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ECOLOGÍA

Flora and similarities of a rocky outcrop in the Caatinga, eastern region of South America

Flora y similitudes de un afloramiento rocoso en la Caatinga, región oriental de Suramérica

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ABSTRACT

Rocky environments show great habitat heterogeneity and very specific microclimatic characteristics that select for appropriately adapted floristic assemblages. A floristic survey was carried out on a rock outcrop in the driest portion of the Cariri Environmental Protection Area (APA) in Paraíba State, northeastern Brazil, to determine its similarity to other Caatinga sites. We recorded 128 species distributed among 103 genera and 52 families. Fabaceae, Convolvulaceae, Malvaceae, Euphorbiaceae, Asteraceae, Cactaceae, Bromeliaceae, Rubiaceae, and Poaceae were the most representative families in terms of numbers of species, with a high representation of herbaceous and shrub components and a predominance of typically Neotropical species, in addition to endemic taxa. *Pectis linifolia* L. (Asteraceae) is recorded here for the first time in the Paraíba state, Brazil. Similarity analysis evidenced that the study area, located in an extremely dry Caatinga zone, evidenced floristic relationships with other rocky outcrops in more humid areas, suggesting that habitat type is important for selecting specific groups, following the theory of refuges.

Keywords: Neotropical flora, refuges, phytogeography.

RESUMEN

Los ambientes rocosos muestran una gran heterogeneidad de hábitats y características microclimáticas muy específicas. Estas condiciones seleccionan especies muy bien adaptadas para componer estos conjuntos florísticos, en comparación con otras áreas de su entorno. En este contexto, se realizó un levantamiento florístico en un afloramiento rocoso en Área de Protección Ambiental (APA) de Cariri

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- Paraíba (07°20’17”–07°12’10.3” Sur, 36°25’40”–36° 10’02.2” Oeste), una región ubicada en la zona más seca de la Caatinga, en el noreste de Brasil, con el objetivo de ampliar el conocimiento sobre la flora local y analizar su similitud con otras flores de Caatinga. Se registraron 128 especies distribuidas en 103 géneros y 52 familias. Fabaceae, Convolvulaceae, Malvaceae, Euphorbiaceae, Asteraceae, Cactaceae, Bromeliaceae, Rubiaceae y Poaceae son las más representativas en cuanto al número de especies. *Pectis linifolia* L. (Asteraceae) es reportada aquí por primera vez en el estado de Paraíba, Brasil. Predominaron los componentes herbáceos y arbustivos. Sin embargo, hay un predominio de especies típicamente tropicales, además de especies endémicas. El análisis de similitud demostró que el área de estudio, ubicada en una zona estrictamente seca, muestra relaciones florísticas con otros afloramientos rocosos en áreas más húmedas. Esto sugiere que el tipo de hábitat fue importante para la selección de grupos específicos basados en la teoría de los refugios.

Palabras clave: Flora neotropical, refugios, fitogeografía.

INTRODUCTION

Rocky environments are geological-geomorphological areas with significant expositions of rocky surfaces intercalated with erosional sediments (Thomas 1994). Those environments can be geologically diverse, varying in terms of their petrochemistry, size, time of formation, and the particular climate to which they are exposed (Shure 1999). Such rocky landscapes can be encountered throughout the world, especially in the dry climates found in Australia (Lima *et al.* 2009b), Africa (Porembski *et al.* 1996), and South America (Ibisch *et al.* 1995, Giraldo-Cañas 2008).

Porembski (2007) pointed out that few plant species can survive the ecological filters found in rocky areas, and even more so if the site is associated with a semiarid climate. Rocky outcrops in semiarid regions are subject to extreme daily temperature variations, intense insolation, and water deficits (Giraldo-Cañas 2001, 2008). Many plant species occurring in these environments therefore evidence several mechanisms to avoid water losses to the external environment, with a predominance of species with C3 and CAM metabolism and dormancy mechanisms (Porembski *et al.* 1996, Giraldo-Cañas 2001).

When the rocky outcrops of Brazil are compared to those found in the rest of South America, or other continents, the co-occurrence of many of the same botanical families can be noted (Larson *et al.* 1999) – predominantly those circumscribed to the order Poales (Porembski 2007, Ribeiro *et al.* 2007, Scarano 2007). In this context, several authors have noted that the taxonomic groups associated with Brazilian rocky outcrops are the same as those encountered in Venezuela (Barthlott *et al.* 1993, Sarthou and Villiers 1998) and Colombia (Giraldo-Cañas 2001, 2008), although the exact species compositions vary due to local topographic heterogeneity.

According to Oliveira and Godoy (2007), rocky environments evidence marked environmental heterogeneities with distinct microhabitats that favor the establishment of different plant assemblages and induce important speciation processes (Larson *et al.* 1999). Plant species in those ecosystems most commonly occur in three basic types of habitats: 1) directly on rock surfaces; 2) in fissures; or, 3) on “islands” of soil (Giraldo-Cañas 2008), reflecting the affinities of those plants with the substrate (Barthlott *et al.* 1993, Porembski *et al.* 1996, Pigott 2000, Porembski 2007). The species that grow in direct contact with rock surfaces are known as rupicolous (or saxicolous) and constitute vegetation “islands” that can cover just a few square centimeters to hundreds of square meters (Meirelles *et al.* 1999).

Those rocky environments are considered refuge zones for the local fauna and flora, and harbor populations very distinct from the surrounding vegetation matrix (Burke 2002, Stewart *et al.* 2010, Keppel *et al.* 2012, Speziale and Ezcurra 2015), not only from the point of view of richness, but also in terms of their intrinsic life histories, where the emergence of the biotope shaped the biocenosis that colonized the place and that undergoes constant environmental and ecological natural selections over time (Andrade-Lima 1981, Ab’Sáber 1992).

Researchers have undertaken numerous floristic inventories in these rocky areas in southeastern (Oliveira and Godoy 2007, Pifano *et al.* 2007) and northeastern Brazil (França *et al.* 1997, Agra *et al.* 2004, Lemos 2004, Barbosa *et al.* 2007, Neves and Conceição 2007, Ribeiro *et al.* 2007, Rodal and Sales 2007, Araújo *et al.* 2008, Porto *et al.* 2008, Costa *et al.* 2009, Gomes and Alves 2010) in the Caatinga biogeographic province. Data are still insufficient, however, given the continental size of that country, and information on the floristic similarities between those rocky environments are still scarce.

We present here a floristic study of a rocky outcrop located in the Cariri Environmental Protection Area (APA), Paraíba State, in northeastern Brazil, designed to characterize its flora and compare it with other Caatinga areas with similar biogeographic conditions to determine if those rocky environments evidence similar floristic compositions.

MATERIAL AND METHODS

Study area

The Cariri Paraibano micro-region is a sub-region of the eastern Borborema Plateau, which is located in the south-central portion of Paraiba State, with Caatinga vegetation. The climate there is characterized by high temperatures (average 25 °C), low rainfall (between 250–800 mm annually), nearly constant winds (average 20 km/h), and high levels of solar radiation (2800–3200 h/year) (Ab'Sáber 1992). The Cariri region occupies an area of approximately 13 845 km² and is considered the driest site within the Caatinga domain. Elevations vary from 400 to 600 m above sea level (Alves 2009). The rocky environment sampled was located on a low inselberg feature called "Sítio Bravo" (Figs. 1, 2), which extends over an area of 7 ha (7°20'17"– 7°12'10.3" S, 36°25'40"– 36°10'02.2" W) with an average elevation of 478 m.a.s.l., between the municipalities of Boa Vista and Cabaceiras.

The name of the study area is "Sítio Bravo". This site is an elongated elliptical (whale-like) dome, similar to the low inselbergs (Bornhardts) initially described in Namibia, Africa (Lima *et al.* 2009b). Few regions in the world have geological characteristics and geomorphological features

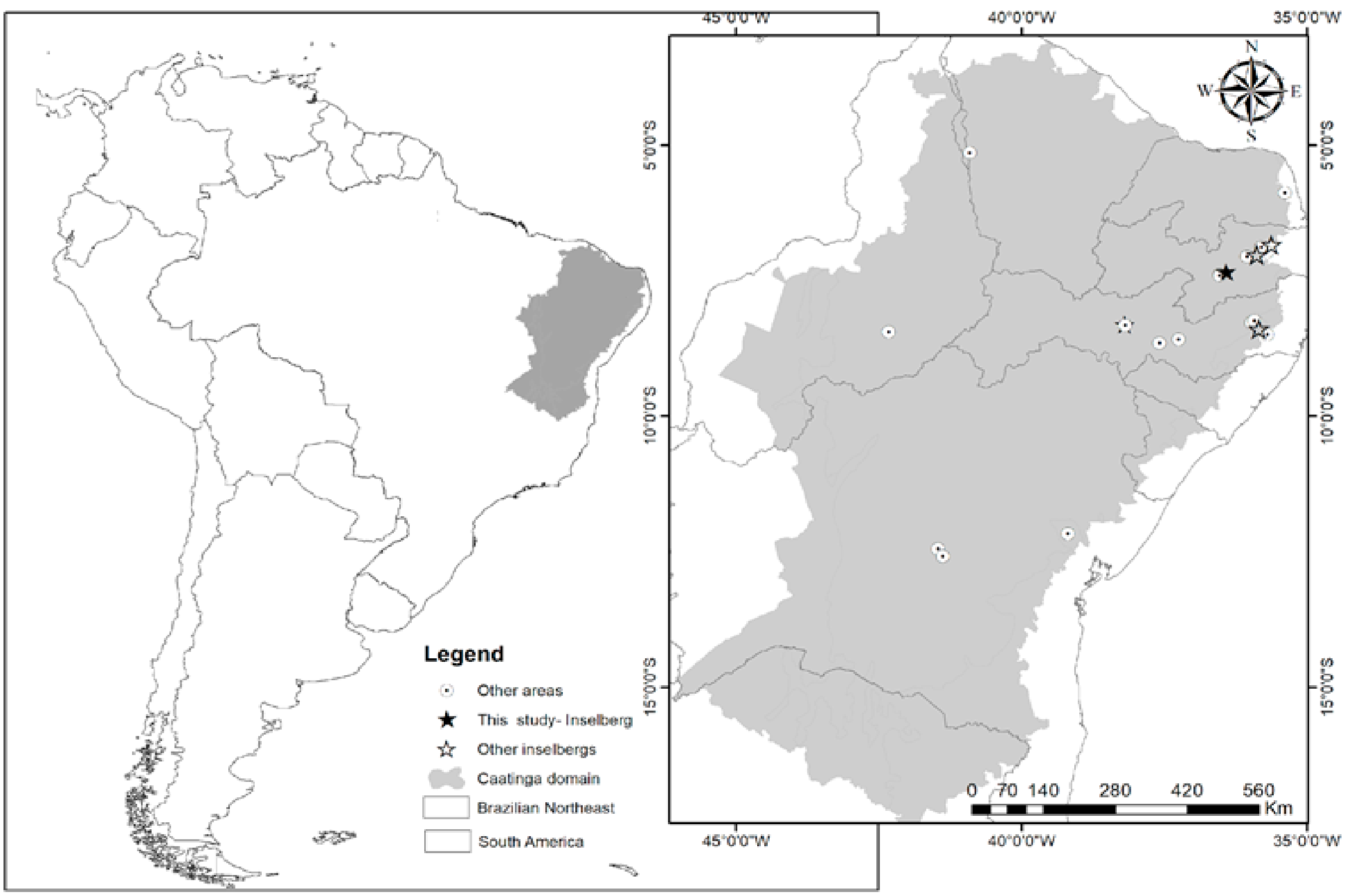

Figure 1. Location map of the "Sítio Bravo" study site, Environmental Conservation Area (APA) of Cariri, municipality of Boa Vista, Paraíba state, Brazil, and the areas considered in the similarity analysis.

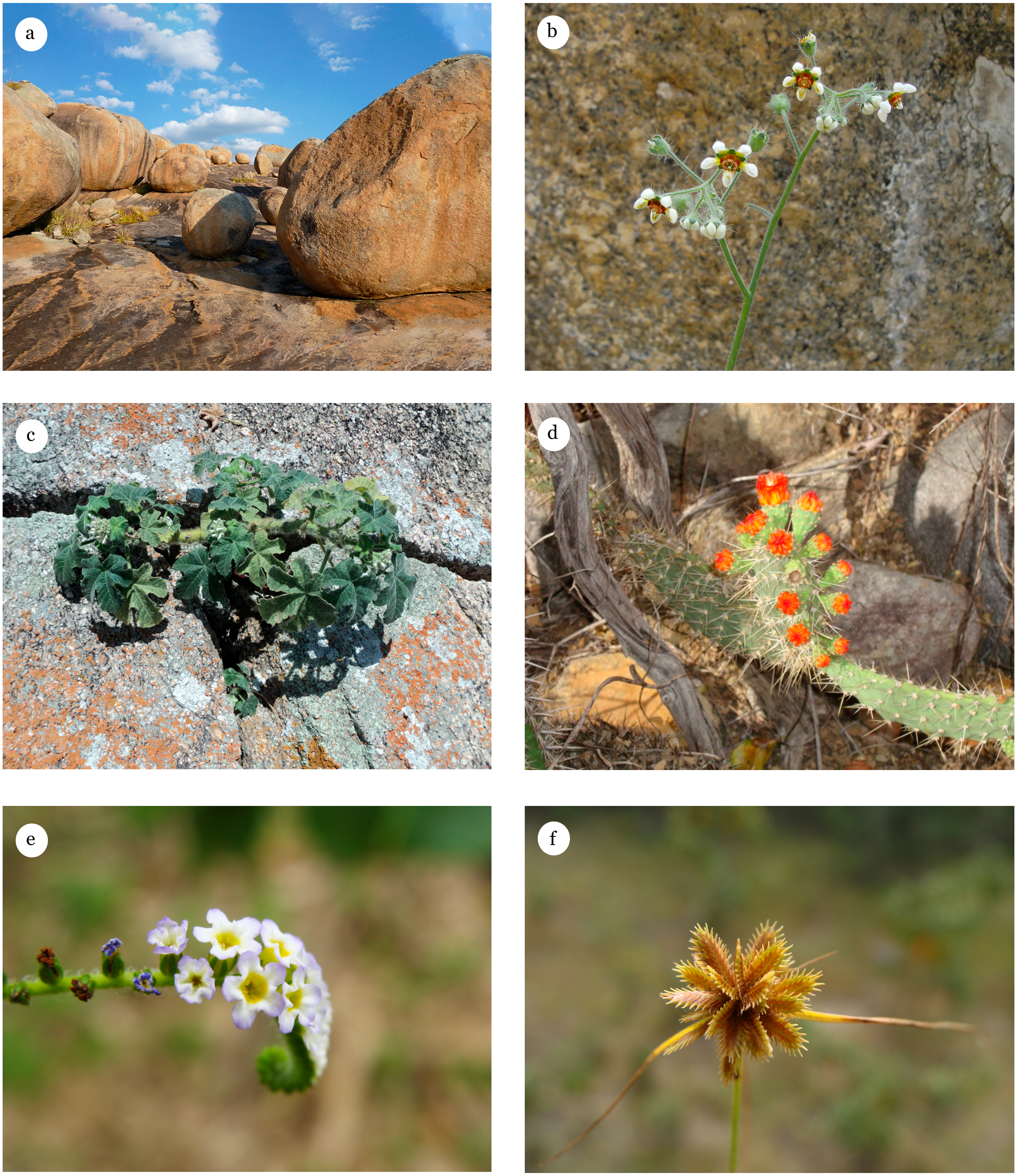

Figure 2. **(a)** Aspects of the "Sítio Bravo" study site, Environmental Conservation Area (APA) of Cariri, municipality of Boa Vista, Paraíba state, Brazil, showing its rocky outcrop popularly known as "matacão". **(b)** *Aosa rupestris* (Loasaceae). **(c)** *Cnidoscolus urens* (Euphorbiaceae). **(d)** *Tacinga palmadora* (Cactaceae). **(e)** *Heliotropium angiospermum* (Boraginaceae). **(f)** *Cyperus uncinulatus* (Cyperaceae).

similar to the study area and there are some similarities with the Devil's Marbles in Australia, the Erongo Mountains in Namibia, and the Hoggar region of Algeria (Lima *et al.* 2009b, Lages *et al.* 2013).

Particularly in this study, it is not cliff or hillside vegetation, but a singular vegetation that appears between rock crevices or in the rock surfaces of a specific type of rocky outcrop that exists only in practically three places in the world mentioned above. This type of outcrop is called "*matacão*", as it became known in Brazil, being also known by the name "*lajedo*" (Lages *et al.* 2013).

The area has abundant boulders formed by the degradation of very large rocks, which present a process of monodevelopment of spheroidal exfoliation of blocks resulting from fractures. Thin, rocky soils (neosoils, hosting saxicolous plants) cover the area, representing a typical geomorphological process of semiarid climates (van Schmus *et al.* 2011). According to Andrade-Lima (1981), the flora of the study area fits a type of seasonally dry Neotropical savanna, called "*Cariri Paraibano*", which is composed of high-medium-sized shrubs and trees.

Floristics

Field works were carried out in the area from March 2010 to October 2011, with surveys every fifteen days, to collect fertile botanical material (flowers and/or fruits) and make *in situ* observations. The collections and their herborization were based on the usual methodologies of floristic studies (Bridson and Forman 2004). The following data were recorded: location, date, collector and collection number, substrate type, life form (herb, sub-shrub, shrub, tree, vine, epiphytic, aquatic and its variants, such as emergent, amphibious, floating and submerged) (Velôso *et al.* 1992), and colors of the reproductive structures (flowers and fruits). Digital images were recorded for the individuals sampled and their habitats (rupicolous, terrestrial, aquatic, and aerial). The habitat types were based on Velôso *et al.* (1992), supplemented with observations made in the field.

Species identifications were based on the specialized literature, especially in Flora and Funga do Brasil (FFB c2022) in addition to consultations with specialists. Several species were confirmed by comparisons with samples deposited in herbaria in Paraíba State (JPB - Herbarium Lauro Pires-Xavier and EAN - Herbarium Jayme Côelho de Moraes, belonging to the Campus I and II of the Federal University of Paraíba; Universidade Federal da Paraíba; UFPB) in the municipalities of João Pessoa and Areia, respectively. The floristic list was prepared following APG IV (2016). Species names and their respective authors were confirmed using the Missouri Botanical Garden (W³ Tropicos c2019) and Flora e Funga do Brasil Online (2022) databases. The collections were incorporated into the Manuel de Arruda Câmara Herbarium (HACAM), belonging to the State University of Paraiba (Universidade Estadual da Paraíba - UEPB).

The geographical distribution of each species was verified by consulting regional floras and the online Global Biodiversity Information Facility (GBIF c2019), Global Invasive Species Database (GISD c2019), Tropicos c2019), and Flora e Funga do Brasil Online (FFB c2022) databases. When a species could not be determined to the specific level (due to the presence of fruits only, which could not provide taxonomic security), its phytogeographic information could not be determined.

Similarity

Based on published articles (including floristic inventories undertaken in the Caatinga domain using the methodology adopted in the present work), a table of all the plant species (plateaus, sedimentary environments, and other rocky environments) was compiled (including this study) – generating a binary data matrix (presence/absence) that was then used to analyze the floristic similarities between the areas following Hubálek (1982). The publications used in this analysis were found using the Google Scholar platform, based on the following bibliometric descriptors: "rocky environments", "Caatinga flora", and "floristic survey".

Cluster analysis was subsequently performed based on an area dendrogram to detect similarities between them (Kent and Coker 1995). The dendrogram was constructed using the UPGMA (unweighted pair group method with arithmetic mean) cluster algorithm applied to the referred index of similarity (Jaccard IDJ). The Jaccard coefficient was used to avoid giving weight to the most common species (as the Sörensen index would) (Gotelli and Ellison 2004). Values above the 25 % cut-off were marked as "most significantly" related to each other (Muller-Dombois and Ellenberg 1974). PAST software version 4.1 was used for the statistical analyses (Gotelli and Ellison 2004).

Table 1. Families and species recorded "Sítio Bravo" study site, Environmental Conservation Area (APA) of Cariri, municipality of Boa Vista, Paraíba state, Brazil, with respective life forms, habitats sampled, determiner and collector / collection number, and phytogeography. Life Forms: Herb (H), Shrub (S), Sub-Shrub (Sb), Tree (T), Epiphyte (E), Liana (L), Parasite (P); Types of habitats: Terrestrial (Ter), Aquatic (Aq), Rupicolous (Rup), Air (Air); Phytogeography: Neotropical (Neotr), Pantropical (Pantr), Cosmopolitan (Cosm), and Endemic/Brazil (End).

Family	Species	Collector	Life form	Habitat	Phyto
1–ACANTHACEAE	1. *Ruellia bahiensis* (Nees) Morong	HOMF 67	H	Ter	Neotr
2–ALISMATACEAE	2. *Echinodorus grandiflorus* (Cham. & Schltdl.) Micheli	HOMF 60	H	Aq	Neotr
	3. *Hydrocleys nymphoides* (Humb. & Bonpl. ex Willd.) Buchenau	HOMF 35	H	Aq	Cosm
3–AMARANTHACEAE	4. *Gomphrena vaga* Mart.	HOMF 31	Sb	Ter	Trop
4–AMARYLLIDACEAE	5. *Zephyranthes sylvatica* (Mart. ex Schult. & Schult. f.) Baker	-	H	Aq	End
5–APOCYNACEAE	6. *Allamanda blanchetii* A.DC.	HOMF 164	L	Ter	Cosm
	7. *Aspidosperma pyrifolium* Mart.	HOMF 140	T	Ter	Neotr
	8. *Mandevilla tenuifolia* (J.C. Mikan) Woodson	HOMF 171	H	Rup	Neotr
6–ARACEAE	9. *Pistia stratiotes* L.	HOMF 175	H	Aq	Cosm
	10. Araceae sp.	-	E	Air	-
7–ARECACEAE	11. Arecaceae sp.	-	T	Ter	-
8-ASPARAGACEAE	12. *Agave* sp.	HOMF 152	H	Ter	Pantr
9–ASTERACEAE	13. *Acmella uliginosa* (Sw.) Cass.	HOMF 176	H	Aq	Pantr
	14. *Ageratum conyzoides* (L.) L.	HOMF 20	H	Ter	Cosm
	15. *Centratherum punctatum* Cass.	HOMF 33	H	Ter	Cosm
	16. *Conocliniopsis prasiifolia* (DC.) R.M. King & H. Rob.	HOMF 62	H	Ter	Neotr
	17. *Eclipta prostrata* (L.) L.	HOMF 98	H	Aq	Cosm
	18. *Pectis linifolia* L.	HOMF 34	H	Ter	Neotr
	19. *Tridax procumbens* (L.) L.	HOMF 170	H	Ter	Pantr
10–BIGNONIACEAE	20. *Handroanthus impetiginosus* (Mart. ex DC.) Mattos	HOMF 75	T	Ter	Neotr
11–BIXACEAE	21. *Cochlospermum vitifolium* (Willd.) Spreng.	HOMF 74	T	Ter	Neotr
12–BORAGINACEAE	22. *Euploca procumbens* (Mill.) Diane & Hilger	HOMF 177	H	Ter	Neotr
	23. *Heliotropium angiospermum* Murray	HOMF 59	H	Ter	Neotr
	24. *Myriopus salzmannii* (DC.) Diane & Hilger	HOMF 03	S	Ter	Neotr
13–BROMELIACEAE	25. *Dyckia spectabilis* (Mart. ex Schult. f.) Baker	HOMF 178	S	Rup	End
	26. *Neoglaziovia variegata* (Arruda) Mez.	HOMF 77	S	Rup	End

(Continúa)

Family	Species	Collector	Life form	Habitat	Phyto
	27. *Tillandsia gardneri* Lindl.	HOMF 55	E	Air	Neotr
	28. *Tillandsia loliacea* Mart. ex Schult. & Schult.f.	HOMF 38	E	Air	Neotr
	29. *Tillandsia recurvata* (L.) L.	HOMF 27	E	Air	Neotr
14–BURSERACEAE	30. *Commiphora leptophloeos* (Mart.) J.B. Gillett	HOMF 139	T	Ter	Neotr
15–CACTACEAE	31. *Cereus jamacaru* DC.	HOMF 179	T	Ter	End
	32. *Melocactus zehntneri* (Britton & Rose) Luetzelb.	HOMF 147	H	Ter	End
	33. *Pilosocereus pachycladus* F. Ritter	AC 08	T	Rup	End
	34. *Tacinga inamoena* (K. Schum.) N.P. Taylor & Stuppy	HOMF 142	Sb	Ter	End
	35. *Tacinga palmadora* (K. Schum.) N.P. Taylor & Stuppy	HOMF 151	Sb	Ter	End
	36. *Xiquexique gounellei* (F.A.C. Weber) Lavor & Calvente	ACL 04	S	Ter	End
16–CLEOMACEAE	37. *Physostemum lanceolatum* Mart. & Zucc.	HOMF 180	H	Ter	Neotr
	38. *Physostemon tenuifolium* Mart. & Zucc.	HOMF 181	H	Ter	End
	39. *Tarenaya longicarpa* Soares-Neto & Roalson	HOMF 19	Sb	Aq	Cosm
17–COMMELINACEAE	40. *Commelina erecta* L.	HOMF 143	H	Ter	Cosm
	41. *Commelina obliqua* Vahl	HOMF 45	H	Ter	Neotr
18–CONVOLVULACEAE	42. *Evolvulus filipes* Mart.	HOMF 129	H	Ter	Neotr
	43. *Evolvulus tenuis* Mart.	HOMF 162	H	Rup	End
	44. *Ipomoea brasiliana* (Mart. ex Choisy) Meisn.	HOMF 09	L	Ter	End
	45. *Ipomoea carnea* Jacq.	HOMF 182	S	Aq	Pantr
	46. *Ipomoea nil* (L.) Roth.	HOMF 209	L	Ter	Cosm
	47. *Ipomoea ramosissima* (Poir.) Choisy	HOMF 50	L	Ter	Neotr
	48. *Ipomoea sericosepala* J.R.I. Wood & Scotland	HOMF 26	L	Ter	Neotr
	49. *Jacquemontia evolvuloides* Meisn.	HOMF 183	H	Ter	Neotr
	50. *Jacquemontia multiflora* Hallier f.	HOMF 09	H	Ter	Neotr
	51. *Jacquemontia* sp.	HOMF 28	H	Ter	-
19–CYPERACEAE	52. *Cyperus uncinulatus* Schrad. ex Nees	HOMF 52	H	Ter	Neotr
	53. *Cyperus* sp.	HOMF 187	H	Ter	-
	54. *Eleocharis elegans* (Kunth) Roem. & Schult.	HOMF 186	H	Aq	Cosm
	55. *Pycreus sanguinolentus* (Vahl) Nees	HOMF 51	H	Ter	Cosm

(Continúa)

Family	Species	Collector	Life form	Habitat	Phyto
20–ERYTHROXYLACEAE	56. *Erythroxylum caatingae* Plowman	HOMF 13	T	Ter	End
21–EUPHORBIACEAE	57. *Croton blanchetianus* Baill.	HOMF 01	S	Ter	End
	58. *Croton* cf. *echioides* Baill.	-	S	Ter	-
	59. *Croton heliotropiifolius* Kunth	HOMF 11	S	Ter	End
	60. *Cnidoscolus urens* (L.) Arthur	HOMF 156	Sb	Rup	Neotr
	61. *Euphorbia attastoma* Rizzini	HOMF 189	S	Ter	End
	62. *Jatropha mollissima* (Pohl) Baill.	HOMF 10	S	Ter	End
	63. *Jatropha ribifolia* (Pohl) Baill.	HOMF 190	Sb	Ter	End
	64. *Tragia volubilis* L.	HOMF 160	L	Ter	Neotr
22–FABACEAE	65. *Anadenanthera colubrina* (Vell.) Brenan	HOMF 141	T	Ter	Neotr
	66. *Cenostigma gardnerianum* Tul.	HOMF 08	T	Ter	End
	67. *Erythrina velutina* Willd.	HOMF 104	T	Ter	Neotr
	68. *Hymenaea courbaril* L.	HOMF 146	T	Ter	Neotr
	69. *Libidibia ferrea* (Mart. ex Tul.) L.P. Queiroz	HOMF 92	T	Ter	Neotr
	70. *Macropsychanthus grandiflorus* (Mart. ex Benth.) L.P. Queiroz & Snak	HOMF 17	L	Ter	End
	71. *Mimosa ophthalmocentra* Mart. ex Benth.	HOMF 120	T	Ter	End
	72. *Poincianella bracteosa* (Tul.) L.P. Queiroz	HOMF 118	T	Ter	End
	73. *Prosopis juliflora* (Sw.) DC.	HOMF 88	T	Ter	Cosm
	74. *Senna macranthera* (DC. ex Collad.) H.S. Irwin & Barneby	HOMF 07	T	Ter	Neotr
	75. *Senna martiana* (Benth.) H.S. Irwin & Barneby	HOMF 70	T	Ter	End
	76. *Senna spectabile* (DC.) H.S. Irwin & Barneby	HOMF 133	T	Ter	Pantr
	77. *Senna splendida* (Vogel) H.S. Irwin & Barneby	HOMF 128	T	Ter	Neotr
	78. *Zornia echinocarpa* (Moric. ex Meisn.) Benth.	HOMF 167	H	Ter	End
23–GENTIANACEAE	79. *Schultesia pohliana* Progel	HOMF 193	H	Ter	Neotr
24–IRIDACEAE	80. *Cypella exilis* Ravenna	HOMF 159	H	Ter	Neotr
25–LAMIACEAE	81. *Mesosphaerum suaveolens* (L.) Kuntze	HOMF 105	Sb	Ter	Pantr
26–LOASACEAE	82. *Aosa rupestris* (Gardner) Weigend	HOMF 134	H	Rup	End
27–LOGANIACEAE	83. *Spigelia anthelmia* L.	HOMF 200	H	Ter	Pantr

(Continúa)

Family	Species	Collector	Life form	Habitat	Phyto
28–LORANTHACEAE	84. *Struthanthus syringifolius* (Mart.) Mart.	HOMF 103	P	Air	Neotr
29–LYTHRACEAE	85. *Cuphea racemosa* (L. f.) Spreng.	HOMF 157	Sb	Ter	Neotr
	86. *Pleurophora anomala* (A. St.-Hil.) Koehne	HOMF 49	T	Ter	End
30–MALVACEAE	87. *Ceiba glaziovii* (Kuntze) K. Schum.	HOMF 144	T	Ter	End
	88. *Corchorus* sp.	HOMF 163	Sb	Ter	-
	89. *Melochia tomentosa* L.	HOMF 16	S	Ter	Neotr
	90. *Pavonia cancellata* (L.) Cav.	HOMF 196	H	Ter	Neotr
	91. *Pseudobombax parvifolium* Carv. –Sobr. & L.P. Queiroz	HOMF 73	S	Ter	End
	92. *Sida galheirensis* Ulbr.	HOMF 197	H	Ter	End
	93. *Sida* sp.	HOMF 106	Sb	Ter	-
	94. *Sidastrum micranthum* (A.St. -Hil.) Fryxell	HOMF 02	Sb	Ter	Neotr
31–MENYANTHACEAE	95. *Nymphoides indica* (L.) Kuntze	HOMF 97	H	Aq	Pantr
32–MOLLUGINACEAE	96. *Mollugo verticillata* L.	HOMF 29	H	Ter	Cosm
33–MYRTACEAE	97. *Stenocalyx dysentericus* (DC.) O. Berg	HOMF 84	S	Ter	Neotr
34–NYCTAGINACEAE	98. *Boerhavia diffusa* L.	HOMF 172	H	Ter	Pantr
35–ONAGRACEAE	99. *Ludwigia octovalvis* (Jacq.) P.H. Raven	HOMF 198	H	Aq	Pantr
36–OXALIDACEAE	100. *Oxalis divaricata* Mart. ex Zucc.	HOMF 25	H	Ter	Neotr
37–PAPAVERACEAE	101. *Argemone mexicana* L.	HOMF 199	H	Ter	Cosm
38–PASSIFLORACEAE	102. *Turnera subulata* Sm.	HOMF 158	H	Ter	Pantr
39–PHYLLANTHACEAE	103. *Phyllanthus niruri* L.	HOMF 192	H	Ter	End
40–PLANTAGINACEAE	104. *Angelonia biflora* Benth.	HOMF 108	H	Aq	Pantr
	105. *Angelonia cornigera* Hook.	HOMF 201	H	Aq	End
	106. *Bacopa* sp.	HOMF 168	H	Ter	-
41–PLUMBAGINACEAE	107. *Plumbago scandens* L.	HOMF 24	H	Ter	Neotr
42–POACEAE	108. *Aristida vagans* Cav.	HOMF 202	H	Ter	Neotr
	109. *Chloris virgata* Sw.	HOMF 203	H	Ter	Cosm
	110. *Paspalum fimbriatum* Kunth	HOMF 204	H	Ter	Neotr
	111. *Setaria parviflora* (Poir.) Kerguélen	HOMF 205	Sb	Ter	Cosm
	112. *Tragus berteronianus* Schult.	HOMF 109	H	Ter	Pantr

(Continúa)

Family	Species	Collector	Life form	Habitat	Phyto
43–PONTEDERIACEAE	113. *Pontederia cordata* L.	HOMF 99	H	Aq	Cosm
44–PORTULACACEAE	114. *Portulaca elatior* Mart. ex Rohrb.	HOMF 69	H	Ter	Neotr
	115. *Portulaca halimoides* L.	HOMF 136	H	Rup	Neotr
45–RHAMNACEAE	116. *Sarcomphalus joazeiro* (Mart.) Hauenschild	HOMF 90	T	Ter	End
46–RUBIACEAE	117. *Mitracarpus baturitensis* Sucre	HOMF 166	H	Ter	End
	118. *Mitracarpus* sp.	HOMF 165	H	Ter	-
	119. *Richardia grandiflora* (Cham. & Schltdl.) Steud.	HOMF 110	H	Ter	Neotr
	120. *Tocoyena formosa* (Cham. & Schltdl.) K. Schum.	HOMF 04	T	Ter	Neotr
47–SAPINDACEAE	121. *Serjania glabrata* Kunth	HOMF 82	L	Air	Neotr
48–SOLANACEAE	122. *Nicotiana glauca* Graham	HOMF 61	S	Ter	Cosm
49–TYPHACEAE	123. *Typha dominguensis* Pers.	HOMF 120	H	Aq	Cosm
50–VERBENACEAE	124. *Lantana camara* L.	HOMF 15	S	Ter	Cosm
	125. *Lippia grata* Schauer	HOMF 06	S	Ter	End
	126. *Stachytarpheta angustifolia* (Mill.) Vahl	HOMF 119	H	Ter	End
51–VIOLACEAE	127. *Pombalia calceolaria* (L.) Paula-Souza	HOMF 122	Sb	Ter	Neotr
52–VITACEAE	128. *Clematicissus simsiana* (Schult. & Schult. f.) Lombardi	HOMF 05	L	Air	Neotr

RESULTS

A total of 128 species, 103 genera, and 52 families were identified in the study area, being 18 % monocots and 82 % eudicots. Most specimens were identified at the species level (91 %), 7 % at the generic level, and 2 % at the family level (Table 1). The families with the largest representativeness were Fabaceae (fourteen species), Euphorbiaceae, Malvaceae, and Convolvulaceae (nine species each), accounting for nearly 30 % of the recorded species (Fig. 3). Other families noteworthy for their representativeness in the study area were: Cactaceae (six species), Asteraceae, Poaceae, and Bromeliaceae (five species each), and Rubiaceae (four species). *Pectis linifolia* L. is recorded for the first time in Paraíba state, Brazil, in this study.

The stratum composed of herbaceous species, which accounts for 37 % of the species richness, completely disappears during the dry season, disappears a marked seasonality to the region (Fig. 4). Arboreal (22 %), sub-shrub (13.4 %), and shrub (8.6 %) individuals together account for 44 % of the total species, followed by aquatic plants (10 %), lianas (5 %), epiphytes (3 %), and a single hemipara-

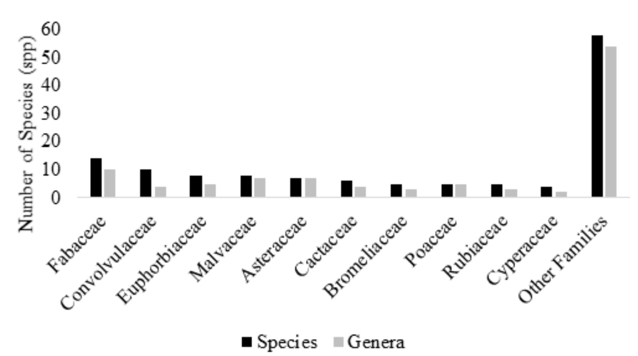

Figure 3. Distribution of the representativeness of genera and species by family of Angiosperms in the "Sítio Bravo" study site, Environmental Conservation Area (APA) of Cariri, municipality of Boa Vista, Paraíba state, Brazil.

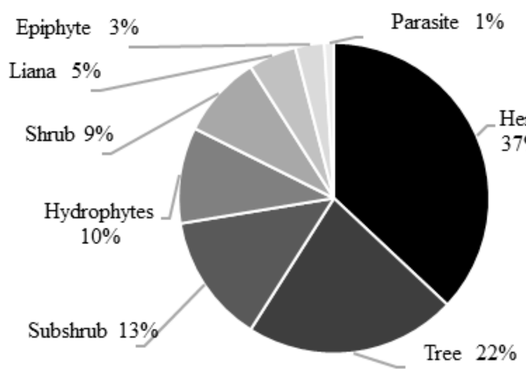

Figure 4. Distribution of Angiosperm species life forms of the "Sítio Bravo" study site, Environmental Conservation Area (APA) of Cariri, municipality of Boa Vista, Paraíba state, Brazil,

site (1 %) belonging to the family Loranthaceae [*Struthanthus syringifolius* (Mart.) Mart.]. This parasitic species is widely distributed in Brazil and is hosted mainly by tree species. It was found in the present study on two species of Fabaceae (*Erythrina velutina* Willd. and *Libidibia ferrea* Mart.) and on one species of Rubiaceae [*Tocoyena formosa* (Cham. and Schltdl.) K. Schum.].

The results show that species colonizing dry soils, full of rocks broken by weathering and rocky crevices composed of a type of neosoil (Table 1) correspond to 72 % of the total species, with preferential occupation of terrestrial habitats. Furthermore, *in situ* observations indicated that most tree species (*Aspidosperma pyrifolium*, *Cochlospermum vitifolium*, *Commiphora leptophloeos*, *Erythroxylum caatingae*, *Handroanthus impetiginosus*, and all Fabaceae arboreal species recorded) occurred mainly in cracks between the rocks, taking advantage of those water-retaining sites and creating distinct microclimates.

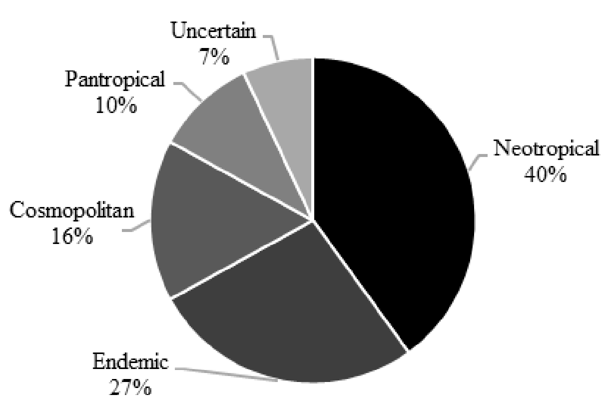

Figure 5. Geographical distribution pattern of plants of the "Sítio Bravo" study site, Environmental Conservation Area (APA) of Cariri, municipality of Boa Vista, Paraíba state, Brazil,

Rupicolous species accounted for only 6 % of the total number of species in the study area and included *Xiquexique gounellei* (F.A.C. Weber) Lavor & Calvante (Cactaceae), *Dyckia spectabilis* (Mart. ex Schult. f.) Baker (Bromeliaceae), *Evolvulus filipes* Mart. and *E. tenuis* Mart. (Convolvulaceae), *Aosa rupestris* (Gardner) Weigend (Loasaceae), and *Portulaca halimoides* L. (Portulacaceae).

Regarding the geographic distributions of the taxa analyzed (Fig. 5), it can be seen that Neotropical species (40 %) predominate, followed by endemic (27 %), cosmopolitan (16 %), and pantropical (10 %) taxa; plants having uncertain distributions, for cases of plants identified only at the generic level or for indeterminate plants, accounted for 7 % of the taxa.

The cophenetic correlation coefficient for the dendrogram was 95.6 %, based on Jaccard's SI, indicating a construct with high explanatory power. The studied area is strongly floristically connected to the other typically rocky/stony areas of the Caatinga, indicating common floristic clusters (Fig. 6). A comparative synoptic is presented (Table 2), as well as comparisons of the richness of the different areas analyzed here (Fig. 7).

DISCUSSION

Bromeliaceae, Cyperaceae, Poaceae, Cactaceae, Euphorbiaceae, and Asteraceae are the families most frequently reported in rocky environments in both Brazil (Porembski 2007, Ribeiro *et al.* 2007, Scarano 2007) and Colombia (Giraldo-Cañas 2001, 2008), with families in the monocotyledon clade being the most common (Pigott 2000, Giraldo-Cañas 2008). Although the families grouped in the monocotyledon clade (17 %) are most common in this type of environment (Pigott 2000, Giraldo-Cañas 2008), we found that the Fabaceae, Euphorbiaceae, Malvaceae, and Convolvulaceae families evidenced greater diversity. It is worth mentioning that the families Bromeliaceae and Cactaceae had significant representativeness in this environment, mainly due to their tendencies to form dense monospecific assemblages in the cracks between the rock surfaces.

The predominance of Fabaceae species in the present study (11 % of the total) reflects the fact that this family has developed effective strategies for survival in xeric and nitrogen-poor environments (N_2 fixation clade), corroborating the findings of Pereira *et al.* (2001) and Barbosa *et al.* (2007) in other Caatinga areas. Fabaceae is a large cosmopolitan family occurring in a wide variety of habitats (Judd *et al.* 2007), and the third largest family of plants in the study area. Fabaceae is predominantly associated with areas of Caatinga (Lima and Lima 1998, Rodal and Nascimento 2002, Cestaro and Soares 2004, Gomes *et al.* 2006, Ribeiro *et al.* 2007, Cardoso *et al.* 2009, Costa *et al.* 2009, Lima *et al.* 2009a, Lemos and Meguro 2010) and has significant presence in anthropogenically modified environments (Andrade *et al.* 2005, 2007). Legumes represent an abundant floristic component of riparian vegetation (Lacerda *et al.* 2005), as have also been reported in high-altitude bogs (Rodal *et al.* 2005).

Euphorbiaceae is one the most taxonomically diverse angiosperm families in the flora do Brazil, evidencing morphological adaptations to dry environments (Judd *et al.* 2007, Lucena and Alves 2009), and represents a well-represented group in the study area. Two species of the genus *Croton* L. (*C. blanchetianus* Baill. and *C. heliotropiifolius* Kunth) were frequently encountered in the study area on rocky outcrops, confirming the findings of Alcoforado-Filho *et al.* (2003). Those authors emphasized a high frequency of Croton individuals in areas of Caatinga and on inselbergs in Colombian Guyana (Giraldo-Cañas 2008).

Still considering the Euphorbiaceae, *Jatropha* Baill. species have wide distributions in Brazil, occurring in all of the

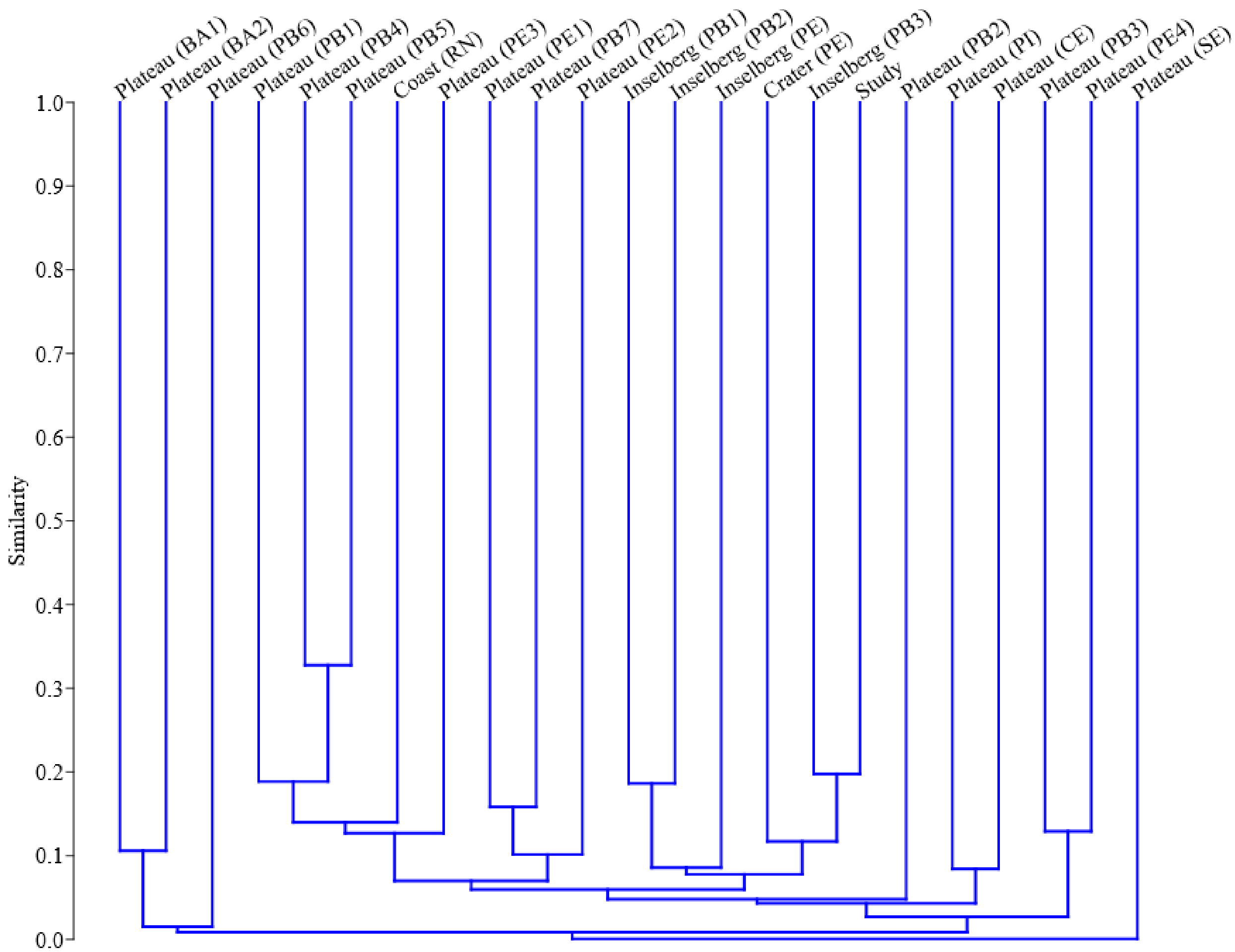

Figure 6. Dendrogram of floristic similarity of the study area using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) method based on Jaccard's index. This study = Study; Ribeiro *et al.* (2007) = Plateau (SE); Conceição *et al.* (2007) = Plateau (BA1); Barbosa *et al.* (2007) = Plateau (PB1); Porto *et al.* (2008) = Inselberg (PB1); Cardoso *et al.* (2009) = Plateau (PB2); Rodal *et al.* (2005) = Plateau (PB3); Rodal and Nascimento (2002) = Plateau (PE1); Andrade *et al.* (2007) = Plateau (PB4); Lemos (2004) = Plateau (PI); Gomes *et al.* (2006) = Plateau (PE2); Cestaro and Soares (2004) = Coast (RN); Lima *et al.* (2009a) = Plateau (CE); Pereira *et al.* (2001) = Plateau (PB5); Costa *et al.* (2009) = Crater (PE); Andrade *et al.* (2005) = Plateau (PB6); Agra *et al.* (2004) = Plateau (PB7); Neves and Conceição (2007) = Plateau (BA2); Pitrez (2006) = Inselberg (PB2); Alcoforado-Filho *et al.* (2003) = Plateau (PE3); Rodal and Sales (2007) = Plateau (PE4); Gomes and Alves (2010) = Inselberg (PE); Tölke *et al.* (2011) = Inselberg (PB3).

northeastern states of that country, particularly in semiarid areas with both sedimentary and crystalline Caatinga in hypo-xerophytic and hyper-xerophytic regions (Lucena and Alves 2009) as well as in the Colombian Guyana (Giraldo-Cañas 2008). *Jatropha mollissima* (Pohl) Baill. was recorded in this study as occurring widely in sedimentary areas, corroborating the findings of Alcoforado-Filho *et al.* (2003); Andrade *et al.* (2005) noted that it showed high densities in degraded areas (as was also seen in the present study).

On the other hand, Asteraceae species – *Ageratum conyzoides* L., *Centratherum punctatum* Cass., *Conoclinopsis prasiifolia* (DC.) R.M. King and H. Rob., *Eclipta prostrata* (L.) L., *Pectis linifolia* L., *Tridax procumbens* L. – are representative in the vegetation of open spaces, as well as those impacted by anthropic activities (Judd *et al.* 2007). *Acmella uliginosa* (Sw.) Cass. is not encountered under those conditions, being common only in humid areas (Silva and Santos 2010).

Information on the synecological characteristics of Cactaceae species in northeastern Brazil is still restricted in floristic studies (Fabricante *et al.* 2010). However, according to Rocha and Agra (2002), the family is very common in seasonally dry areas in northeastern Brazil, and its species are well adapted to rocky environments.

The woody flora of the Cariri APA was quite notorious, reaching heights of up to 10 m and contradicting the common view that the seasonally dry vegetation in Brazil does not usually feature tall trees (Alves 2009). This more robust vegetation was encountered mainly in sedimentary valleys among cracks in the rocks, where the richest soils are presumably found (Lenza *et al.* 2011), and in areas of difficult access (which diminishes deforestation). Andrade-Lima (1981) suggested that there would be a subtype of tall Caatinga growing on crystalline soils in the Brazilian semiarid region (although without clearly defining it). That study also stated that this biocenosis was mainly associated with the Borborema Plateau, where the study area was located.

The Bromeliaceae family stood out among epiphytic species (*Tillandsia* spp.), confirming the observations of Porembski (2007), and reaffirming that this family is extremely common in treetops or on bare rock environments throughout the world. Although the study region has a low annual rainfall rate and evidences variations in tree canopy spacing, the epiphyte community was present throughout the area and formed dense populations.

Based on the habitat preferences of the species inventoried, it is interesting to note that their richness in these low rainfall and rocky environments is related to the variety of microhabitats found there. Species with adaptations that allow them to occupy similar habitats are thought to share similar biological adaptations in response to their common life history attributes (Gentry 1991). Rocky habitats can be considered "favorable" or "safe location" environments for many plant species (Barthlott *et al.* 1993).

The similarity analysis showed a cophenetic correlation coefficient of 90.55 %. The analysis of flora in plateau areas (16), inselbergs (4), and sedimentary environments (2) in the Caatinga domain showed an average floristic sharing of 20 % of its species. The floristic similarity dendrogram demonstrated that the study area flora was grouped into a subgroup composed of inselbergs ("lajedos", as they are known locally). Although those geomorphological features

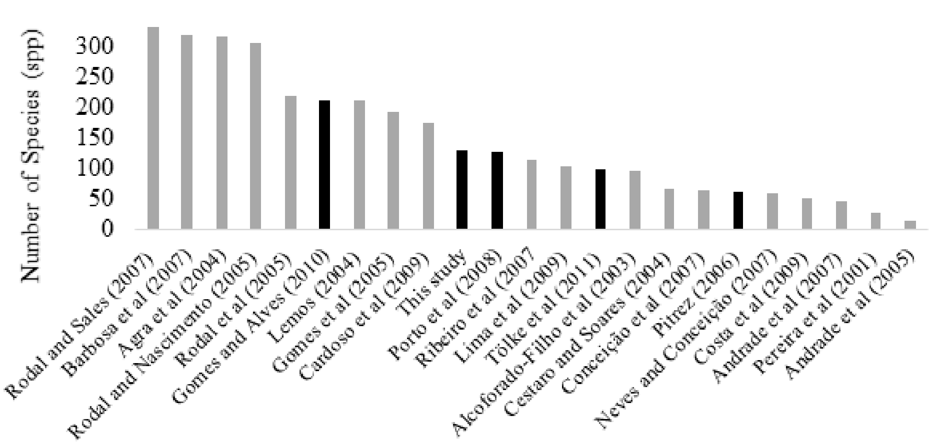

Figure 7. Richness of Caatinga areas (rocky outcrop areas highlighted in bold).

Table 2. The studies included in the floristic similarity analysis of the Caatinga Biogeographic Province (eastern South America), and data of altitude, coordinates, and minimum distances to the studied area. Brazilian States designations: **BA**=Bahia; **CE**= Ceará; **PB**=Paraíba; **PE**=Pernambuco; **PI**=Piauí; **RN**=Rio Grande do Norte.

Author (s)	Year	Location	Elev. (m)	Coordinates	Distance (km)
Pereira *et al.*	2001	Remígio (PB)	593	06°52'S;35°47'W	58.39
Rodal and Nascimento	2002	Inajá (PE)	355	08°39'S;37°35'W	252.31
Alcoforado-Filho *et al.*	2003	S. Caetano (PE)	545	08°14'S';35°55'W	118.80
Agra *et al.*	2004	Maturéia (PB)	1.197	06°57'S;35°41'W	121.34
Cestaro and Soares	2004	Macaíba (RN)	15	05°53'S;35°23'W	184.73
Lemos	2004	S.R. Nonato (PI)	400	08°26'S;42°19'W	726.00
Andrade *et al.*	2005	S.J. Cariri (PB)	458	07°24'S;36°32'W	35.00
Rodal *et al.*	2005	Bonito (PE)	443	08°29'S;35°41'W	148.97
Gomes *et al.*	2006	Buíque (PE)	798	08°35'S;37°15'W	184.57
Pitrez	2006	Serraria (PB)	526	06°50'S;35°37'W	82.33
Andrade *et al.*	2007	Pocinhos (PB)	634	07°03'S;36°03'W	28.75
Conceição *et al.*	2007	Palmeiras (BA)	697	12°27'S;41°28'W	826,47
Barbosa *et al.*	2007	Sumé (PB)	533	07°23'S;36°31'W	85.36
Neves and Conceição	2007	Lençóis (BA)	394	12°35'S;41°23'W	816.56
Ribeiro *et al.*	2007	Aiuruoca (CE)	989	22°21'S;44°40'W	1.866
Rodal and Sales	2007	Caruaru (PE)	552	08°17'S;35°58'W	101.58
Porto *et al.*	2008	Esperança (PB)	631	07°1'S;35°52'W	49.23
Cardoso *et al.*	2009	F. Santana (BA)	234	12°10'S;39°11'W	628.86
Costa *et al.*	2009	Betânia (PE)	441	08°18'S;38°11'W	228.18
Lima *et al.*	2009a	Crateús (CE)	274	05°08'S';40°54'W	542.08
Gomes and Alves	2010	Agrestina (PE)	150	08°22'S;35°50'W	135.97
Tölke *et al.*	2011	Puxinanã (PB)	657	07°08'S';35°58'W	32.65

are also found in plateau areas, their floras are subject to very complex microhabitat restrictions, such as the absence of a well-defined soil layer, a high insolation rate, and high reflection of the sun's rays, extreme daily thermal amplitudes; all selective factors for species that can colonize those areas (Porembski 2007). The windward flank of the low inselberg studied here has microclimatic conditions with higher levels of relative humidity, while the study area had a leeward position (in addition to being in the driest Caatinga area).

These observed links between the floras of rocky areas reinforce the "theory of refuges" (Ab'Sáber 1992), which is used to explain the distributions of certain floristic groups by their predilection habitats that select for similar advantageous evolutionary traits, but also provide protection against predators. Although this theory is strongly related to both the historical and current distributions of species that reflect Pleistocene events (Burke 2002, Stewart *et al.* 2010), there are scientific proposals defining those zones as areas of stability "protecting" species from anthropic disturbances (Birks and Willis 2008). Today, those spaces could shelter regional biodiversity from the threats of climate change projected for coming years (Keppel *et al.* 2012).

Regarding the richness of rocky outcrops as compared to other Caatinga areas, the floristic diversity of these ecosystems, which despite evidencing similar floristic assemblies as other areas, demonstrate species diversities intermediate between plateau and mountainous Caatinga regions (Fig. 7; Agra *et al.* 2004, Rodal *et al.* 2005, Rodal and Nascimento 2005, Rodal and Sales 2007, Barbosa *et al.* 2007), terrestrial ecosystems, and regenerating areas (Pereira *et al.* 2001, Andrade *et al.* 2005, Andrade *et al.* 2007, Neves and Conceição 2007, Costa *et al.* 2009). This mesic richness is closely related to the severe environmental conditions found in rocky environments that act to filter for species having appropriate adaptations to survive extreme environmental conditions (such as abrupt temperature variations, water scarcity, and shallow soils with low nutrient contents) (Porembski *et al.* 1996, 2006; Giraldo-Cañas 2001, 2008).

Implications for conservation

Despite being established in rocky environments under semiarid conditions typical of the Caatinga ecosystem, the study area community exhibited significant floristic diversity, with a flora typical of seasonally dry areas in South America (the Xeric corridor). Fabaceae, Convolvulaceae, Malvaceae, Euphorbiaceae, Asteraceae, Cactaceae, Bromeliaceae, Rubiaceae, and Poaceae are the most significant plant families in this type of environment, and the herbaceous and shrub strata are the richest in terms of species numbers (although the former are ephemeral in the highly seasonal Caatinga domain).

The species composition found in the study area differed substantially from other surveys carried out in environments of the Caatinga itself, confirming a distinct flora of the western plateau of Borborema, as predicted by Andrade-Lima (1981). This implies that wetlands, mountains, and rocky outcrops areas are the habitats most indicated by botanists as shelters for biodiversity (Birks and Willis 2008; Speziale and Ezcurra 2015), and will require greater attention in terms of public policies due to their species richness and uniqueness environment (Rose and Burton 2011).

Our results suggest that historical factors (dispersal and floristic connections) are important elements in Caatinga fragments, although ecological factors, such as the interactions between plants and their physical environment, especially rock outcrops, need to be further studied for a greater understanding their floras and their autecological aspects.

AUTHORS PARTICIPATION

Conceptualization: HMF; data curation: HMF; formal analysis: HMF; funding acquisition: JIMM; investigation: HMF; methodology: HMF, JIMM; project administration: JIMM; resources: JIMM; software: HMF; supervision: JIMM; DGC; validation: JIMM; DGC; visualization: HMF; JIMM; DGC; writing – original draft: HMF; JIMM. writing – review & editing: HMF; JIMM.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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