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Structure and diversity of a tropical dry forest on residual reliefs in northeastern Brazil

Augusto B. de Queiroz Barbosa Queiroz *, Valéria Raquel Porto de Lima **, Rafael Camara Artigas *, Bartolomeu Israel Souza*, Zelma Glebya Maciel Quirino *,**

** Universidade Estadual do Ceará, e-mail: abqueiiroz@gmail.com*
** Universidade Estadual da Paraíba, e-mail: vrportol@yahoo.com.br*
**** Universidade de Sevilla - ES, e-mail: rcamara@us.es*
**Universidade Federal da Paraíba, e-mail: bartolomeuisrael@gmail.com*
** Universidade Federal da Paraíba, e-mail: zelmablebya@gmail.com*

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Abstract

We studied the structural characteristics of forests to better understand their current condition and help plan for the sustainable management of their resources. We delimited 14 sampling units, according to physiognomy and geomorphological position (base, medium slope 1, medium slope 2, and inselberg). To characterize vegetation structure, we used the transect method (50 x 2 m) following to Method of Phanerophytes and Chamaephyties Inventory. After this step, we classified the transects into four biotopes: (CAR: Caatinga on rocky substrate, CBA: Caatinga with open woods, CBC: Caatinga with closed woods, and CDA: degraded shrubby "Caatinga"), according to geomorphological position. Our objective was to test the hypothesis that adjacent areas with different topography differ from one another. For those comparisons, we calculated parametric and non-parametric tests in the software R. We recorded a total of 67 species, including trees, shrubs, and herbs, and high values for diversity (3.4 nats/individual) and evenness (0.83). Based on the comparison between rarefaction curves and non-parametric estimates, we observed the highest diversity in the category Caatinga with closed woods (CBC). Considering its species composition and abundance the group degraded shrubby Caatinga (CDA) is undergoing succession. The Jaccard index did not suggest floristic similarity between biotopes, but rather pointed to a diverse floristic composition in the area, with the presence of species either common or rare to the Caatinga and a higher heterogeneity than among other Brazilian semiarid areas.
Keywords: caatinga; phytosociology; geographic position.

Resumo

O objetivo é analisar as características estruturais para compreender melhor as condições atuais das florestas secas e auxiliar na gestão sustentável dos recursos. Para isso, foram estabelecidas 14 unidades amostrais, conforme a fisionomia e a posição geomorfológica (base, vertente média 1, vertente média 2, *inselberg*), utilizando o método de transectos (50 x 2 m), para a caracterização da vegetação e os parâmetros estruturais, seguindo o Inventário metodológico de fanerófitas e caméfitos. Após a caracterização da estrutura da vegetação, os transectos foram ordenados em quatro biótopos (CAR: caatinga sobre substrato rochoso, CBA: caatinga com bosque aberto; CBC:

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caatinga com bosque fechado e CBA: caatinga arbustiva degradada) de acordo com a sua posição geomorfológica, objetivando testar a hipótese de que áreas adjacentes com características topográficas distintas apresentem características distintas. Os dados paramétricos e não-paramétricos foram calculados no software R. Um total de 67 espécies foi registrado, incluindo árvores, arbustos, herbáceas e ervas e altos valores de diversidade e equabilidade (3,4 nats/indivíduos e 0,83, respectivamente). A partir da comparação entre as curvas de rarefação e estimativas não-paramétricas, observou-se uma maior diversidade para o grupo CBC. Considerando a composição e abundância das espécies, o grupo CDA se encontra em um processo de resiliência. O índice de Jaccard não apontou uma expressiva similaridade florística entre os biótopos, evidenciando que as áreas apresentaram composição florística variada, com presença de espécies comuns e raras às caatingas e heterogeneidade superior em relação às outras áreas do semiárido brasileiro.
Palavras-chave: caatinga; fitossociologia; posição geográfica.

I. INTRODUCTION

Understanding aspects related to diversity and structure, through phytosociological studies, is a basis for defining a management and conservation strategy. The caatinga is a type of dry tropical forest (PENNINGTON et al., 2004), which occupies 9% of the Brazilian territory. Despite its wide extension, the caatinga, typical of the Brazilian Northeast, is the least protected ecosystem in the country and only 2% of its area is protected (LEAL et al., 2008). In addition, the remnants located in Conservation Units generally do not have adequate management plans and have been going through a process of environmental change and deterioration that is leading to species loss (GIULIETTI et al., 2002).

The Environmental Protection Area (APA) of Onças (State Decree nº 22.880 / 2002), for example, has a high biological value, as it houses remnants of caatinga and other Brazilian biomes, but still suffers threats, such as fires, deforestation, livestock (LIMA; CAMARA, 2013). In APA das Onças, the caatinga vegetation is dominant, occurring phytophysiognomies that vary from the most hyperxerophilous in the rocky outcrops, passing through transition zones, with remnants of Atlantic Forest, which can be considered a refuge area (Ab 'Saber, 2003).

It is known that the great floristic and physiognomic variability found in the Brazilian semiarid is due to the heterogeneity of climatic, geomorphological and edaphic factors (Andrade-Lima, 1981). At a local scale, topography has been considered the most important driver of the spatial structure of tropical forests, because it is usually correlated to differences in soil properties, water regime, and fertility (FERREIRA JUNIOR et al., 2007). The abundance and distribution of species reflect the consequences of the ways in which the niche requirements of species and the dynamics of populations interact with spatial and temporal variation in the environment (WHITTAKER, 1965).

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In general, species richness and diversity tend to be greater for areas located at higher altitudes, according to Araújo et al. (1999). However, there are many gaps in knowledge about how topography impacts the distribution of plants and the structure of the plant community (Amorim, Sampaio and Araujo, 2005; Rodal, Costa and Lins-e-Silva, 2008).

Considering the influence of topography on the richness, structure and diversity of species in plant communities at a local scale, we hypothesize that the topography and climatic conditions characteristic of the area influence the formation of different plant assemblies. To test this hypothesis, we analyzed the richness and diversity of plants in four previously defined biotopes in an environmental protection area in northeastern Brazil.

II. MATERIAL AND METHOD

Study area

We carried out the present study in the Borborema mesoregion, municipality of São João do Tigre, Paraíba state (Lat. 8°04'44"S and long. 36°50'52"W.Gr.), northeastern Brazil, with our study site almost totally enclosed within Onças Protected Area, which has an extension of 36,000 ha (Figure 1).

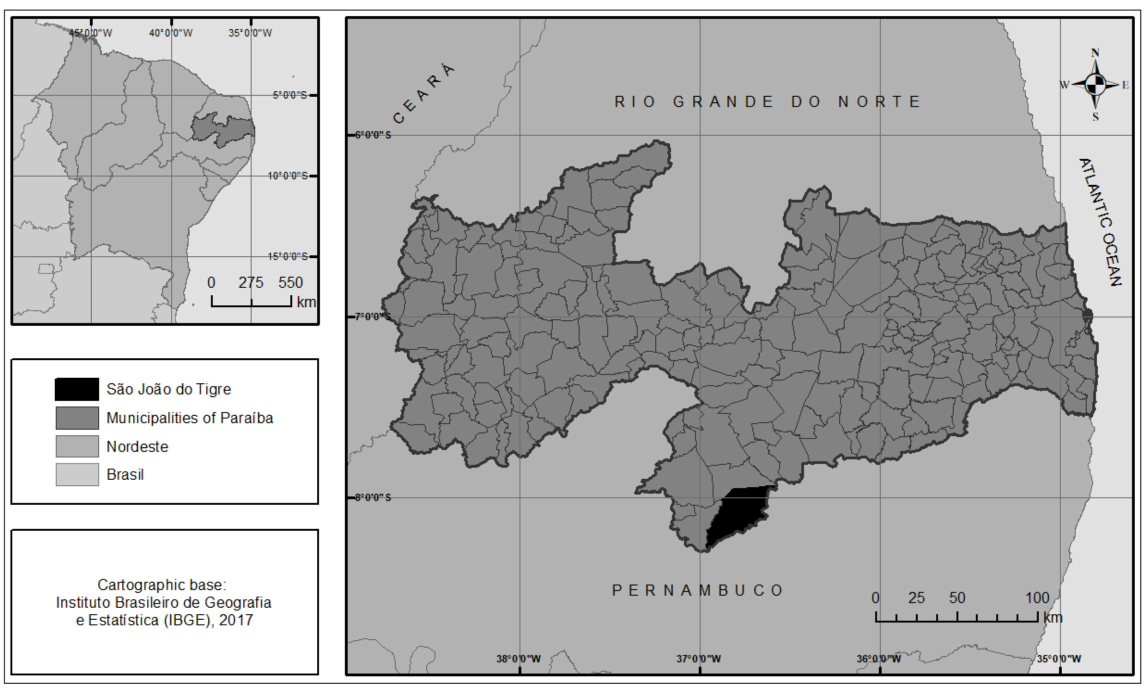

Figure 1: Location of the study area. The Environmental Onças Protected Area is delimited based on the Topographic Chart SC.24-X-B-II (Folha Pesqueira), scale 1:100000, of the Northeast Development Superintendence - SUDENE. Located between the points of geographical coordinates Lat. 06º17'56"S, Long. 36º58'05 W.Gr. and Lat. 08º00'00"S, Long. 36º37'20"W.Gr.

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The vegetation is basically composed of caatinga (shrubby-arboreal tropophilous), with parts of deciduous forest (LIMA; CAMARA, 2013). The climate is type tropical semi-arid (BSh') in the Köppen system (KOTTEK et al., 2006). The relief is predominantly mild-wavy, cut by narrow valleys, with dissected slopes, inserted in the upstream domains of the Paraíba River Basin. The average annual rainfall is 500 mm. The soil is characterized as litholic neosol, haplic planosol, and red-yellow argisol. In the slope inselberg Serra do Paulo, which we studied, there are soil layers of the type organosols, which associated with water, bioclimate, and geomorphological conditions allow the presence of humid mesophilous forests (LIMA, 2012).

Floristic and Phytosociology

We carried out a floristic inventory to characterize the local flora. We collected fertile specimens (flowers and/fruits) from all species sampled in the study area. Next, the botanical material collected was herborized and prepared to be incorporated to the Lauro Pires Xavier Herbarium (JPB – UFPB). We made the taxonomic identification through specialized literature, consultation to local herbaria collections and specialists. The floristic list followed the APG IV (2016).

To describe the vegetation, we used the method of Gentry (1988) adapted by Cámara y Díaz del Olmo (2013), known as the Method of Phanerophytes and Chamaephyties Inventory (MIFC). This method allows the description and quantitative and structural analysis of plant formations composed of phanerophytes and chamaephyties. The method was developed by the group of Estudios Tropicales y Cooperación al Desarollo (GETCD) from the University of Seville, Spain. To describe the vegetation structure of the shrubby and sub-shrubby woody species, in individuals with DBH (diameter at breast height) below 2cm, the MIFC considers height, largest and smallest diameter, whereas in individuals with DBH ≥ 2 cm, the MIFC considers the largest and smallest radius of the canopy. This way, more individuals can be included to the analysis. In plants with branched stems, all branches were measured and summed.

The criteria used to choose the areas for the application of the transects were the caatinga vegetation physiognomy and the geomorphological position, in order to gather data to relate the floristic composition of Onças Protected Area and its unique physiognomy to the influence of the geomorphology, soils, and climate in different parts of the area. A priori, we defined four biotopes based on the topographic and elevation: slope base (721 m), medium slope 1 (800 m), medium slope 2 (880 m), and inselberg top (1,115 m). To characterize the vegetation, we established 14 transects (50 x 2 m).

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After the characterization of the vegetation structure, we separated the biotopes in groups to calculate the parametrical and non-parametrical methods for these areas:

Group 1 (CAR: Caatinga on rocky substrate) comprises the transects T7 and T8, slope medium 2;

Group 2 (CBA: Caatinga with open woods): transects from T10 to T13, slope medium 1;

Group 3 (CBC: Caatinga with closed woods): transects T1 to T5 and T9, slope base;

Group 4 (CDA: Caatinga degraded shrubby): transects T6 and T14, inselberg top.

In groups 1, 2 and 3, the water balance data indicate an average rainfall of 400mm per year. Water deficit of 10 months in the year and recharge of 2 months in March and April. The bioclimatic balance shows five months of vegetative paralysis from August to December. Groups 1 have different water and bioclimatic conditions than other groups, due to the influence of orographic rains that affect Serra do Paulo. The average annual rainfall of 900mm. There are two months of water deficit and there is no vegetative paralysis due to hydraulic factors (LIMA, 2012).

Statistical Analyzes

We calculated non-parametrical methods, such as: Shannon (H'), Simpson (C), and Pielou (J). The limitation in parametrical methods has collaborated to the increasing use of non-parametrical methods in the past decades. As they do not have strict assumptions and allow comparison among samples and communities, richness estimates have been used in biodiversity inventories and conservation (GOTELLI; COLWELL, 2011).

The phytosociological parameters: relative density (RD), relative dominance (RDo), relative frequency (FR), beyond the importance value index (IVI) were calculated for each species, according to Muller-Dombois & Ellemberg (1974). Hence, for each area we built abundance matrices for the parametric analyses (MAGURRAN, 1988). The species-abundance curve, the models for the species distribution patterns, and the k-dominance curve were calculated in the package Vegan (Community Ecology Package) (DIXON, 2003) and Biodiversity R (KINDT, 2004) in the software R.

We assessed the floristic similarity among biotopes with the Jaccard coefficient, as it does not consider the frequency of species and, therefore, should be used when all species have the same weight (KREBS, 1999).

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III. Results

In the transects, we sampled 808 individual plants of 65 species (Table 1). Among the species sampled, 32 were trees, 25 were shrubs, 4 herbs, and 3 herbaceous.

Table 1: Species in Onças (Environmental Protection Area) - São João do Tigre - PB.

FAMILY	SPECIES	POPULAR NAME
Amaryllidaceae	*Hippeastrum* sp.	
Anacardiaceae	*Myracroduon urundeuva* Allemão	Aroeira
	Spondias tuberosa Arruda	Umbuzeiro
Annonaceae	*Rollinia leptopetala* R.E. Fr.	Rolinha
Apocynaceae	*Allamanda blancheti* A.DC.	Pente de Macaco
	Aspidosperma pyrifolium Mart.	Pereiro
	Himatanthus bracteatus (Mull. Arg.) Woodson	Agoniada
Arecaceae	*Mauritia flexuosa* L.f.	Buriti
	Syagrus oleraceae (Mart.) Becc.	Coco Catolé
Bignoniaceae	*Tabebuia aurea* (Silva Manso) Benth & Hook.f. ex. S. Morre	Craibeira
Boraginaceae	*Cordia globosa* (Jacq.) Kunth	
	Cordia leucocephalla Moric.	Moleque Duro
	Cordia sellowiana Cham.	Frei Jorge
Capparaceae	*Capparis flexuosa* (L.) L.	Feijão Bravo
	Capparus yco Mart. & Eichler	Icó
Bromeliaceae	*Neoglaziovia variegata* (Arruda) Mez.	Caroá
Burseraceae	*Commiphora leptophloeos* (Mart.) J.B. Gillet	Imburana
Cactaceae	*Cereus jamacaru* DC.	Mandacarú
	Melocactus zehntneri (Britton & J.N. Rose Luetzelb.	Coroa de frade
	Pilosocereus catingicola (Gürke) Byles & G.D. Rowley	Facheiro
	Pilosocereus gounellei (F.A.C. Weber) Byles & G.D. Rowley	Xique-Xique
	Tacinga inamoema (K. Schum.) Taylor & Stuppy	Cambeba/Quipó
	Tacinga palmadora (Britton & Rose) N.P. Taylor & Stuppy	Palmatória
Celastraceae	*Maytenus* sp.	
Erythroxylaceae	*Erythroxylum* sp.	
	Erythroxylum spp.	
Euphorbiaceae	*Jatropha mollissima* (Pohl) Baill.	Pinhão
	Cnidoscolus quercifolius Pohl.	Favela
	Cnidoscolus urens (L.) Arthur	Urtiga
	Croton argyrophyllus Junkth	Angolinha
	Croton echioides Baill.	Velame
	Croton jacobinenes Baill.	Marmeleiro
	Croton rhamnifolioides Pax & K. Hoffm	Catinga Branca
	Croton tricolor Klotzch ex Baill.	Croton Preto

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	Euphorbia phosphorea Mart.	
	Euphorbia tirucalli L.	Aveloz
	Manihot glaziovii Mull. Arg.	Maniçoba
	Sapium glandulatum (Vell.) Pax	Burra Leiteira
Fabaceae	*Acacia glomerosa* Benth	Espinheiro
	Anadenanthera colubrina (Vell.) Brenan	Angico
	Bauhinia cheilantha (Bong.) Steud	Mororó
	Caesalpinia ferrea Mart.	Jucá/Pau Ferro
	Cenostigma pyramidale (Tul.) E. Ganon & G. P. Lewis	Catingueira
	Enterolobium contortisiliquum (Vell.) Morona	Tambor
	Luetzelburgia auriculata (Allemão) Ducke	Pau Mocó
	Mimosa ophtalmocentra Mart. ex Benth	Jurema Vermelha
	Mimosa tenuiflora (Willd.) Poir	Jurema Preta
	Piptadenia stipulaceae (Benth.) Ducke	Jurema Branca
	Senna martiana (Benth.) H.S. Irwin & Barneby	Canafístula
	Senna sp.	
Lamiaceae	*Mellissa officinalis* L.	Erva Cidreira
Lauraceae	*Ocotea* sp.	
Malvaceae	*Melochia pyramidata* L.	
	Pseudobombax marginatum (A. St. -Hil., Juss. & Cambess) A. Robyns	Imbiratanha
Myrtcaeae	*Eugenia uniflora* L.	
	Myrtaceae sp.	
Nyctaginaceae	*Guapira laxiflora* (Choisy) Lundell	Pau Piranha
	Guapira pernambucensis (Casar.) Lundell	
Piperaceae	*Piper* sp.	
Rhamnaceae	*Ziziphus joazeiro* Mart.	Juazeiro
Rubiaceae	*Randia* sp.	
Solanaceae	*Nicotiana* sp.	
	Solanum paniculatum L	Jurubeba
Verbenaceae	*Lonchocarpus sericeus (Poir.) Junth ex DC.*	
	Lippia microphylla Cham	Alecrim

The species with the highest abundance were *Poincianella pyramidalis* with 89 individuals (11.3%), followed by *Croton jacobinensis* with 87 (10.3%), *Croton echioides* with 60 (7.4%), *Mimosa ophtalmocentra* with 53 (6.5%), *Anadenanthera colubrina* with 48 (6%), *Croton argyrophyllus* with 39 (4.8%), *Aspidosperma pyrifolium* with 28 (3.5%), *Neoglaziovia variegata* with 24 (3%), *Acacia glomerosa* with 23 (2.8%), and *Sapium glandulatum* with 20 (2.5%), which together comprised 58.1% of the individuals sampled (Table 2).

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Table 2: Phytosociological parameters characterizing the horizontal distribution of the species sampled in Onças Protected Area, São João do Tigre, Paraíba state, in decreasing order of IV.

Species	N	BA (m²)	RD (%)	RDo (%)	RF (%)	IVI (%)
Cenostigma pyramidalis	91	1,02	11,2	13,6	4,57	9,83
Mimosa ophthalmocentra	53	0,33	6,56	11,6	5,08	7,76
Croton jacobinensis	87	0,08	10,7	4,86	4,04	6,56
Anadenanthera colubrina	48	0,20	5,94	8,68	4,57	6,39
Croton echioides	60	0,42	7,42	3,35	6,09	5,62
Croton argyrophyllus	39	0,11	4,83	5,09	3,55	4,49
Piptadenia stipulacea	19	0,05	2,53	4,31	2,03	2,96
Sapium glandulatum	20	0,06	2,48	3,69	2,54	2,90
Acacia glomerosa	23	0,06	2,87	2,64	2,54	2,68
Cordia sellowiana	20	0,17	2,48	3,51	1,52	2,50
Aspidosperma pyrifolium	28	0,08	3,46	2,24	1,52	2,41
Maytenus sp.	15	0,14	1,86	3,12	1,52	2,17
Cynophalla flexuosa	12	0,23	1,49	2,94	2,03	2,15
Manihot glaziovii	11	0,03	1,36	2,09	2,54	2,00
Neoglaziovia variegate	24	-	2,97	0,35	2,54	1,95
Jatropha mollissima	12	0,04	1,49	1,74	2,54	1,92
Piper sp.	16	0,18	1,99	2,20	1,52	1,90
Croton rhamnifolioides	4	0,03	0,5	0,90	4,06	1,82
Senna martiana	10	0,02	1,24	1,50	2,54	1,76
Cordia leucocephala	12	-	1,49	0,91	2,54	1,64
Bauhinia cheilantha	8	-	1	0,79	2,54	1,44
Cnidoscolus urens	10	-	1,24	0,02	3,05	1,44
Pseudobombax marginatum	8	0,04	1	1,59	1,52	1,37
Croton tricolor Klotzch ex Baill.	13	0,01	1,61	1,38	1,02	1,33
Commiphora leptophloeos	6	0,20	0,74	1,43	1,52	1,23
Erythroxylum sp.	9	-	1,11	1,44	1,02	1,19
Erythroxylum spp.	5	0,17	0,62	0,96	1,52	1,03
Melocactus zehntneri	13	0,63	1,61	0,46	1,02	1,03
Mimosa tenuiflora	8	0,04	1	0,42	1,52	0,98
Cereus jamacaru	4	0,07	0,5	0,37	2,03	0,97
Melochia pyramidata	8	0,01	1	1,34	0,51	0,95
Enterolobium contortisiliquum	2	1,67	0,25	2,03	0,51	0,93
Luetzelburgia auriculata	7	0,02	0,87	0,73	1,02	0,87
Pilosocereus catingicola	7	0,15	0,87	0,19	1,52	0,86
Tacinga palmadora	11	-	1,36	0,16	1,02	0,85
Cnidoscolus quercifolius	5	0,18	0,62	1,26	0,51	0,79
Capparis yco	3	0,01	0,37	0,46	1,52	0,78
Pilosocereus gounellei	6	0,02	0,74	0,27	1,02	0,68
Mauritia flexuosa L.f.	2	0,09	0,25	0,70	1,02	0,66
Tabebuia aurea	4	0,01	0,5	0,44	1,02	0,65
Himatanthus bracteatus	2	0,45	0,25	1,19	0,51	0,65
Cordia globose	5	-	0,62	0,78	0,51	0,64
Ziziphus joazeiro	6	-	0,74	0,13	1,02	0,63
Tacinga inamoema	7	-	0,87	-	1,02	0,63
Syagrus oleracea	2	0,18	0,25	0,36	1,02	0,54
Guapira pernambucensis	1	-	0,12	0,93	0,51	0,52
Euphorbia phosphorea	6	-	0,74	0,02	0,51	0,42
Nicotiana sp.	2	0,36	0,25	0,49	0,51	0,42

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Guapira laxiflora	1	-	0,12	0,60	0,51	0,41
Myrtaceae sp.	1	0,06	0,12	0,48	0,51	0,37
Melissa officinalis	4	-	0,5	0,07	0,51	0,36
Lippia microphylla Cham	3	-	0,37	0,15	0,51	0,34
Senna sp.	3	-	0,37	0,44	0,51	0,30
Ocotea sp.	2	-	0,25	0,12	0,51	0,29
Spondias tuberosa	1	0,02	0,12	0,24	0,51	0,29
Euphorbia tirucalli	1	-	0,12	0,24	0,51	0,29
Randia sp.	1	-	0,12	0,17	0,51	0,27
Eugenia uniflora	2	-	0,25	-	0,51	0,25
Myracrodruon urundeuva	1	-	0,12	0,02	0,51	0,21
Allamanda blanchetii	1	-	0,12	0,01	0,51	0,21
Solanum paniculatum	1	-	0,12	-	0,51	0,21
Rollinia leptopetala	1	-	0,12	-	0,51	0,21
Hippeastrum sp.	1	-	0,12	-	0,51	0,21
Lonchocarpus sericeus	1	-	0,12	-	0,51	0,21
Libidibia ferrea	1	-	0,12	-	0,51	0,21

N = number of individuals; BA = basal area (m^2); RD = relative density (%); RF = relative frequency (%); RDo = relative dominance (%), and IV = importance value (%).

The average density found in the present study was 2.238 ind. ha^{-1}. The basal area was 7.72 m^2. The value found for the vegetation diversity estimated with the Shannon Index (H') was 3.49. The Simpson dominance index (C) was 0.95 and Pielou evenness was 0.83.

The Shannon index (Table 3) scored highest for the Caatinga with closed woods (CBC: 3.11) and lowest for the degraded shrubby Caatinga (CDA: 2.29). The four groups showed an important dominance of some species (Simpson index), but high evenness (J), which corresponds to an even share of the individuals among the species set, except for the dominant ones.

Table 3: Quantitative parameters of the vegetation of Onças Protected Area.

	CAR	CBA	CBC	CDA
R	27	27	42	16
N	103	253	330	122
(H')	2.90	2.68	3.11	2.29
(D)	0.92	0.90	0.93	0.86
(J)	0.88	0.81	0.83	0.83
(d)	0.16	0.23	0.13	0.21

R = Number of species sampled, N = number of individuals sampled, H' = Shannon diversity index, D = Simpson index, J= Pielou evenness index, d= Berger-Parker dominance index. Groups: CAR,: Caatinga on rocky substrate, CBA: Caatinga with open woods, CBC: Caatinga with closed woods, and CDA: degraded shrubby Caatinga.

In the species-abundance curve (Figure 2 a), diversity was highest for the category Caatinga with closed woods (CBC), followed by Caatinga with open woods (CBA), Caatinga on rocky substrate (CAR), and degraded shrubby Caatinga (CDA). The distribution models expressed in the randfit graph (Figure 2 b) showed that the

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groups Caatinga with closed woods (CBC) and degraded shrubby Caatinga (CDA) fit to a lognormal distribution model: CBA to a logarithmic model and CDA to a geometric progression model. The k-dominance curve (Figure 2 c) confirmed a higher diversity for Caatinga with closed woods (CBC), followed by Caatinga on rocky substrate (CAR), Caatinga with open woods (CBA), degraded shrubby Caatinga (CDA), and it also showed a situation of low degradation for CBC and maximum degradation for CDA. The rarefaction curves (Figure 2 d) showed stabilized species richness for the Caatinga with open woods (CBA) and the degraded shrubby Caatinga (CDA), contrary to the Caatinga on rocky substrate (CAR) and the Caatinga with closed woods (CBC), which did not stabilize.

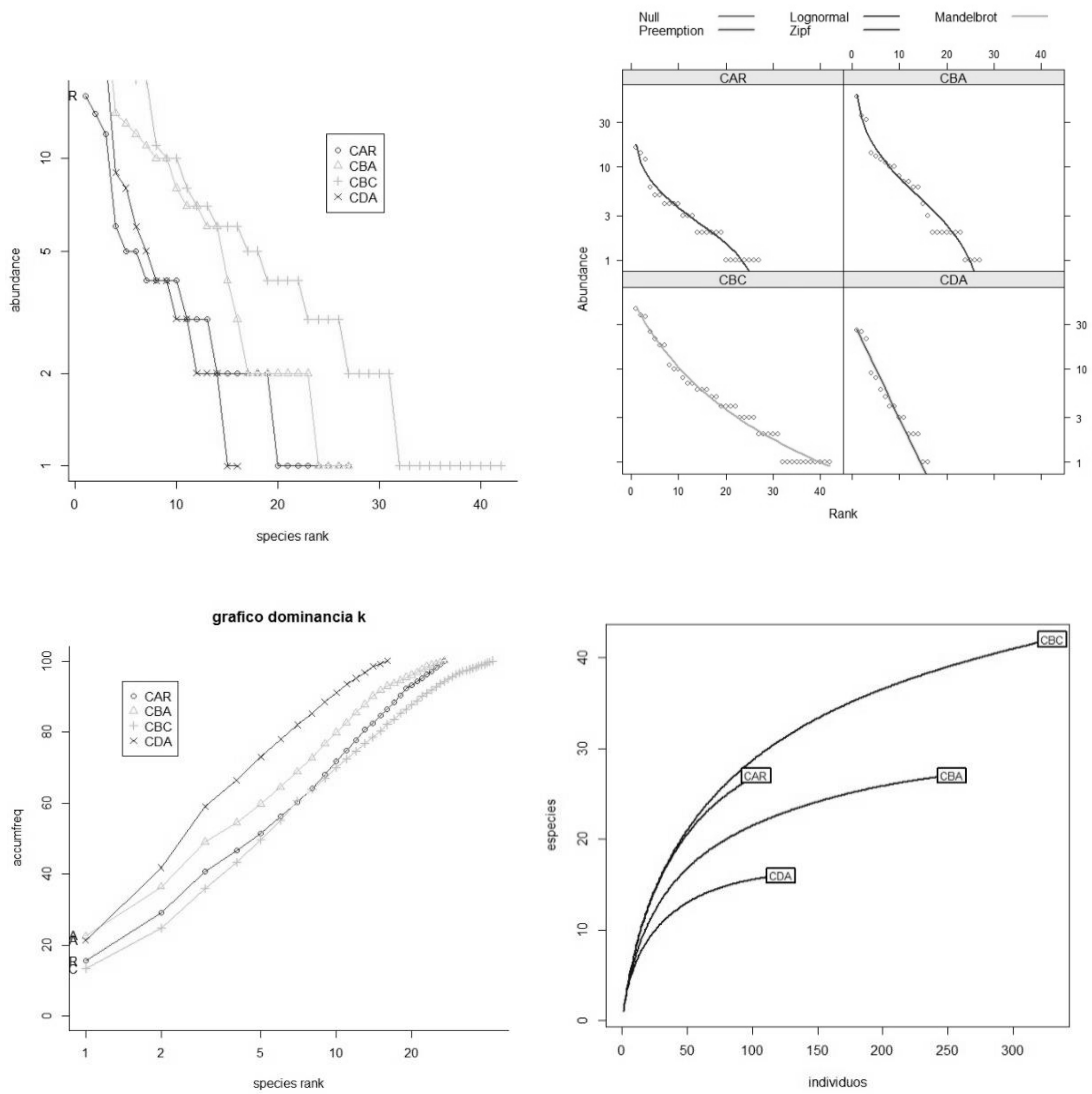

Figure 2. a) Species abundance distribution; b) radfit, distribution models; c) k-dominance; d) rarefaction curves, for the groups Caatinga on rocky substrate (CAR), Caatinga with open woods (CBA), Caatinga with closed woods (CBC), and degraded shrubby Caatinga (CDA).

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The Jaccard binary similarity coefficient for the floristic composition of the biotopes studied is shown in Table 3. There were not large differences in species composition between categories. We found a greater similarity between the groups Caatinga with open woods (CBA) and Caatinga with closed woods (CBC; (45.7 %). These results indicate a more even distribution of the species among groups.

Table 3: Floristic similarity (Jaccard index) among the four biotopes sampled in Onças Protected Area.

Jaccard	CAR	CBA	CBC	CDA
CAR	1	0.12766	0.245283	0.108108
CBA	0.12766	1	0.456522	0.272727
CBC	0.245283	0.456522	1	0.195652
CDA	0.108108	0.272727	0.195652	1

CAR,: Caatinga on rocky substrate, CBA: Caatinga with open woods, CBC: Caatinga with closed woods, and CDA: degraded shrubby Caatinga.

IV. Discussion

Our results corroborate the hypothesis that abiotic factors influence the distribution, structure, and diversity of plant communities at a local level. The comparison of the four biotopes indicates that the degraded shrubby Caatinga (CDA) is undergoing ecological succession.

The Caatinga with closed woods (CBC) is the result of a more evolved process than the previous one, in which an ecological factor dominates the development of the community. The other two models showed more stable distribution of communities that respond to the action of several environmental factors. Micro-topographic factors (such as slope, slope aspect and slope position) exert a strong influence on plant community structure and species distribution (WANG et al., 2010). Topografic position also affects forest microclimates because incident solar radiation varies across the surface of a slope (POULOS; CAMP, 2010).

Despite the small size in comparison with other Caatinga areas studied, Onças Protected Area, in particular Serra do Paulo inselberg, shows a considerable floristic richness when compared with areas, such as Serra da Capivara National Park (PARNA) in Piauí inventoried by Lemos and Rodal (2002), who recorded 56 species and 19 families. Pereira et al. (2002) used the same inclusion criteria adopted by Lemos and Rodal (2002), and found 54 species and 22 families in a forest remnant in the Agreste of the state of Pararíba. Santana and Souto (2006) studied the floristic composition of the Seridó Ecological Station, Serra Negra do Norte, state of Rio Grande do Norte, and recorded 22 species and 12 families, though only individuals with arboreal or shrubby habits were sampled. The basal area of the study was similar to the study by Queiroz et al. (2006), which

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corresponded to 6.1 m² ha^{-1}. The number of species and families found in the remnant studied is within the average of the inventories made in the Caatinga.

In general, studies in the Caatinga do not show high richness and diversity, but, in the present study, we evidenced a high diversity, even above other studies carried out in these areas. The vegetation of the fragment studied showed higher species richness when compared to these areas, which may result from a high degree of anthropization in these habitats and edaphoclimatic conditions. According to Saporetti-Jr. et al. (2003), values above 3.11 for the Shannon index indicate well-preserved plant formations, which is a definition that fits the study area. According to Felfili and Rezende (2003), the Shannon index can reach values up to 4.5 in tropical forest habitats.

The species *Poincianella pyramidalis* and *Croton blanchetianus* stand out in number of individuals in studies in Caatinga areas (FARIAS et al., 2016). In other words, even using different methods, the results were similar. Due to the abundance of its population, the species *Poincianella pyramidalis* showed considerable values of density (11.26%), frequency (4.57%), and dominance (13.66%), i.e., it is broadly distributed and has great ecological importance in the study area. This species tends to dominate the sites where it is present, and it is pointed out as one of the most frequent (FABRICANTE; ANDRADE, 2007). According to Pereira et al. (2001), one of its characteristics is the broad dispersal in the semi-arid region of northeastern Brazil.

The grouping per area evidenced floristic differences, corroborating our hypothesis. The group Caatinga with closed woods, located at a geomorphological position of medium slope showed a dense arboreal "Caatinga". In the group degraded shrubby "Caatinga", the transect 6 was carried out in an area of open Caatinga with the predominance of *Cnidoscolus quercifolius*. According to Cordeiro and Secco (2011), this species is endemic to Brazil, has arboreal habit, and is very resistant to drought and adapted to areas with saline soils. The transect 14, carried out in an area of degraded Caatinga with shrubby-arboreal physiognomy, showed the dominance of *Commiphora leptophloeos, Aspidosperma pyrifolium*, and *Mimosa ophtalmocentra.*

The transects 7 and 8 (caatinga on rocky substrate) were carried out in a rocky outcrop area (inselberg). The floristic physiognomy of the transect 7 showed particularities in its structure and composition; it is a sample of 200 m² with two plant physiognomies. The first type of vegetation with an arboreal physiognomy and species of rainforest corroborates the hypothesis of the application of the theory of the Atlantic Forest Refuges within the Caatingas domain. The theory of the refuges states that during the climatic changes of the Quaternary, the biota of the tropical rainforests remained isolated in more humid areas, such as the reliefs, and underwent

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adaptations resulting from the isolation (VIADANA; CAVALCANTI, 2006). The second type of vegetation of the rocky outcrop is a shrubby physiognomy, with a high abundance of Cactaceae, Bromeliaceae, and Euphorbiaceae. The reasons for two very distinct vegetation types under a same climatic condition are the soil conditions or the rock where they are settled. The transect 8 showed a more diversified and fragile flora. This diversity can vary according to climatic and edaphic environmental conditions to which it is submitted and there is the fragility in the process of morphological and physiological adaptation of the flora. This transect is characterized by a strong dominance of *Melocactus zehntneri* and *Euphorbia phosphorea*. The former has its distribution restricted to northeastern Brazil (TAYLOR; ZAPPI, 2004), and is one of the most resistant species to severe conditions of water scarcity in the family Cactaceae. Carneiro et al. (2002) developed floristic studies in rocky outcrops in northeastern Brazil, which indicated a predominance of species from the family Euphorbiaceae in these environments. The transects 11, 12, and 13 (caatinga with open woods) were carried out in a medium slope, with arboreal physiognomy, where there is a predominance of *Anadenanthera colubrina, Poincianella pyramidallis,* and *Mimosa ophtalmocentra*.

V. Conclusions

The diversity analyses showed a better conservation status for the caatinga with closed woods and caatinga on rocky substrate. Considering that these slopes were impacted by human management, these communities are under a high resilience process, so that the management of the protected area will preserve these aspects and control logging, which affects the impoverishment of these forests.

The present study broadens the knowledge of the floristic composition of an important Caatinga area in the semi-arid of the state of Paraíba. Onças Protected Area differs from other caatinga areas mostly because of its higher richness of species and families. It also has an expressive diversity value, which may represent a well-preserved remnant, and therefore classifies it as an area of extreme biological importance for the caatinga biome.

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