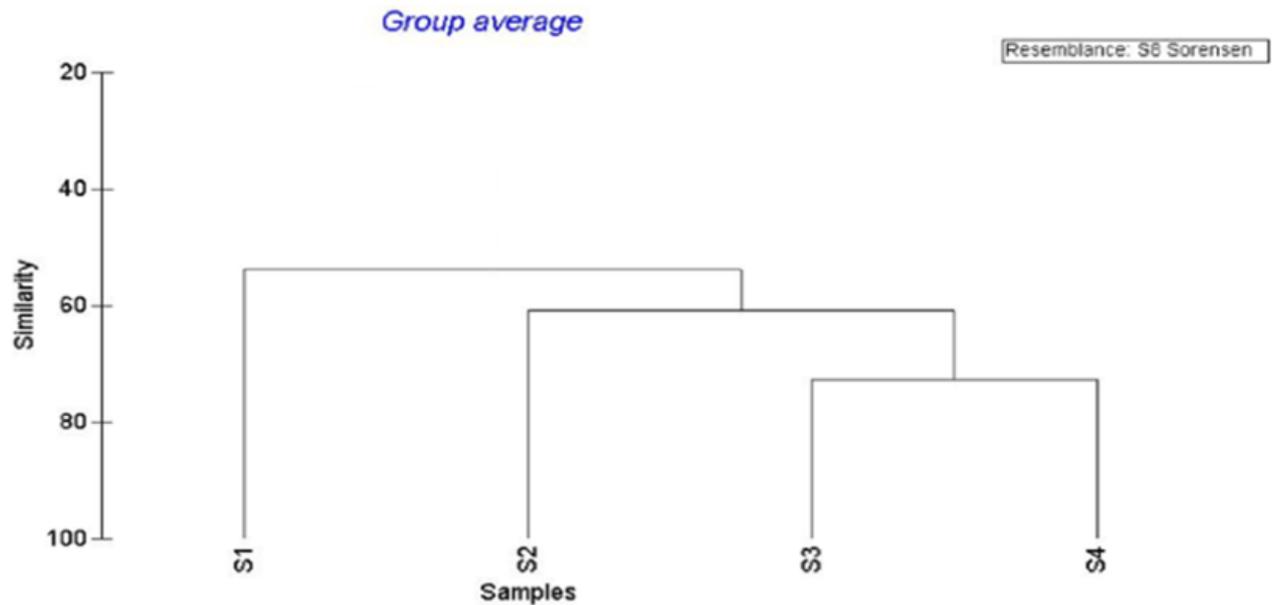


Figure-6. Dendrogram of similarity/floristic Jaccard registered in the four areas based on the Jaccard index.

Source: MARQUES, 2020.

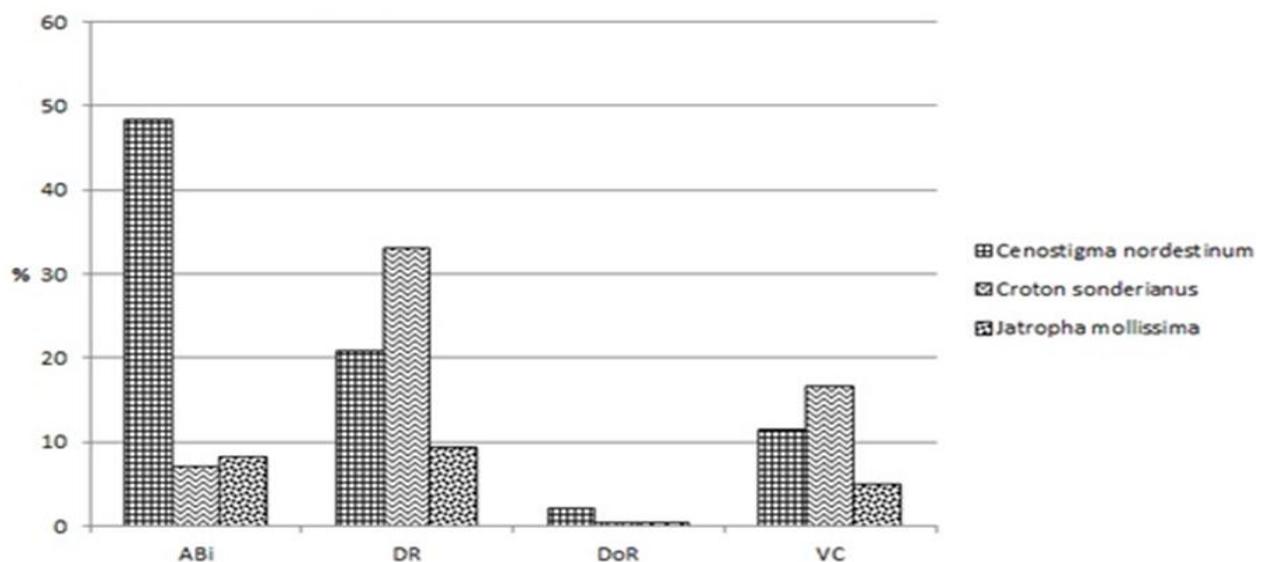
Based on the Sorensen similarity index [Figure 7](#) there was no difference in the results, and both found that the floristic composition between the 20 - 15 year old mineral exploration areas was similar, with the preservation area it has large vegetation while in those aged 20-15 years there is dominance of medium to small vegetation, or shrub.



**Figure-7.** Dendrogram of similarity/floristic Sorensen recorded in the four areas based on the Sorensen index.

Source: MARQUES, 2020.

For the four areas, the values of Basal Area (ABi), Relative Density (DR), Relative Dominance (DoR) and Coverage Value (VC) were calculated. Considering the most numerous species recorded in the four areas: Catingueira (*Cenostigma nordestinum*), Marmeleiro (*Croton sonderianus*) and Pinhão Branco (*Jatropha mollissima*), the results of the phytosociological parameters were as follows: For the reference area explored 50 years ago, the Basal Area (ABi) values were the highest for all species considered, reaching 48.3% for *C. nordestinum*. The Relative Density (DR) values were more balanced between species in this area, varying between 32.9 and 9.3%. Regarding the Coverage Value (VC), there is a variation of 16.6 to 4.8% between the values presented by the species [Figure 8](#).



**Figure-8.** Percentages of Basal Area (ABi), Relative Density (DR), Relative Dominance (DoR) and Coverage Value (CV) presented by the reference area explored 50 years ago.

Source: MARQUES, 2020.

These results demonstrate that the area is the most preserved of the four areas considered. Thus, the species *C. nordestinum*, *C. sonderianus* and *J. mollissima*, presented a variation in abundance, being considered as self-regenerating, as they have the capacity for rapid growth. According to studies by Araújo, et al. [35]; Sabino, et al. [28]; Fernandes and Queiroz [36] these species have a higher density in degraded environments, located according to the phytophysiology and degree of conservation the location.

For the area explored 20 years ago, it was observed that the parameter that presented the highest value was the relative density (DR) of the species *C. sonderianus*, reaching 86.4% Figure 9. This fact demonstrates that this species is more resistant to dry periods and remains more dense than other species in degraded areas. The coverage value for the same species was also the highest among the species considered, reaching 44.4%.

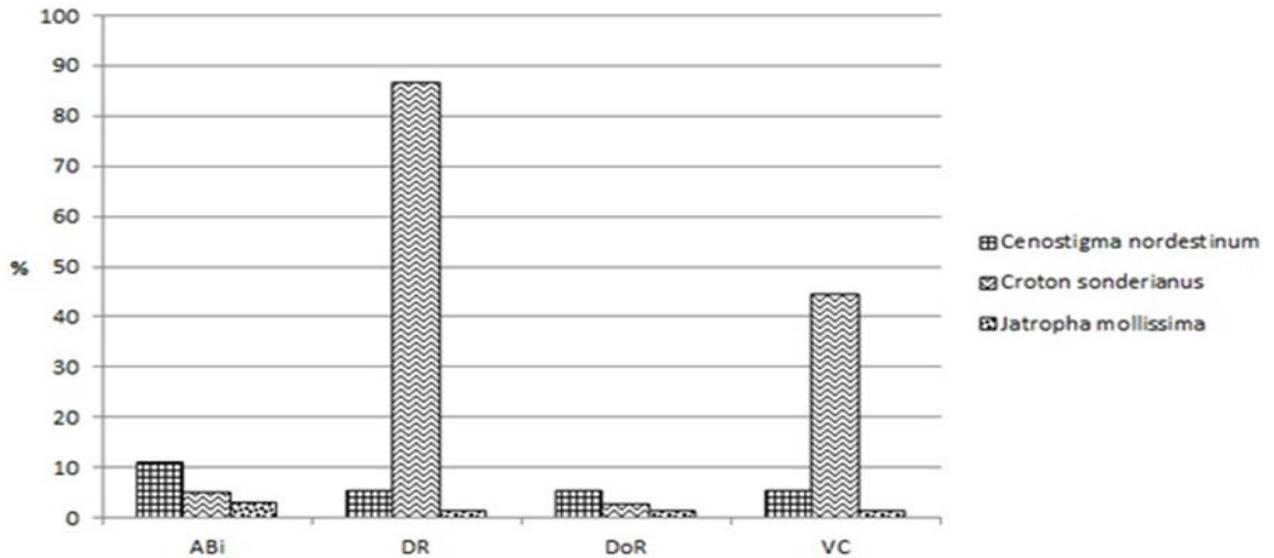


Figure-9. Percentages of Basal Area (ABi), Relative Density (DR), Relative Dominance (DoR) and Coverage Value (CV) presented by the area referring to 20 years.  
Source: MARQUES, 2020.

The values of Relative Density (DR) and Coverage Value (VC) for *C. sonderianus* were the highest in the area for 15 years, reaching 74.3 and 49.5% respectively. The relative dominance (DoR) of the species in this area was well balanced, varying between 33.9%, for *C. nordestinum* 24.8%, for *C. sonderianus* and 22.1% for *J. mollissima* Figure 10.

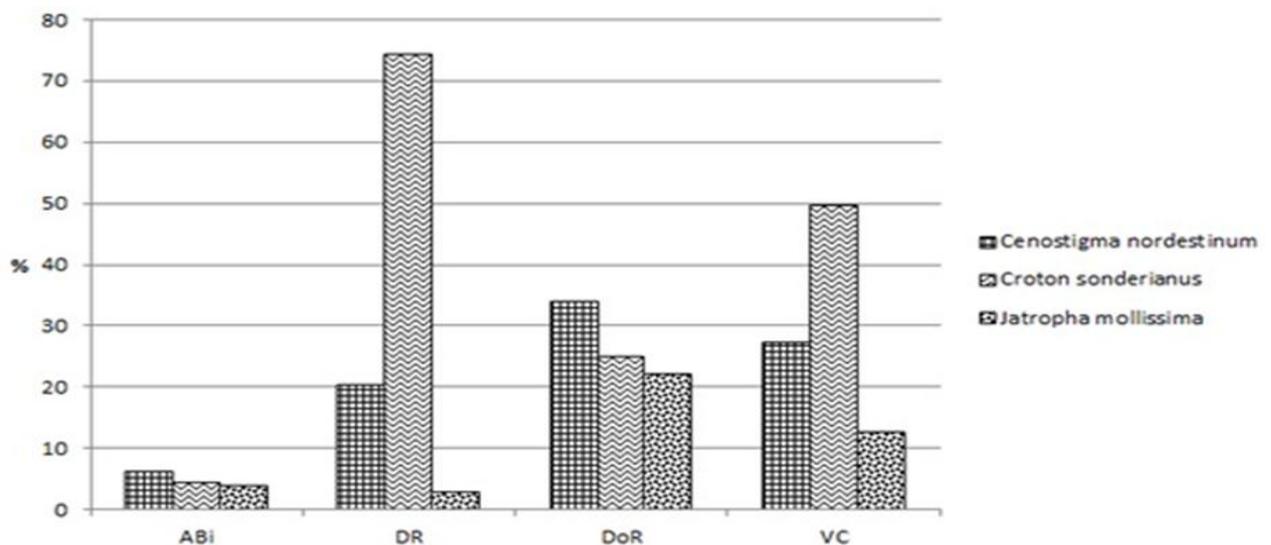


Figure-10. Percentages of Basal Area (ABi), Relative Density (DR), Relative Dominance (DoR) and Coverage Value (CV) presented by the area referring to 15 years.  
Source: MARQUES, 2020.

In the area referring to 10 years of exploration, the values of Relative Density (DR) and Coverage Value (VC) were close to the values found in the area of 15 years for *C. sonderianus*, these being 75.7 and 50.4% respectively however, with regard to Relative Dominance (DoR), *J. mollissima* obtained a higher value than that found in the 15-year area, registering 38.6% Figure 11.

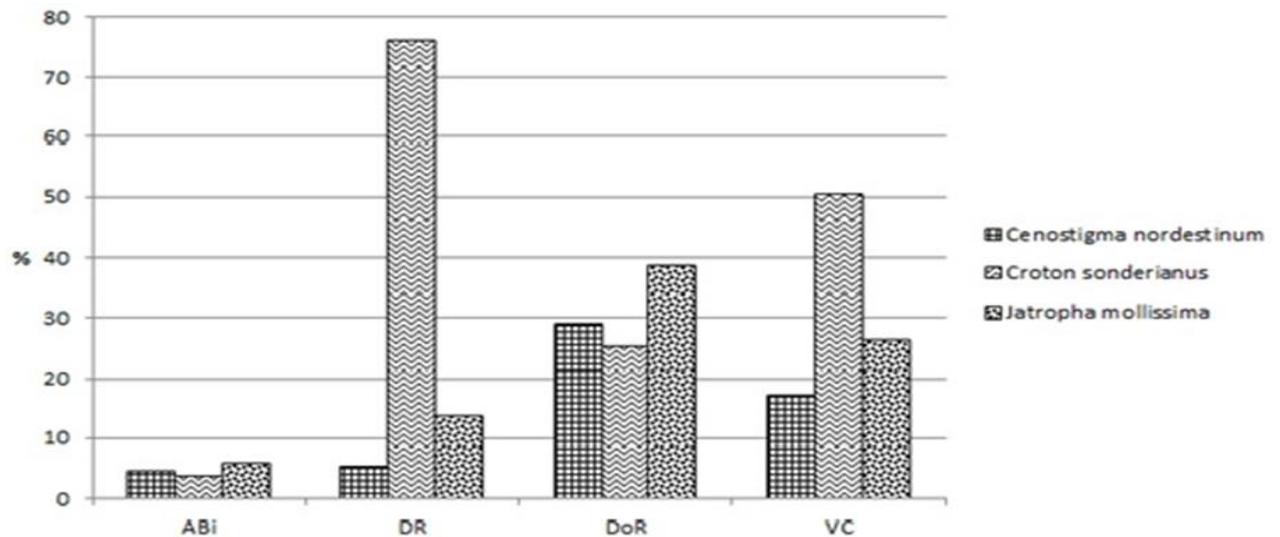
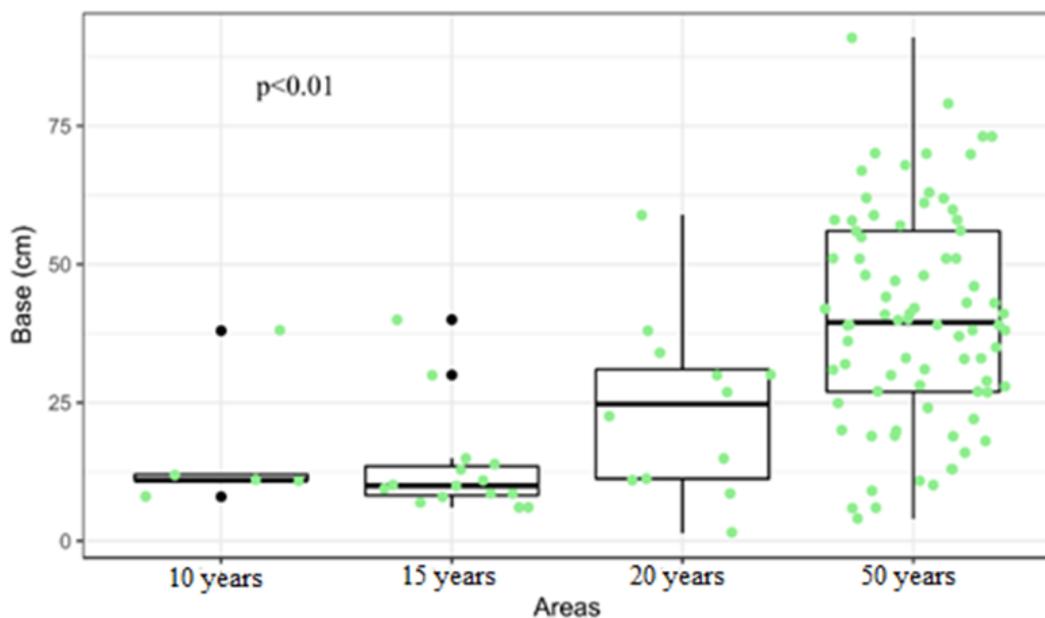


Figure-11. Percentages of Basal Area (ABi), Relative Density (DR), Relative Dominance (DoR) and Coverage Value (CV) presented by the area referring to 10 years.  
Source: MARQUES, 2020.

In general, the species *C. sonderianus* (Marmeleiro) is present in all areas with greater Relative Density and Coverage Value than the others. This demonstrates the importance of this species in the recovery process of degraded areas, since it is a successional pioneer species, responsible for initiating the process of ecological succession and consequently the recovery of native vegetation.

Figure 12 shows a similar effect for all parameters analyzed. Due to its size, *C. nordestinum* needs time to develop, mainly due to ecological succession. Newly devastated areas are expected to have grassy and herbaceous plant species. And, with the late levels of succession, even after their presence in the environment, species of shrub and arboreal size need time to develop until they obtain high DAP values, base diameter and height.



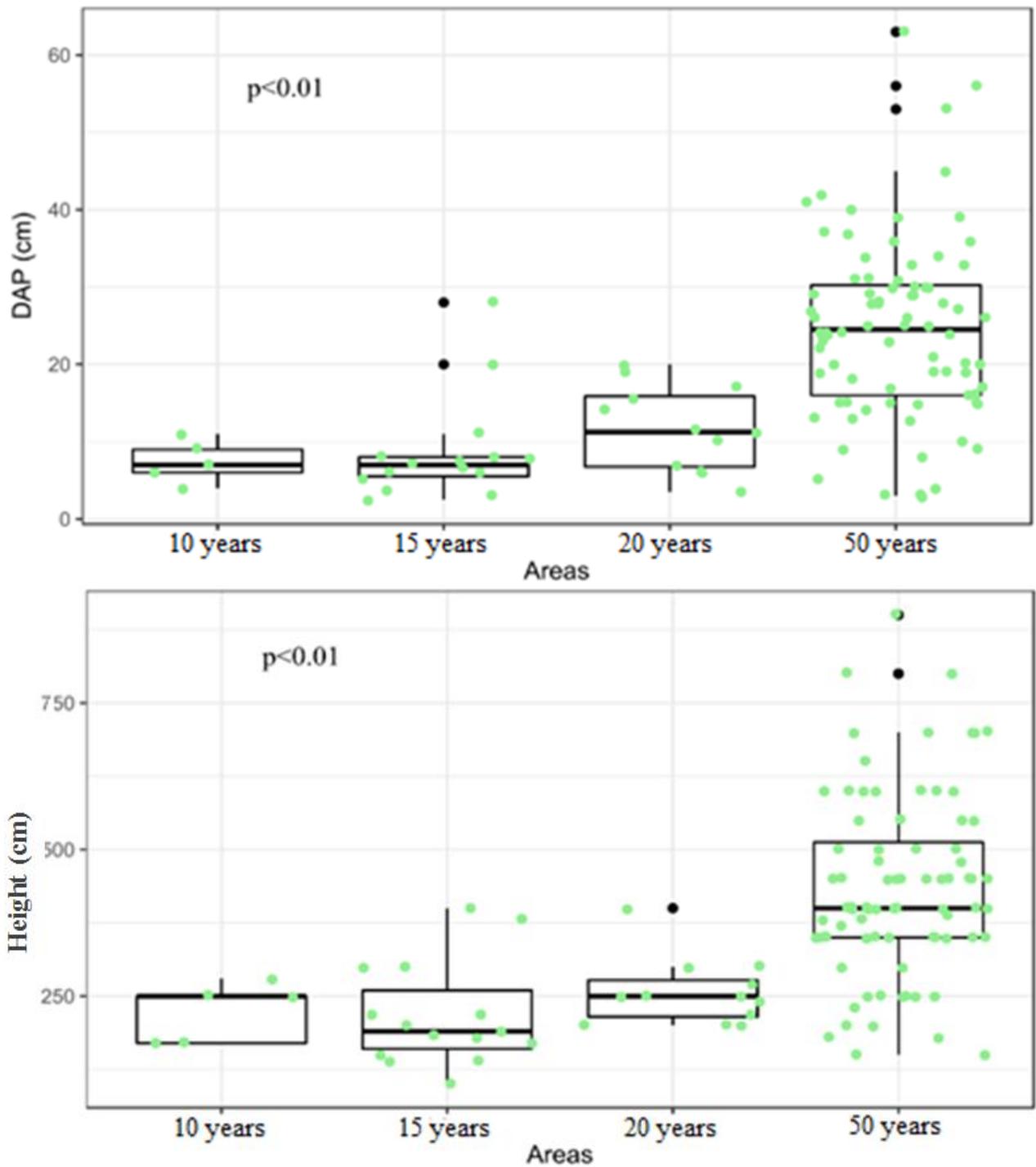
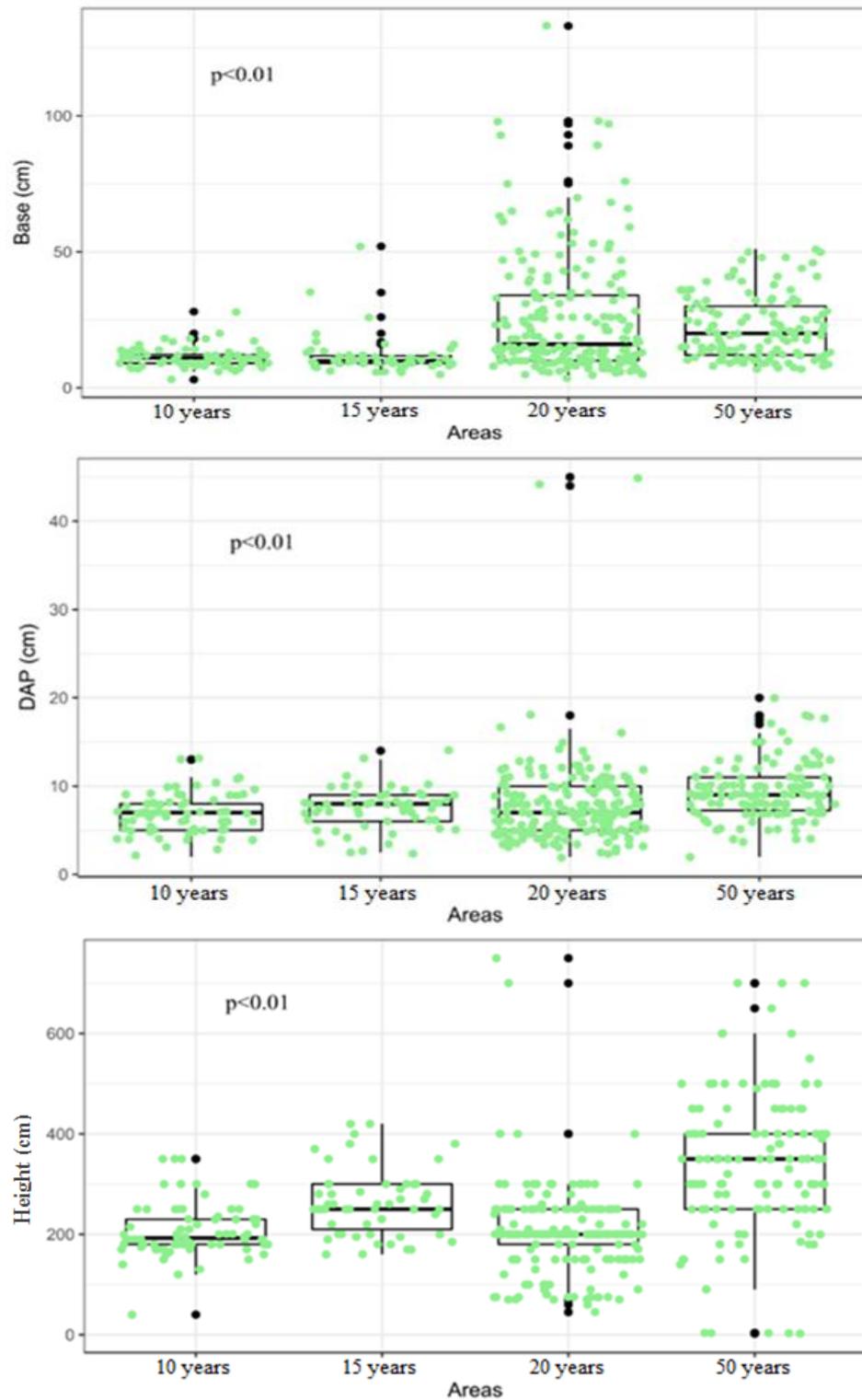


Figure-12. Base diameter, DAP and *Cenostigma nordestinum* height according to the areas studied.

Source: MARQUES, 2020.

As for *C. sonderianus* Figure 13 as it is a species that is present in initial levels of ecological succession, its parameters do not show a standardization similar to *C. nordestinum*. However, the reference area also had higher averages in all parameters analyzed, differing significantly.



**Figure-13.** Base diameter, DAP and *Croton sonderianus* height according to the studied areas.  
Source: MARQUES, 2020.

#### 4. CONCLUSIONS

The shrub caatinga is considered a secondary vegetation of 20 years, where there was granite and gneiss exploration, which is in a natural regeneration stage. The floristic composition of the shrub caatinga is more similar to the shrub arboreal Caatinga of the less impacted area for at least the last 50 years. The 10-year and 15-year exploration areas (the most degraded in relation to the 50-year reference area) presented Relative Dominance of the species with larger and well-balanced values. This means that in these areas the species considered are responsible

for triggering the recovery process, since, even with low basal area, they are present in large numbers and throughout the area.

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