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EXTENDING THE LIMITS OF CAMPOS RUPESTRES IN BRAZIL

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ABSTRACT

Campos rupestres are typical ecosystems of rock outcrops with high biodiversity and endemism, located in Brazilian territory, with vegetation analogous in Africa and Australia. The Campos Rupestres cover deeply dystrophic soils on highlands inserted in Amazon rainforest, Atlantic rainforest, and Cerrado biomes. Despite recognition of *Campos Rupestres* as a global biodiversity hotspot, little is known its occurrence in dry forests. So, this work aimed to describe vegetable cover and soil properties in highlands associated to rock outcrops on Caatinga biome. A pristine area in Borborema plateau was chosen as study area. Frequency of species and life forms indicate high vegetable density and herbaceous habits predominance. Although the high similarity of species with Caatinga biome, presence of *Albizia*, *Dalbergia*, *Poecilanthe* e *Platymiscium* indicates a truly distinct floristic composition. Soils are shallower, less fertile and has lower water storage capacity than predominant soils in Caatinga. This work reveals the presence of Campos Rupestres beyond the areas previously considered favorable to its presence, extending its occurrence to regions of lower precipitation. The occurrence of the Campos Rupestres is attributed to an additional supply of water from fog in consonance with organic soils. Therefore, areas with similar characteristics should be prioritized to be preserved.

Keywords: Semiarid climate. Dry florests. Borborema province. Edaphology. Umbrisols. Water storage capacity.

EXTENDENDO OS LIMITES DOS CAMPOS RUPESTRES NO BRASIL

RESUMO

Campos rupestres são ecossistemas típicos de afloramentos rochosos com alta biodiversidade e endemismo, localizados no território brasileiro, com vegetação análoga na África e Austrália. Os Campos Rupestres cobrem solos profundamente distróficos em terras altas inseridas nas florestas da Amazônia, Mata Atlântica e biomas do Cerrado. Apesar do reconhecimento dos Campos Rupestres como hotspot da biodiversidade global, pouco se sabe sobre sua ocorrência em florestas secas. Assim, este trabalho teve como objetivo descrever a cobertura vegetal e as propriedades do solo em terras altas associadas a afloramentos rochosos no bioma Caatinga. Uma área intocada no planalto de Borborema foi escolhida como área de estudo. A frequência de espécies e formas de vida indica alta densidade vegetal e predominância de hábitos herbáceos. Embora a alta similaridade de espécies com o bioma Caatinga, a presença de *Albizia, Dalbergia, Poecilanthe* e *Platymiscium* indica uma composição florística verdadeiramente distinta. Os solos são mais rasos, menos férteis e com menor capacidade de armazenamento de água do que os solos predominantes na Caatinga. A ocorrência dos Campos Rupestres é atribuída a um suprimento adicional de água do nevoeiro em consonância com solos orgânicos. Portanto, áreas com características semelhantes devem ser priorizadas para preservação.

Palavras-chave: Clima semiárido. Florestas secas. Província Borborema. Edafologia. Organossolos. Capacidade de armazenamento de água.

INTRODUCTION

Campos Rupestres ("rocky fields") are Brazilian endemic neotropical azonal ecosystems known as predominantly herbaceous-shrub vegetation, with sparse trees up to two meters high. They occur as a mosaic of rocky archipelagos on cliffs, plateaus, and highlands inserted in a matrix of zonal biomes, similar to rocky fields in South Africa and Southeastern Australia (FIEDLER, 2015; MORELLATO; SILVEIRA, 2018). The *Campos Rupestres* has a high diversity and hosts several endemic genera, although they not rely exclusively on a combination of them (ALVES; KOLBEK, 2010) and share several plant species with surrounding biomes, as the Atlantic rainforest (SANTOS et al., 2015), the *Cerrado* (Brazilian savanna) (WEBERLING, 2008) or the Amazon rainforest biomes (DA COSTA-LIMA, 2018). Although classified as endemic to Brazil, similar vegetation occurs in eastern Bolivia (NEVES et al., 2018).

Altitude, climate, and soils are the abiotic factors commonly indicated as determinants in the spatial distribution of the Campos Rupestres (ALVES et al., 2014; SILVEIRA et al., 2016). Its occurrence is frequent in elevations above 900 meters above sea level (m.a.s.l.) and annual precipitation areas between 800 and 1,500 mm year^{-1}, under the influence of orographic rain and fog. The soils are shallow, incipient, deficient in nutrients, acidic, gravel, and low water storage capacity (VASCONCELOS, 2011). Consequently, few plant species successfully occupy these areas, and endemism is high (BENITES et al., 2003; SILVA et al., 2004). The Campos Rupestres host more than 5,000 vascular plant species, representing 14% of the total plant diversity of Brazil in only 1% of the total area (SILVEIRA et al., 2016).

Caatinga (xeric shrubland) biome is a semiarid biome of the northeast of Brazil, which covers about 12% of the country's territory. Xerophytic, woody, thorny, and deciduous physiognomies dominate flat surfaces in a hot and dry climate since at least 14,000 years before present (DE QUEIROZ et al., 2017; SANT'ANNA NETO; GALVANI; VIEIRA, 2015). Borborema plateau is highlighted in the Caatinga biome due to its wetter climate favored by a mean altitude five times higher than the rest of the biome (KAYANO; ANDREOLI, 2009). Borborema plateau has an area of approximately 65,000 km² and covers four states in Brazil. It is one of the most prominent features derived from Brasiliano orogenic systems affected by the Cretaceous uplift, as Serra do Mar uplift and the Mantiqueira range in Southeastern Brazil (SALGADO et al., 2015).

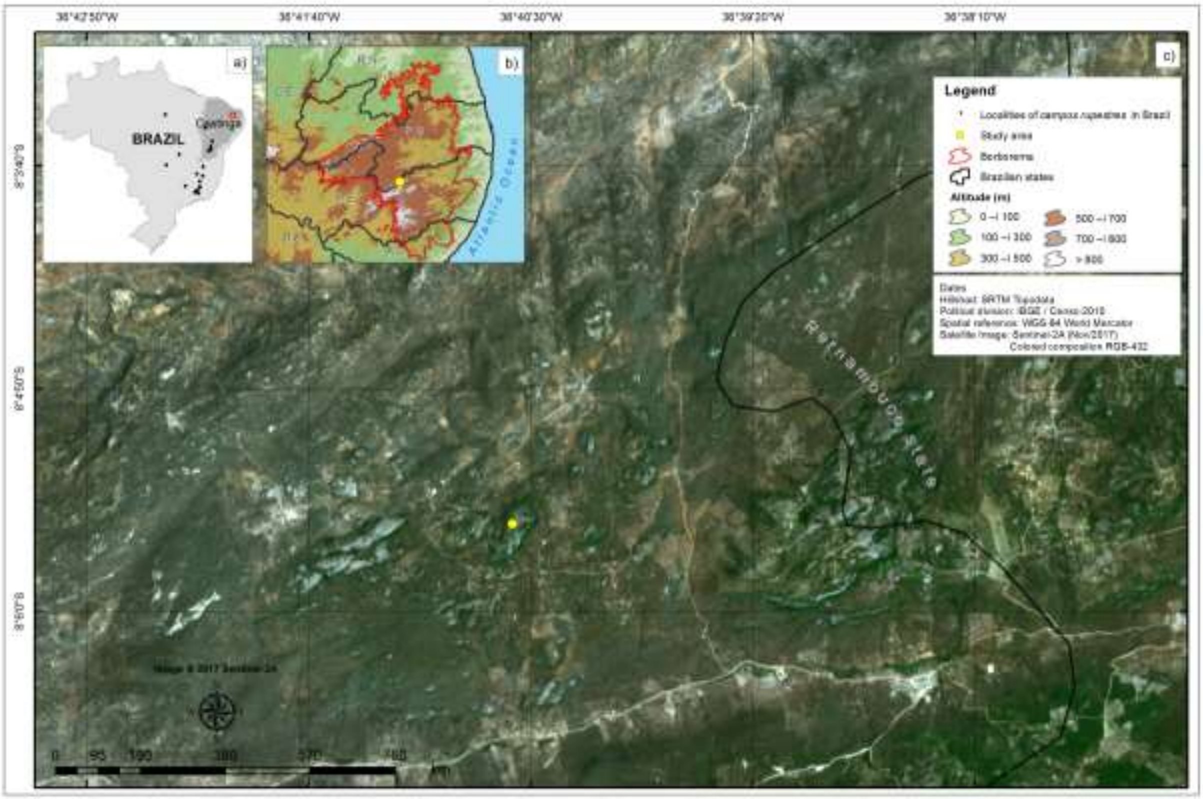
The highlands in Borborema province archive 1,200 m.a.s.l. and have poorly studied ecosystems variability (SANTOS et al. 2011), where unknown areas of Campos Rupestres may even be present. We believe that Campos Rupestres are straight related to edaphic characteristics and hypothesized that its spatial distribution is more extensive than actual limits and comprehends highlands in the Caatinga biome. A detailed description of these sites is fundamental to understanding semiarid ecological processes and conservative policy development.

METHODOLOGY

Study area

Onças Environmental Protected Area (OEPA) was chosen as the study area (Figure 1). OEPA has a total area of 36,000 ha and particular landscape diversity. Altitudes vary between 600 m.a.s.l., in the valleys, and 1,200 m.a.s.l., in cliffs associated with resistant rocks and horst-graben systems. The site is located at Borborema plateau, which shows slightly dissection and typical characteristics of erosional surfaces in arid and semiarid regions, such as cliffs and inselbergs developed in Proterozoic granites/granitoids, playas, and pediments (Byran 1922; King 1953). Shallow and low weathered Leptsols (correlate to Neossolos Litólicos in the Brazilian Soil Classification System), Luvisols (Luvissolos), Inceptsols (Cambissolos), and Regosols (Neossolos Regolíticos) represent 65 % of the area (SANTOS et al., 2011).

Figure 1 - Brazil: (a) Location of Caatinga biome, (b) highlands in Northeastern Brazil and (c) study area location, 2017.



Sampling and data analysis

Precipitation, temperature, and humidity were measured between January 2017 and June 2018 by a Davis meteorological station in the study area. Although the data series is not sufficient to indicate the climate pattern of the site, we highlight that there is the first and the only meteorological station on a radio of 40 km.

Habits, frequency, and vegetation species were identified by floristic surveys realized in representative sites of the study area between July and August 2018 (Supplemental material – Table). Photographic records of branches, leaves, inflorescences, flowers, fruits, and seeds were taken with a Nikon Coldpix P600 digital camera with a resolution of 16 megapixels to help identify and create a photographic record.

The identifications were made by consulting the relevant literature ("Reflora - Virtual Herbarium", 2018) and consultations with the specialists. The frequency of species was classified as: rare (1 to 5 individuals), frequent (6 to 10 individuals), or abundant (more than ten individuals). Life forms of plants were classified according to Raunkiaer (1934), and the geographical distribution of species was described according to literature.

One pedon was taken, described, and classified according to the World Reference Base soil classification system (IUSS WORKING GROUP WRB, 2014) to represent soil dominance in the site. Pedon also was classified according to the Brazilian Soil Classification System (SANTOS et al., 2018). Soil samples were collected from the surface down to the lithic contact.

According to methods established for tropical soils, samples were air-dried and sieved through a 2 mm sieve prior to texture and chemical analysis (DONAGEMA et al., 2011). Sand, silt, and clay were determined by the pipette method after dispersion with 0.1 M NaOH. Soil pH was measured with a glass electrode in a 1:2.5 suspension v/v soil and deionized water (H_2O pH) and 1 M KCl solution (KCl pH). The potential acidity (H + Al) was extracted by 1 M ammonium acetate solution at pH 7. The content of exchangeable Ca^{2+}, Mg^{2+}, and Al^{3+} were determined in a 1 M KCl extract. Exchangeable K^{+} and Na^{+} were determined after Melhich-1 extraction. From these results, the sum of bases (SB), base saturation (V), aluminum saturation (m), equivalent cation exchange capacity (ECEC), and total cation exchange capacity (CEC) were calculated.

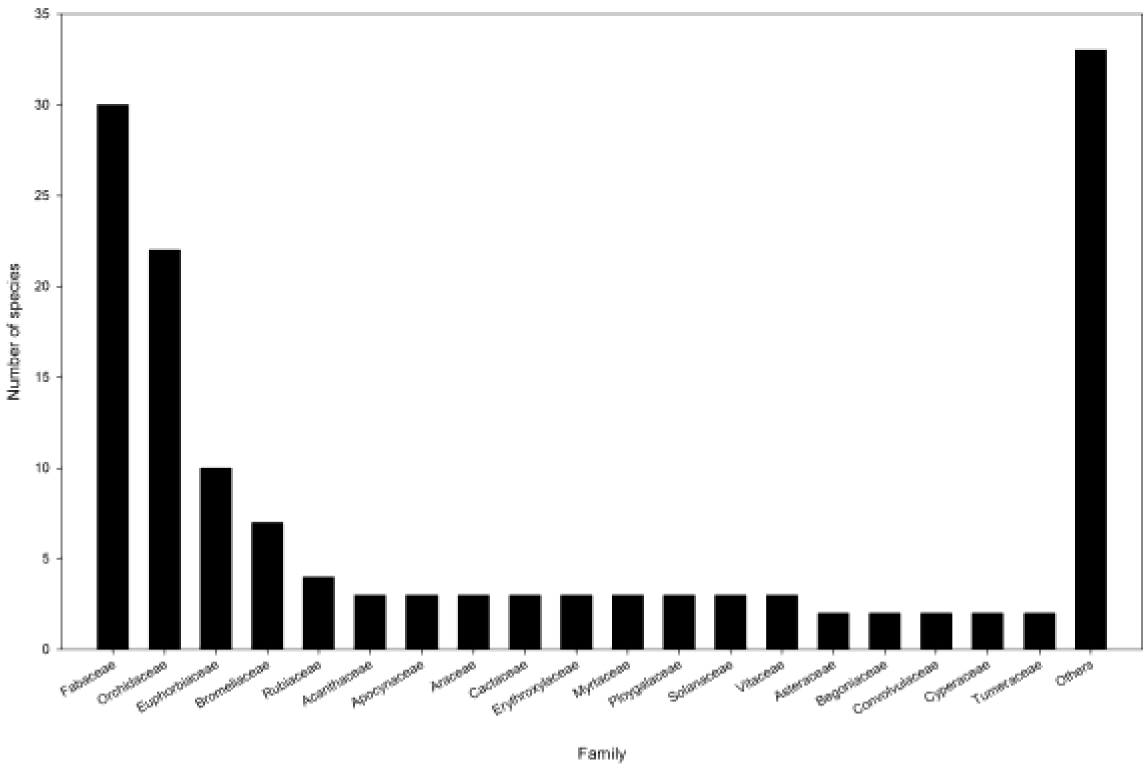
The available phosphorus content (P_M) was determined by a Mehlich-1 extraction solution. The soil organic carbon (SOC) was determined by wet combustion (YEOMANS; BREMNER, 1988). Total nitrogen (N) was determined by the Kjeldahl method and titration (EMBRAPA, 1997). The carbon to nitrogen ratio (C/N) was calculated on a mass basis. The P adsorption capacity of the soil was determined after stirring for 1 hour with 2.5 g of soil in 0.01 M $CaCl_2$ containing 60 mg of P L^{-1}. The suspension was filtered, and the remaining P in solution (P_{REM}) was determined by photocolorimetry (ALVAREZ et al., 2000).

Bulk density, particle density and water retention curve (-6, -10, -30, -60, -100, -300, -1500 kPa tensions) were determined in undisturbed soil samples collected by volumetric rings (EMBRAPA, 1997). Total porosity, available water, and non-available water were calculated from these results.

RESULTS

One hundred and forty-four species, distributed among fifty-two families, were identified and (Figure 2). One basal angiosperm (one sp.), two monilophytes (one sp. each one), nine monocotyledon and forty-one eudicotyledon were the major groups identified. *Senna, Mimosa* (4 sp. each one), *Chamaecrista*, *Erythroxylum*, *Habenaria*, *Solanum* e *Tillandsia* (3 spp.) were the genres most representative in the study area.

Figure 2 - Borborema province: Number of species of major families identified in study area, 2020.



Thirty-nine percent (n=53) and thirty-three percent (n=45) of species are phanerophytes and chamaephytes, respectively (Supplemental material – Table). The majority of species have a frequency between 6 to 10 individuals, indicating a high vegetable density in the study area. Herbaceous habits predominate (57 species or 41.9 % of total), followed by shrub habits (39 species or 28.7 %). Trees are dominantly short (between 0.25 cm to 5 m of height), with buds above the soil surface and protected from dehydration by cataphyll (VELOSO; RANGEL FILHO; LIMA, 1991).

Seventhly-six percent of total species are found in more than one Brazilian biome (Supplemental material - Table). Thirty-two species identified (23.5 % of total) are associated to other Brazilian biomes: Amazon rainforest (2.78 %), Atlantic rainforest (18.05 %), or Cerrado (Brazilian savanna) (2.67 %) ("Reflora - Virtual Herbarium", 2018).

Seventh percent of the precipitation is concentrated between February and July. Mean annual precipitation was 470.57 mm $year^{-1,}$ and mean monthly humidity is dominantly below 70 %. The annual temperature range is high, with maximum temperature (30.4° C) measured in March and minimum (15.4° C) in July; the mean temperature is 21.4 °C.

A Umbrisols (Organossolo, according to Brazilian System of Soil Classification) was described according to WRB in a summit of a slope, above 1,000 m.a.s.l., and associated with rock outcrops. Topsoil is classified as folic epipedon according to World Reference Soil Base.

The soil is composed of a sequence of O and A horizons above continuous rock (Table 1). The soil is shallow, and the transition between horizons was gradual and abrupt with the R layer. The soil color is black in umbric and folic epipedons. The structure is weakly developed, with granular type. The consistence of Umbrisols is soft, non-stick, and non-plastic.

Table 1 - Borborema province: Morphological properties of soil, 2020.

Horizon	**Depth (cm)**	**Boundary (distinctness, topography)**	**Color (moist, dry)**	**Structure (grade, size, type)**	**Consistence (dry, moist, wetter, cementation)**	**Roots (quantity, size)**	**Pores (quantity, size, shape)**
Epifolic Endoleptic Umbrisols (Pantoloamic, Pantohyperhumic)/ ORGANOSSOLO FÓLICO Sáprico lítico							
O	0-10	G-S	5Y 1/1, 5Y 2.5/1	1, m, gr	S, FR, so, po, NC	3, f-vf	3, m-f, DT
A	10-20	A-S	5Y 2.5/1, 5Y 3/1	1, f, gr	S, FR, so, po, NC	3, m-f-vf	3, co-m, DT
R	20+						

/= Distinctness: A=abrupt, G=gradual. Topography: S=smooth. Structure: Grade: 1=weak. Size: f=fine, m=medium. Type: gr=granular. Consistence: Dry: S=soft. Moist: FR= friable. Wetter: po=nonplastic, so=nonsticky. Cementation: NC= non-cemented. Roots and pores: 3=many, co=coarse, f=fine, m= medium, DT=dendritic tubular.

Roots are abundant, and their growth is limited by lithic contact. Fine and very fine roots are dominant in the soil profile. Medium roots occur above 10 cm of depth. Dendritic tubular pores are abundant, indicating widespread bioturbation. The soil profile is loam, and coarse sand is the main fraction of soil (Table 2). Umbrisol is extremely acid, dystrophic, KCl pH is below 5.0, and delta pH is negative in all horizons, indicating that negative charges dominate (Table 3). $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ is the base dominance in the exchange complex. SB, CEC, P_M, C, and N content decrease with the increase of depth. Values of P-rem below 20 mg L^{-1} indicates a high P adsorption capacity by organic compounds. The C/N ratio decreased with increasing depth, suggesting a lower degree of humification of organic residues at 10-20 cm depth.

Table 2 - Borborema province: Physical soil properties, 2020.

Horizon	**Depth** cm	**Coarse sand**	**Fine sand**	**Silt**	**Clay**	**Texture**
		------------------ % ---------------------				
Epifolic Endoleptic Umbrisols (Pantoloamic, Pantohyperhumic)/ ORGANOSSOLO FÓLICO Sáprico lítico						
O	0-10	34.1	14.8	29.5	21.6	loam
A	10-20	35.1	17.9	25.2	21.8	gravelly-sandy clay loam
R	20+					

Table 3 - Borborema province: Chemical soil properties of the study area and comparison data.

Horizon	**Depth**	**H_2O pH**	**KCl pH**	**P_M**	**K^+**	**Na^+**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**H + Al**	**SB**	**ECEC**	**CEC**	**V**	**m**	**C**	**N**	**C/N**	**P_{REM}**
	cm			------------ mg dm^{-3} ----------			---------------------------- cmolc dm^{-3} ---- ---------------------							------------- % ----- ---------					mg L^{-1}
Epifolic Endoleptic Umbrisols (Pantoloamic, Pantohyperhumic)/ ORGANOSSOLO FÓLICO Sáprico lítico																			
O	0-10	4.46	4.14	24.7	70	39.0	7.93	2.62	0.19	16.2	10.90	11.09	27.10	40	2	20.24	1.15	17.6	20.0
A	10-20	4.47	3.90	16.2	42	39.6	3.29	1.05	1.07	21.0	4.62	5.69	25.62	18	19	8.41	0.91	9.2	7.3
R	20+																		
Comparison data																			
BR		4.40-18	-	5.0-138	-	-	-	-	3.45-155	30.2-66	7.25-131	-	44.8-54	16-100	-	22.9-53	-	-	-
PA		4.40-15	3.20-18	2.0-25	78-18	14.4-1	1.05-47	0.45-16	1.30-33	21.5-6	1.75-28	3.20-4	23.20-8	8-20	46-26	20.04-23	-	-	24.6-23
PB		5.90-19	4.8-20	1.0-360	5-100	23-321	3.9-121	2.1-118	0.10-157	1.3-100	5.4-123	6.6-87	27.6-99	78-48	0-161	0.4-89	0.05-63	8.0	-

BR= Organic soil horizons in Brazil (Beutler and others 2017, n=280); PA= campo rupestre soils in Pará (Schaefer and others 2015, n=6); PB=Paraíba soils (EMBRAPA, 2017, n=327).

The soil profile presented particle and bulk densities values close to the density of light fraction and weakly humified soil organic compounds (BARRIOS; BURESH; SPRENT, 1996; VASILINIUC; PATRICHE, 2015) (Table 4). Field capacity and available water represent approximately 60 and 27 % of total porosity, respectively.

Table 4 - Physical soil properties determined in undisturbed samples.

Horizon	Depth	Particles density	Bulk density	Total porosity	Field capacity	Available water	Wilting point
	cm	---------------------- kg/ kg	----------------------	------------------- %		--------------------	
Epifolic Endoleptic Umbrisols (Pantoloamic, Pantohyperhumic)/ ORGANOSSOLO FÓLICO Sáprico lítico							
O	0-10	1.71	0.95	44.44	26.80	13.20	13.60
A	10-20	1.77	0.95	46.33	26.70	12.30	14.40
R	20+						

DISCUSSION

The presence of *Albizia*, *Dalbergia*, *Poecilanthe* and *Platymiscium* indicates a truly distinct floristic composition. Rocky outcrops have been cited as one of the most representative sites for Orchidaceae in Northeast Brazil (Rapini others 2008; Pessoa and Alves 2014). Orchidaceae is the family with the second-largest diversity in the study area, whereas it is composed of only a few species or even not present in Caatinga.

The dominance of Fabaceae and high similarity of species with Caatinga biome (CORDEIRO; SOUZA; FELIX, 2018; LUCENA et al., 2015; PEREIRA et al., 2018; SALES-RODRIGUES; BRASILEIRO; MELO, 2014) suggest that the composition of Campos Rupestres is highly influenced by distribution and connection of highlands, as well the heterogeneity of neighborhood ecosystems (ALVES; KOLBEK, 2010; NEVES et al., 2018; SILVEIRA et al., 2016). Besides that, species associated with neighborhood ecosystems showing a distinct physiognomy influenced by shallow dystrophic soils, high diurnal seasonality, and relief (ALVES et al., 2014; ALVES; CARDIN; KROPF, 2007; NEVES et al., 2018; VASCONCELOS, 2011).

The low fertility of the soil profile conditioned the development of survival strategies involving physiological and morphological adaptations (EITEN, 1983; SILVEIRA et al., 2016) (Supplemental material – Figures I to XI). Some nutrients, significantly P, which is extremely limiting for plant development, show negligible amounts (Table 3).

The decrease of soil fertility with the increase in depth suggests that chemical soil properties are straight associated with organic residue input. So, biogeochemical cycling of nutrients in dystrophic soils seems essential for vegetation maintenance against leaching (DE SOUZA et al., 2018; LUCAS, 2001; MANZONI et al., 2010; SARCINELLI et al., 2013). The abundance of fine and very fine roots in soil profile reinforces this hypothesis (FERREIRA et al., 2018; HASENMUELLER and SCOTT, 2017).

The adaptive mechanisms of plants to hydric stress is attributed to low precipitation and low water availability in soils (Supplemental material – Figures I to XI). Annual precipitation in 2017 is 22 % and until 70 % lower than predicted precipitation (FUNK et al., 2015) and mean annual precipitation registered in Campos Rupestre sites around Brazil (ALVES et al., 2014), respectively. On the other hand, the high mean monthly humidity suggests high input of water no measured by meteorological station as the condensation of fog (Supplemental material – Figure XII).

In general, organic materials and soil horizons with high organic content have high water availability (BENITES et al., 2007; MINASNY; MCBRATNEY, 2018). However, the high wilting point indicates that less than 50% of water retained by soil is available for plants (Table 4). So, the soil seems to be essential to the genesis of the Campos Rupestres. Dystrophia and low water availability favor the occupation of species of more efficient nutrient uptake, reduced nutrient consumption, and efficient water storage. Improvements in nutrient uptake are facilitated by root adaptations such as nitrogenfixing root nodules, mycorrhizae, and clustered roots (NOGUEIRA et al., 2005; OLIVEIRA et al., 2015). Consumption is reduced by very slow growth rates (MORELLATO; SILVEIRA, 2018) and the efficient use of low-availability nutrients (ATAÍDE; CASTRO; FERNANDES, 2011; BENZING, 1990a). Absorption and retention of water are complemented by roots and pseudobulbs that exploit fog (GUGLIERI; ZULOAGA; LONGHI-WAGNER, 2004) and reduce water vapor loss (BENZING, 1990b). The occurrence of species with these adaptive mechanisms in oligotrophic soils suggests climatic stability and should be investigated in future studies (SILVEIRA et al., 2016).

CONCLUSION

This work highlights the high heterogeneity of ecosystems that composes the Caatinga biome, establishing several phytophysiognomies (DE QUEIROZ et al., 2017; SILVA et al., 2014). Shrubs xerophilous vegetation on shallow eutrophic soils of flat and lowlands bellow 200 m.a.s.l. are replaced by semideciduous forests on plateaus which range in altitude from 500 to 750 m.a.s.l. (ARAÚJO FILHO et al., 2017; DOMBROSKI et al., 2011) This denser vegetation is favored by lower evapotranspiration, orographic rainfall, and more developed soils with higher potential for water storage (RIBEIRO et al., 2016; SCHULZ et al., 2016). The discovery of Campos Rupestres in the Caatinga biome further elevates this heterogeneity and indicates the needy for researches in this part of Brazil, particularly those that integrate soil to ecological processes. The areas covered by rupestrian fields are highly sensitive and require special attention in the conservation strategies of biotic and abiotic resources that compose these ecosystems.

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SUPPLEMENTAL MATERIAL

Table. Composition of *campos rupestres* in study area.

Family	Cientific name	Habit	Life form	Biome	Frequency		
					1-5	6-10	11-20
Araliaceae	*Aralia warmingiana*	Tree	Chamaephyte	Caatinga, Atlantic rainforest	x		
Acanthaceae	*Harpochilus neesianus* Mart. ex Nees	Herb	Chamaephyte	Caatinga		x	
Acanthaceae	*Justicia aequilabris* (Nees) Lindau	Herb	Therophyte	Amazon rainforest, Caatinga, Cerrado		x	
Acanthaceae	*Ruellia geminiflora* Kunth	Herb	Therophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Alstroemeriaceae	*Bomarea edulis* (Tussac) Herb.	Climbing herb	Geophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Anacardiaceae	*Schinopsis brasiliensis* Engl.	Tree	Phanerophyte	Caatinga, Cerrado		x	
Anemiaceae	*Anemia* sp.	Herb	Hemicriptófito	Atlantic rainforest			x
Apocynaceae	*Aspidosperma* sp.	Tree	Phanerophyte	Atlantic rainforest		x	
Apocynaceae	*Mandevilla dardanoi* M.F.Sales et al.	Liana	Liana	Caatinga		x	
Apocynaceae	*Marsdenia caatingae* Morillo	Liana	Liana	Caatinga, Atlantic rainforest			x
Araceae	*Anthurium affine* Schott	Herb	Hemicriptófito	Caatinga, Cerrado, Atlantic rainforest		x	
Araceae	*Philodendron leal-costae* Mayo & G.M.Barroso	Herb	Chamaephyte	Atlantic rainforest		x	
Araceae	*Thaumatophyllum bipinnatifidum* (Schott ex Endl.) Sakur., Calazans & Mayo	Herb	Chamaephyte	Cerrado, Atlantic rainforest		x	
Arecaceae	*Syagrus coronata* (Mart.) Becc.	Tree	Phanerophyte	Caatinga, Cerrado		x	
Aristolochiaceae	Aristolochia birostris Duch.	Liana	Liana	Caatinga, Cerrado, Atlantic rainforest		x	
Asteraceae	*Cyrtocymura scorpioides* (Lam.) H.Rob.	Herb	Therophyte	Amazon rainforest, Cerrado		x	
Asteraceae	*Chresta pacourinoides* C.M. Siniscalchi & B. Loeuille	Herb	Therophyte	Caatinga, Atlantic rainforest		x	
Begoniaceae	*Begonia lealii* Brade	Herb	Chamaephyte	Caatinga		x	
Begoniaceae	*Begonia ulmifolia* Willd.	Herb	Chamaephyte	Caatinga, Atlantic rainforest		x	
Bignoniaceae	*Handroanthus impetiginosus* (Mart. ex DC.) Mattos	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Boraginaceae	*Varronia globosa* Jacq.	Shrub	Phanerophyte	Caatinga, Atlantic rainforest		x	
Bromeliaceae	*Tillandsia gardneri* Lindl.	Herb	Chamaephyte	Caatinga, Cerrado, Atlantic rainforest, Pampa		x	
Bromeliace	*Dyckia limae* L.B.Sm.	Herb	Chamaephy	Caatinga		x	

ae			te				
Bromeliaceae	*Encholirium spectabile* Mart. ex Schult. & Schult.f.	Herb	Chamaephyte	Caatinga, Cerrado, Atlantic rainforest			x
Bromeliaceae	*Hohenbergia horrida* Harms	Herb	Chamaephyte	Caatinga		x	
Bromeliaceae	*Orthophytum disjunctum* L.B.Sm.	Herb	Chamaephyte	Caatinga, Atlantic rainforest		x	
Bromeliaceae	*Tillandsia stricta* Sol.	Herb	Chamaephyte	Caatinga, Cerrado, Atlantic rainforest, Pampa		x	
Bromeliaceae	*Tillandsia tenuifolia* L.	Herb	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Burseraceae	*Commiphora leptophloeos* (Mart.) J.B.Gillett	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Cerrado		x	
Cactaceae	*Cereus jamacaru* DC.	Tree	Phanerophyte	Caatinga, Cerrado		x	
Cactaceae	*Melocactus bahiensis* (Britton & Rose) Luetzelb.	Herb	Chamaephyte	Caatinga, Cerrado		x	
Cactaceae	*Pilosocereus chrysostele* (Vaupel) Byles & G.D.Rowley	Shrub	Phanerophyte	Caatinga		x	
Celastraceae	*Maytenus* sp.	Shrub	Chamaephyte	Atlantic rainforest		x	
Clusiaceae	*Clusia hilariana* Schltdl.	Tree	Phanerophyte	Atlantic rainforest			x
Commelinaceae	*Commelina erecta* L.	Herb	Geophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Convolvulaceae	*Ipomoea bahiensis* Willd. ex Roem. & Schult.	Climbing herb	Therophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Convolvulaceae	*Evolvulus filipes* Mart.	Herb	Therophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Cyperaceae	*Bulbostylis sp.*	Herb	Therophyte	Atlantic rainforest		x	
Cyperaceae	*Cyperus schomburgkianus* Nees	Herb	Therophyte	Caatinga, Cerrado, Pantanal		x	
Eriocaulaceae	*Paepalanthus* sp.	Herb	Therophyte	Atlantic rainforest		x	
Erythroxylaceae	*Erythroxylum revolutum* Mart.	Shrub	Phanerophyte	Caatinga, Atlantic rainforest		x	
Erythroxylaceae	*Erythroxylum suberosum* A.St.-Hil.	Shrub	Phanerophyte	Amazon rainforest, Cerrado			x
Erythroxylaceae	*Erythroxylum pulchrum* A.St.-Hil.	Tree	Phanerophyte	Caatinga		x	
Euphorbiaceae	*Croton grewioides* Baill.	Shrub	Phanerophyte	Caatinga			x
Euphorbiaceae	*Sapium glandulosum* (L.) Morong	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Euphorbiaceae	*Sebastiania macrocarpa* Müll.Arg.	Shrub	Phanerophyte	Caatinga		x	
Euphorbiaceae	*Croton heliotropiifolius* Kunth	Shrub	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	

Euphorbiaceae	*Cnidoscolus halteris* Fern.Casas	Shrub	Chamaephyte	Atlantic rainforest		x	
Euphorbiaceae	*Cnidoscolus urens* (L.) Arthur	Shrub	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Euphorbiaceae	*Dalechampia schenckiana* Pax & K.Hoffm.	Climbing herb	Therophyte	Atlantic rainforest		x	
Euphorbiaceae	*Euphorbia heterodoxa* Müll.Arg.	Herb	Chamaephyte	Caatinga		x	
Euphorbiaceae	*Euphorbia phosphorea* Mart.	Shrub	Phanerophyte	Caatinga			x
Euphorbiaceae	*Stillingia trapezoidea* Ule	Shrub	Chamaephyte	Caatinga			x
Fabaceae	*Machaerium hirtum* (Vell.) Stellfeld	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Fabaceae	*Mimosa tenuiflora* (Willd.) Poir.	Shrub	Phanerophyte	Caatinga, Cerrado		x	
Fabaceae	*Erythrina velutina* Willd.	Tree	Phanerophyte	Caatinga, Cerrado		x	
Fabaceae	*Albizia polycephala* (Benth.) Killip ex Record	Tree	Phanerophyte	Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Anadenanthera colubrina* (Vell.) Brenan	Shrub	Phanerophyte	Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Bauhinia subclavata* Benth.	Shrub	Phanerophyte	Caatinga, Cerrado		x	
Fabaceae	*Bowdichia virgilioides* Kunth	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Fabaceae	*Canavalia brasiliensis* Mart. ex Benth.	Liana	Liana	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Centrosema arenarium* Benth.	Climbing herb	Therophyte	Caatinga, Cerrado, Atlantic rainforest			x
Fabaceae	*Chamaecrista amiciella* (H.S.Irwin & Barneby) H.S.Irwin & Barneby	Herb	Therophyte	Caatinga		x	
Fabaceae	*Chamaecrista calycioides* (DC. ex Collad.) Greene	Herb	Therophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Chamaecrista zygophylloides* (Taub.) H.S.Irwin & Barneby	Shrub	Phanerophyte	Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Chloroleucon foliolosum* (Benth.) G.P.Lewis	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Crotalaria vitellina* Ker Gawl.	Herb	Therophyte	Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Dalbergia catingicola*	Tree	Phanerophyte	Atlantic rainforest		x	
Fabaceae	*Dioclea lasiophylla* Mart. ex Benth.	Liana	Liana	Caatinga, Atlantic rainforest		x	
Fabaceae	*Enterolobium* sp.	Tree	Phanerophyte	Atlantic rainforest		x	
Fabaceae	*Libidibia ferrea* (Mart. ex Tul.) L.P.Queiroz	Tree	Phanerophyte	Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Mimosa arenosa* (Willd.)	Shrub	Phanerophyte	Caatinga, Cerrado,		x	

	Poir.		te	Atlantic rainforest			
Fabaceae	*Mimosa borboremae* Harms	Shrub	Hemicriptófito	Caatinga		x	
Fabaceae	*Mimosa sensitiva* L.	Climbing herb	Therophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Muellera campestris* (Mart. ex Benth.) M.J. Silva & A.M.G. Azevedo	Tree	Phanerophyte	Atlantic rainforest		x	
Fabaceae	*Piptadenia stipulacea* (Benth.) Ducke	Shrub	Phanerophyte	Caatinga		x	
Fabaceae	*Platymiscium floribundum* Vogel	Tree	Phanerophyte	Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Poecilanthe grandiflora* Benth	Tree	Phanerophyte	Caatinga		x	
Fabaceae	*Senegalia polyphylla* (DC.) Britton & Rose	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Fabaceae	*Senna martiana* (Benth.) H.S.Irwin & Barneby	Shrub	Phanerophyte	Caatinga		x	
Fabaceae	*Senna rizzinii* H.S.Irwin & Barneby	Shrub	Chamaephyte	Caatinga, Cerrado		x	
Fabaceae	*Senna angulata* (Vogel) H.S. Irwin & Barneby	Shrub	Phanerophyte	Atlantic rainforest			x
Fabaceae	*Senna spectabilis* (DC.) H.S.Irwin & Barneby	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Fabaceae	*Stylosanthes viscosa* (L.) Sw.	Herb	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Lamiaceae	*Leptohyptis macrostachys* (Benth.) Harley & J.F.B.Pastore	Herb	Therophyte	Caatinga, Cerrado		x	
Linderniaceae	*Ameroglossum pernambucense* Eb. Fisch. et al.	Shrub	Therophyte	Caatinga		x	
Loasaceae	*Aosa rupestris* (Gardner) Weigend	Herb	Therophyte	Caatinga, Atlantic rainforest		x	
Malpighiaceae	*Byrsonima stipulacea* A.Juss.	Tree	Phanerophyte	Amazon rainforest, Atlantic rainforest		x	
Marantaceae	*Maranta protracta* Miq.	Herb	Geophyte	Amazon rainforest, Atlantic rainforest		x	
Melastomataceae	*Tibouchina gardneriana* (Triana) Cogn.	Shrub	Chamaephyte	Atlantic rainforest		x	
Myrtaceae	*Campomanesia eugenioides* (Cambess.) D.Legrand ex Landrum	Tree	Phanerophyte	Caatinga, Cerrado, Atlantic rainforest		x	
Myrtaceae	*Eugenia* sp.	Shrub	Phanerophyte	Atlantic rainforest		x	
Myrtaceae	*Myrcia tomentosa* (Aubl.) DC.	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest			x
Nyctaginaceae	*Guapira laxa* (Netto) Furlan	Tree	Phanerophyte	Caatinga		x	
Oleaceae	*Ximenia americana* L.	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Orchidaceae	*Alatiglossum barbatum*	Herb	Chamaephyte	Atlantic rainforest		x	

Orchidaceae	*Brasilidium gravesianum/Sin. Gomesa praetexta* (Rchb.f.) M.W.Chase & N.H.Williams	Herb	Chamaephyte	Caatinga		x		
Orchidaceae	*Brassavola tuberculata* Hook.	Herb	Chamaephyte	Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Campylocentrum crassirhizum* Hoehne	Herb	Chamaephyte	Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Catasetum purum* Nees & Sinnings	Herb	Chamaephyte	Atlantic rainforest		x		
Orchidaceae	*Catasetum uncatum* Rolfe.	Herb	Chamaephyte	Atlantic rainforest		x		
Orchidaceae	*Coppensia flexuosa* (Lodd.) Campacci	Herb	Chamaephyte	Atlantic rainforest		x		
Orchidaceae	*Cyrtopodium gigas* (Vell.) Hoehne	Herb	Chamaephyte	Cerrado, Atlantic rainforest		x		
Orchidaceae	*Cyrtopodium holstii* L.C.Menezes	Herb	Chamaephyte	Amazon rainforest, Caatinga, Atlantic rainforest		x		
Orchidaceae	*Encyclia oncidioides* (Lindl.) Schltr.	Herb	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Epidendrum fulgens* Brongn.	Herb	Chamaephyte	Atlantic rainforest		x		
Orchidaceae	*Epidendrum secundum*	Herb	Chamaephyte	Atlantic rainforest		x		
Orchidaceae	*Gomesa barbata* (Lindl.) M.W.Chase & N.H.Williams	Herb	Chamaephyte	Caatinga, Cerrado		x		
Orchidaceae	*Gomesa hydrophila*	Herb	Chamaephyte	Caatinga, Cerrado		x		
Orchidaceae	*Habenaria hexaptera* Lindl.	Herb	Geophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Habenaria obtusa* Lindl.	Herb	Geophyte	Amazon rainforest, Caatinga, Cerrado		x		
Orchidaceae	*Habenaria petalodes* Lindl.	Herb	Geophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Oeceoclades maculata* (Lindl.) Lindl.	Herb	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Anathallis rubens* (Lindl.) Pridgeon & M.W.Chase	Herb	Chamaephyte	Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Prescottia petalodes*	Herb	Chamaephyte	Atlantic rainforest		x		
Orchidaceae	*Sacoila lanceolata* (Aubl.) Garay	Herb	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x		
Orchidaceae	*Sarcoglottis schwackei*	Herb	Geophyte	Atlantic rainforest		x		
Orchidaceae	*Vanilla palmarum* (Salzm. ex Lindl.) Lindl.	Herb	Chamaephyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x		
Turneraceae	*Turnera cearensis* Urb.	Herb	Chamaephyte	Caatinga, Atlantic rainforest		x		
Passifloraceae	*Passiflora silvestris* Vell.	Liana	Liana	Cerrado, Atlantic rainforest		x		
Turneraceae	*Piriqueta duarteana* (Cambess.) Urb.	Herb	Therophyte	Amazon rainforest, Caatinga, Cerrado,		x		

				Atlantic rainforest			
Phyllanthaceae	*Phyllanthus claussenii* Müll.Arg.	Shrub	Chamaephyte	Atlantic rainforest			x
Piperaceae	*Piperomia* sp.	Herb	Therophyte	Atlantic rainforest		x	
Poaceae	*Melinis glutinosa*	Herb	Therophyte	Cerrado		x	
Polygalaceae	*Acanthocladus dichromus* (Steud.) J.F.B.Pastore	Shrub	Phanerophyte	Caatinga	x		
Polygalaceae	*Polygala paniculata* L.	Herb	Therophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pampa		x	
Polygalaceae	*Securidaca diversifolia* (L.) S.F.Blake	Liana	Liana	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Polygonaceae	*Ruprechtia laxiflora* Meisn.	Tree	Phanerophyte	Caatinga, Atlantic rainforest		x	
Polypodiaceae	*Microgramma vacciniifolia* (Langsd. & Fisch.) Copel.	Herb	Chamaephyte	Atlantic rainforest		x	
Rubiaceae	Randia armata (Sw.) DC.	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Rubiaceae	*Tocoyena sellowiana* (Cham. & Schltdl.) K.Schum.	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Atlantic rainforest		x	
Rubiaceae	*Chiococca alba* (L.) Hitchc.	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pantanal		x	
Rubiaceae	*Staelia* sp.	Herb	Therophyte	Atlantic rainforest		x	
Rutaceae	*Zanthoxylum rhoifolium* Lam.	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest, Pampa, Pantanal		x	
Salicaceae	*Prockia crucis* P.Browne ex L.	Shrub	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Sapindaceae	*Allophylus quercifolius* (Mart.) Radlk.	Tree	Phanerophyte	Caatinga, Cerrado		x	
Sapotaceae	*Manilkara rufula* (Miq.) H.J.Lam	Tree	Phanerophyte	Caatinga, Cerrado		x	
Schoepfiaceae	*Schoepfia brasiliensis* A.DC.	Tree	Phanerophyte	Amazon rainforest, Caatinga, Cerrado, Atlantic rainforest		x	
Solanaceae	*Solanum jabrense* Agra & M.Nee	Shrub	Chamaephyte	Caatinga, Atlantic rainforest	x		
Solanaceae	*Solanum rhytidoandrum* Sendtn.	Shrub	Chamaephyte	Amazon rainforest, Caatinga, Cerrado		x	
Solanaceae	*Solanum stipulaceum* Willd. ex Roem. & Schult.	Shrub	Chamaephyte	Caatinga, Cerrado, Atlantic rainforest		x	
Vitaceae	*Clematicissus simsimiana*	Liana	Liana	Caatinga		x	
Vitaceae	*Cissus blanchetiana* Planch.	Liana	Liana	Caatinga, Atlantic rainforest		x	
Vitaceae	*Cissus subrhomboidea*	Liana	Liana	Caatinga, Atlantic rainforest		x	

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Figure I - a – *Harpochilus neesianus* Mart. ex Nees; b – *Bomarea edulis* (Tussac) Herb.; c-d – *Chresta pacourinoides* C.M. Siniscalchi & B. Loeuille; e-f – *Begonia lealii* Brade

Figure III - a – *Brasiliopuntia brasiliensis* (Willd.) A.Berger; b – *Tacinga palmadora* (Britton & Rose) N.P.Taylor & Stuppy; c-d – *Celtis alnifolia* (Wedd.) Miq.; e-f – *Clusia hilariana* Schltdl.

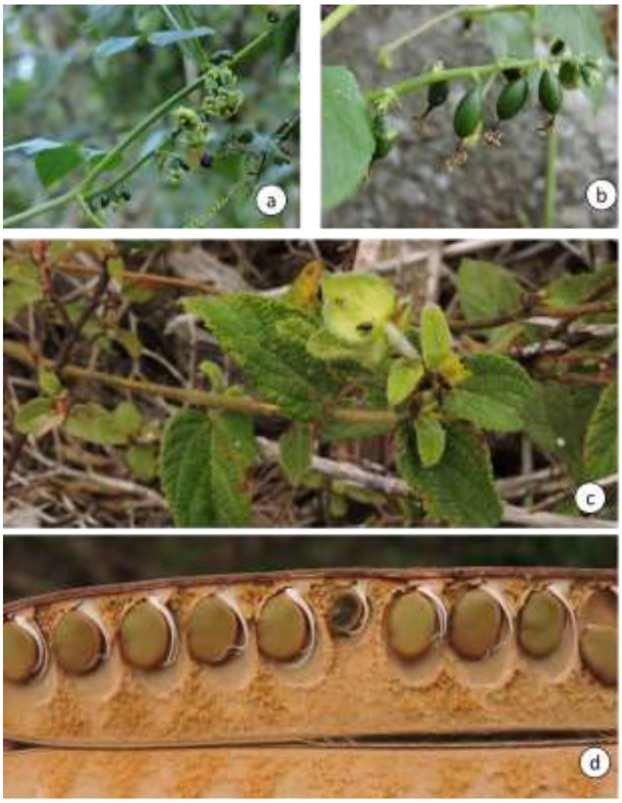

Figure V - a – *Centrosema arenarium* Benth.; b-c – *Crotalaria vitellina* Ker Gawl; d – *Dalbergia* sp.; e – *Dioclea lasiophylla* Mart. ex Benth.

Figure VII - a – *Brasilidium gravesianum*; b – *Brassavola tuberculata* Hook.. fotos:

Figure IX - a-b – *Acianthera ochreata* (Lindl.) Pridgeon & M.W.Chase; a-b – *Coppensia flexuosa* (Lodd.) Campacci; e-f – *Epidendrum fulgens* Brongn.

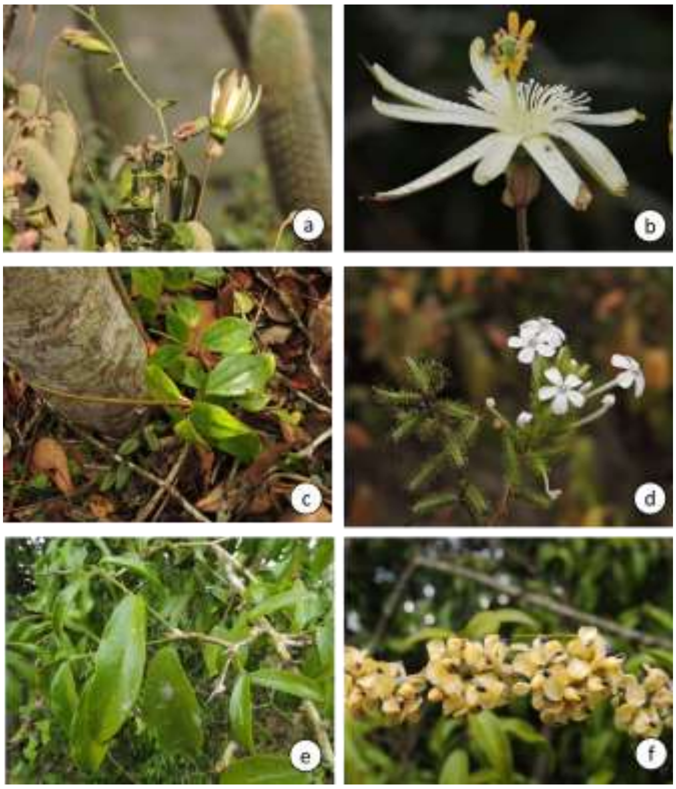

Figure XI - a-b – *Manilkara rufula* (Miq.) H.J.Lam; c-d. Schoepfia brasiliensis A.DC.; e – *Solanum stipulaceum* Willd. ex Roem. & Schult.; f – *Urera nitida* (Vell.) P.Brack

Figure XII. Landscape in study area.

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