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Original Paper

Effects of topographic factors on distribution of cacti along an elevation gradient in Brazilian Caatinga

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Abstract
The Cactacea family comprises 128 genera and 1450 species with predominantly neotropical distribution. Cacti are commonly found in arid and semi-arid regions and have great ecological relevance due to their interactions with animals and other groups of plants. Abiotic interactions, such as topography, altitude, rainfall, temperature and soils, also influence the composition and distribution of cacti. The objective of the present study was to assess patterns of species composition and distribution for cacti along an elevation gradient in Brazilian Caatinga vegetation. Four transects (composed by 25 plots of 100 m² each) were established at each of two mountain sites. The topographic variables of elevation, slope, rockiness and soil depth were evaluated to determine if they affect the distribution of richness and abundance of cacti along the elevation gradient using Spearman's (rs) correlation coefficient. A total of 554 individuals of five cacti species (*Pilosocereus gounellei, Pilosocereus pachycladus, Tacinga palmadora, Tacinga inamoena* and *Melocactus zehntneri)* were sampled. Cacti richness and abundance were found to be negatively correlated with elevation, slope and rockiness, and positively correlated with soil depth ($p<0.05$). All species exhibited aggregate spatial distribution patterns, which may be related to different environmental conditions produced by interactions among topographic variables (slopes, rockiness and soil depth), that synergistically influence the patterns of species richness and abundance along the elevation gradient.
Key words: Brazil, Cactaceae, mountain, Sem-arid, topographic factors.

Resumo
A família Cactaceae compreende 128 gêneros e 1450 espécies com distribuição predominantemente neotropical. Os cactos são comumente encontrados em regiões áridas e semi-áridas e possuem grande relevância ecológica devido às suas interações com animais e outros grupos de plantas. As interações abióticas, como topografia, altitude, precipitação, temperatura e solos, também influenciam a composição e distribuição dos cactos. O objetivo do presente estudo foi avaliar os padrões de composição e distribuição de espécies de cactos ao longo de um gradiente de elevação na vegetação da Caatinga brasileira. Quatro transectos (compostos por 25 parcelas de 100 m² cada) foram estabelecidas em cada um dos dois locais da serra. As variáveis topográficas de elevação, declividade, rochosidade e profundidade do solo foram avaliadas para determinar se afetam a distribuição da riqueza e abundância de cactos ao longo do gradiente de elevação usando o coeficiente de correlação de Spearman (rs). Um total de 554 indivíduos de cinco espécies de cactos (*Pilosocereus gounellei, Pilosocereus pachycladus, Tacinga palmadora, Tacinga inamoena* e *Melocactus zehntneri*) foram amostrados. A riqueza e abundância de cactos foram correlacionadas negativamente com a elevação, declividade e rochosidade, e positivamente correlacionada com a profundidade do solo ($p<0,05$). Todas as espécies exibiram padrões de distribuição espacial agregados, que podem estar relacionados a diferentes condições ambientais produzidas

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por interações entre variáveis topográficas (encosta, rochosidade e profundidade do solo), que influenciam sinergicamente os padrões de riqueza e abundância de espécies ao longo do gradiente de elevação.
Palavras-chave: Brasil, Cactaceae, serra, semi-árido, fatores topográficos

Introduction

In order to understand the functioning of tropical ecosystems, it is necessary to consider interactions between abiotic and biotic factors (Born *et al.* 2014; Ricklefs 2015), including anthropogenic disturbance (Martorel & Peeters 2005; Ribeiro *et al*. 2015), which vary in space and time and act synergistically on the distribution and structure of plant communities (Boulangeat *et al*. 2012; Rito *et al*. 2017; Silva & Souza 2018). On a local scale, environmental factors, such as soil characteristics, temperature, humidity, altitude and topography, act as environmental filters that play paramount roles in the assembly of plant communities (Salas-Morales *et al*. 2015; Méndez-Toribio *et al.* 2016; Rodrigues *et al*. 2018).

The mountains of the Brazilian semi-arid region are considered relictual areas of climatic and environmental conditions that prevailed in the past and have become refuges of Caatinga vegetation (Velloso *et al*. 2002; Moro *et al*. 2016). Geomorphological processes that occurred during the Tertiary left some high (altitudes up to 1,000 m a.s.l.) and isolated areas of relief in the middle of the surrounding matrix (Moro *et al*. 2016; Silva & Souza 2018). These areas have a set of particularities that make them indispensable environments for understanding the Caatinga and its environmental complexity (Silva *et al*. 2014). Despite having a low altitudinal range, severe changes occur in the structure, composition and pattern of species richness, characterized by an increase in the number of species as the elevation gradient progresses (Lopes *et al*. 2017; Almeida *et al*. 2020).

Topographic conditions in these areas can influence the composition and structure of plant communities due to micro-environmental heterogeneity (Kouba *et al*. 2014; Kraft *et al*. 2015; Méndez-Toribio *et al*. 2016; Silva & Souza 2018). For example, gravity-driven movement of nutrients from mountain top downwards has resulted in deeper and more fertile soils at the base of mountains (Santos *et al*. 2009; Ramos *et al*. 2020). In addition, the stock and composition of litter varies along these gradients, which can contribute to changes in patterns of species richness (Almeida *et al*. 2020). Playing a synergetic role, anthropic disturbances are evident in the lower areas of these elevation gradients and, consequently, drive changes in land cover and in tree shrub communities (Silva *et al.* 2014; Lopes *et al.* 2017; Silva & Souza 2018). Therefore, anthropic impacts are expected to affect the structure of cacti (Zappi *et al*. 2011a), since they are widely used to feed herds during periods of drought (Martorel & Peeters 2005; Zappi *et al*. 2011a; Lucena *et al.* 2012).

The plant formation present in these areas, classified as Seasonally Dry Tropical Forests (SDTFs), is considered to harbor high biodiversity and environmental complexity (Silva & Souza 2018), and is regarded as one of the world's most threatened tropical ecosystems (Koch *et al.* 2017). In Brazil, SDTFs are known as Caatinga, which is considered the most diverse dry forest (Queiroz *et al*. 2017), and also the most populous semi-arid region in the world (Moro *et al*. 2015). The Caatinga is marked by the influence of spatial and temporal variability of rains and landscapes with different types of soils and high endemism (Moro *et al*. 2015; Queiroz *et al*. 2017; Silva *et al*. 2017).

The floristic composition of Caatinga (Queiroz *et al*. 2017; Fernandes et al. 2020), Cactaceae stands out with high abundance (Zappi *et al*. 2011a) and as the family with the highest proportion of endemism (~50% of species) (Fernandes *et al.* 2020). The Cactaceae comprises 128 genera and 1450 species with predominantly neotropical distribution (Hunt et al. 2013). Currently, 81 genera and 484 species are recognized in the Brazilian territory, of which 99 species occur in the Caatinga (Zappi & Taylor 2020). In semiarid environments, cacti represent a group of great ecological relevance due to the numerous interactions established with other plants and animals, including human populations, which adopt them as an important source of food resources (Ortega-Baes & Godínez-Alvarez 2006).

In this work, we investigate the effects of topographic variables on the distribution of cacti assemblages along an elevation gradient in the Brazilian Caatinga. Our main question is: how do topographic variables influence patterns of composition, species richness and structural parameters of the assemblage of Cactaceae? In this context, we aimed to (1) determine the species of cacti inhabiting a single elevation gradient; (2) analyze the effects that topographic variables have on composition, species richness, abundance and structural parameters (density, mean diameter and height); and (3) analyze the distribution dispersion patterns of cactus species along the elevation gradient. The results of this study have the potential to provide useful information for the management and conservation of Cactaceae in general, but especially in the Caatinga.

Material and Methods

TThe study was carried out in the Caatinga Domain, a semi-arid ecological region of Brazil, in the Serra da Arara (07°23'8.12" S, 36°23'36.74" W; Fig. 1) which is located in the Planalto da Borborema (Borborema Plateau), in the São João do Cariri municipality, Paraiba State, Northeastern Brazil. With lively relief, granitic massif, soils very susceptible to erosion, with varied depth and fertility (in general, fertile) (Velloso *et al*. 2002). Comprises an altitudinal range of 480 to 660 m a.s.l., with a heterogeneous topography and soil along this gradient (Ramos *et al*. 2020), and in some areas with peaks reaching up to 1.000 m a.s.l. The climate of the region is tropical, dry and hot (Álvares *et al*. 2014), with annual rainfall between 300 and 600 mm, concentrated within a two to four-month period, which accounts for 65% of the total annual rainfall (Souza *et al*. 2020). Annual average relative humidity is approximately 70% (Andrade et al. 2009), with temperatures ranging from 18 to 22 °C between July and August and maximum temperatures between 28 and 31 °C in November and December (Souza *et al.* 2020). The soils of the region are Chromic Luvissols (FAO/UNESCO) and are frequently rocky and with a low water retention capacity but rich in nutrients (Santos *et al*. 2011). The vegetation in the region is predominantly the seasonally dry tropical forest (Silva & Souza 2018). The region exhibits a mosaic of vegetation types strongly determined by environmental factors (Prado 2003; Moro *et al*. 2016). Surrounding the mountain occurs a mosaic of natural vegetation and areas managed for agriculture and extensive livestock, with trails left by grazing domestic animals, mainly goats (*Capra aegagrus*), and selective cut marks in the vegetation, are commonly found at the base of mountain (Ramos *et al.* 2020). The vegetation within the gradient is predominated by the shrubby strata with few trees, but, at the intermediate elevation to the top, with a greater rock cover and steep slopes (Diniz 2016), occurs a Caatinga arborea with higher tree density and size

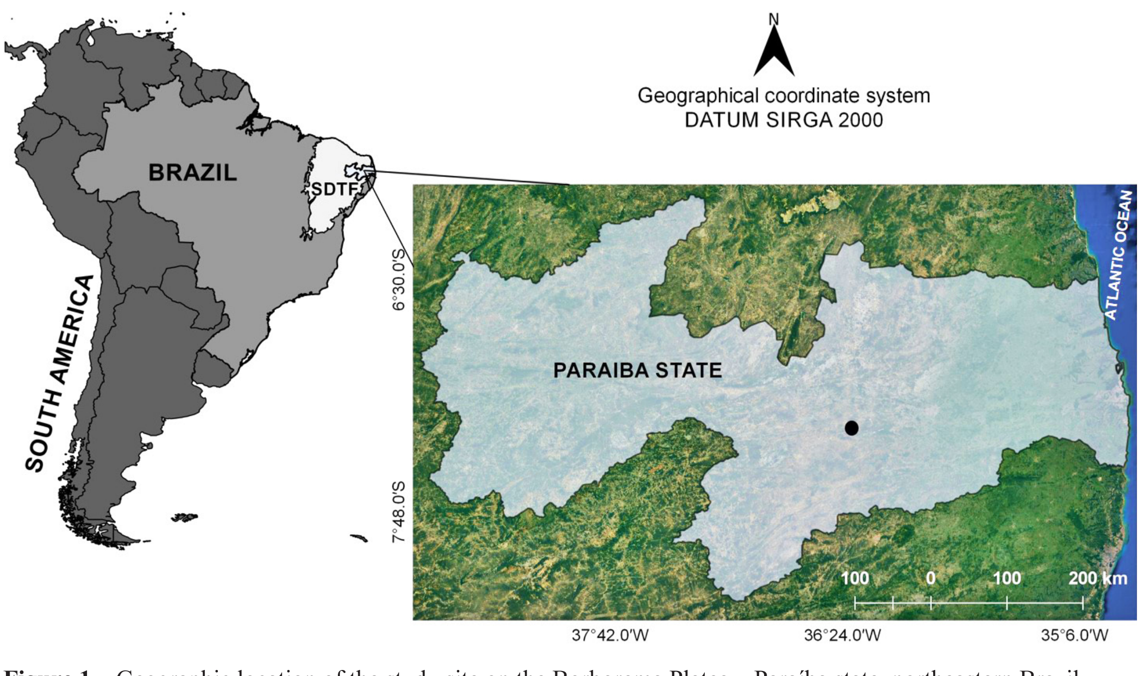

Figure 1 – Geographic location of the study site on the Borborema Plateau, Paraíba state, northeastern Brazil. (● = Arara mountain).

with bromeliads in the understory, as well as species richness and the presence of some typical taxa of humid regions (*e.g. Clusia paralicola* G.Mariz), when compared to lower altitude vegetation (Diniz 2016; Almeida *et al*. 2019; Ramos *et al*. 2020).

The vegetation around and at the base the mountain is characterized by a mosaic of fragments of Caatinga and areas managed for agriculture and extensive livestock, which are the main economic activities in the region. Trails left by grazing domestic animals, mainly goats (*Capra aegagrus*), and selective cut marks in the vegetation, are commonly found at the base of the mountain (Diniz 2016; Ramos *et al*. 2020). The intermediate portion to the top of Serra da Arara is characterized by greater rock cover, steep slopes and the presence of bromeliads (Almeida *et al.* 2020; Diniz 2016) contribute to the formation of distinct microhabitats which has a more arboreal size, greater species richness and the presence of some typical taxa from more humid regions, when compared to lower altitude vegetation (Diniz 2016; Ramos *et al.* 2020).

Sampling design and topographic variables

Fieldwork was carried out between January 2014 and December 2016. To survey the structure and composition of vegetation, four transects were establish - two windward and two leeward of the Serra da Arara. Each transect comprised 25 plots of 100-m² each spaced 10 m apart forming a continuum along the topographic gradient, with a total coverage of the four transects being one hectare (1.0 ha). We identified all living individuals of cacti of all sizes and life forms ≥ 1 m in height (measured with 12-m long measuring rod) and with stem diameter at ground level (DGL) ≥ 3 cm (measured with a caliper or tape measure), with the exception of the species *Melocactus zehntneri* (Britton & Rose) Luetzelburg and *Tacinga inamoena* (K. Schum.) N.P. Taylor & Stuppy, for which all individuals were included regardless of the inclusion criteria. Abundance, mean diameter (cm) and height (m) were determined for each species.

Species were identified in the field whenever possible; otherwise, exsiccates were collected for determination with the consultation of experts or through comparison with vouchers kept at the herbarium Manuel de Arruda Câmara (HACAM) of the Universidade Estadual de Paraíba (UEPB). Spelling and synonyms we verified for all species using the Flora do Brasil 2020 database (<http://floradobrasil.jbrj.gov.br>) and Reflora databases. The species were classified in families according to Angiosperm Phylogeny Group IV (APG IV 2016).

Elevation (m), slope (degrees), soil depth (cm) and rockiness (%) were measured for each plot. Elevation was measured using a Garmin 3.0 GPS (by satellite). Slope and soil depth were measured within each plot using a clinometer and an auger, respectively. The percentage of above-ground rock cover (rockiness) was visually estimated and classified into one of four categories, according to Abreu *et al* (2012): Class 1 0–25% coverage; Class 2 26–50%; Class 3 51–75%; and Class 4 76–100%.

Data analysis

Data were first tested for normality with the Shapiro-Wilk test and homoscedasticity of variances with Bartlett's test. Spearman rank correlation coefficients (r_s), calculated with software PAST 2.17c (Hammer *et al.* 2001), were used to determine whether topographic variables affect the distribution, richness and abundance of cacti along the elevation gradient.

The Morisita dispersion index (Iδ), calculated with the program R version 3.2.1 (2015) was used to determine the pattern of spatial dispersion of cactus species sampled for all plots (2015). Calculated values for the Morisita index (Imor) can range from 0 to n, while values of Mclu and Muni represent the upper and lower limits of the Morisita index (Imor) for a random distribution. If Imor > Mclu, there is an aggregate spatial distribution, while if Imor < Muni, there is a regular spatial distribution. Finally, the standardized Morisita index (Imst), ranges from -1 to 1, with values between -0.50 and 0.50 indicating a random distribution. Values if Imst lower than -0.50 indicate a regular distribution while values above 0.50 indicate an aggregate distribution.

Results

A total of 554 individuals belonging to five species were sampled, being two columnar: *Pilosocereus gounellei* (F.A.C. Weber) Byles and G. D. Rowley, Pilosocereus pachycladus (F. Ritter), two complained: *Tacinga palmadora* (Britton and Rose) e *Tacinga inamoena*, and one globular: *Melocactus zehntneri*. The species *T. palmadora* had the highest abundance (434 individuals), while *M. zehntneri* had the lowest (five individuals) (Tab. 1). The greatest mean height and mean volume were for *P. pachycladus*, while *T. inamoena* had the lowest mean volume and mean diameter (Tab. 1). The species *P. gounellei* and *T. palmadora* were observed to have greater abundance in plots bellow 500 m and, therefore, were negatively correlated with elevation (rs= -0.370 and rs= -0.401, respectively; p<0.05), slope (rs=-0.470 and rs=-0.350; p<0.05), and rockiness (rs=-0.234 and rs=-0.437; p<0.05), and positively correlated with soil depth (rs=0.330 and rs=0.295; p<0.05). On the other hand, *P. pachycladus* was characterized as a generalist, exhibiting a broad distribution throughout the mountain and, thus, was not correlated with any of the analyzed variables (p>0.05). Finally, *M. zehntneri* was found only in plots located at elevations between 500 and 563 m, and *T. inamoena* was positively correlated with rockiness (rs=0.261; p<0.05) at the highest elevations.

All of the studied cacti species exhibited aggregate distribution patterns. The species *M. zehntneri* had the highest Morista index, indicating an aggregate distribution pattern, followed by *T. inamoena* and *P. gounellei* (Imor > Mclu; Imst > 0.50), while *P. pachycladus* and *T. palmadora* had the least aggregated distributions due to the formation of groups of individuals at all elevations (Imor > Mclu; Imst = 0.50), although *T. palmadora* formed larger groups at lower elevations.

Discussion

The species richness and abundance found here are similar to values reported by other studies carried out in the semi-arid region of Brazil (Rodal & Nascimento 2002; Barbosa *et al.* 2007; Lacerda *et al.* 2007; Parente *et al.* 2010; Araújo *et al.* 2012; Pereira *et al.* 2012; Ferreira *et al.* 2016). Although species richness was found to be similar to other studies, the five sampled species corresponded to 50% of the total richness of cacti species present in the semi-arid region of Brazil (Barbosa *et al.* 2007), which likely reflects the high environmental heterogeneity of the mountain for the establishment of species with different habitat and condition requirements.

Despite the narrow altitudinal range, the mountains of the Brazilian semi-arid region have high environmental heterogeneity (Lopes *et al*. 2017). Among other factors, variation in topographic characteristics along the gradient promotes the formation of different micro-habitats, which influences the distribution of cacti (Costa *et al.* 2007) since each species reacts with particular adjustments to distinct abiotic conditions and ecological requirements (Kraft *et al*. 2015).

The decrease in abundance and richness of cacti at higher elevations can be explained by the different environmental characteristics of this area, such as the greater presence of rockiness, greater slope, and shallow soil. In addition, a more species in the arboreal community is found at higher altitudes, which can provide greater shade and humidity, thus inhibiting the presence of cacti. Distinct environmental conditions (topographic factors) can result in differences in community composition (Urbanetz *et al.* 2012; Rocha & Amorim 2012; Kouba *et al.* 2014; Gurvich *et al.* 2014). The synergic influence of slope, rockiness and soil depth results in different microhabitats that are responsible for variation in the abundance and composition of cacti along the elevation gradient.

The distinct morphophysiological characteristics of some species reflect adaptations of their different life forms to specific microhabitats

Table 1 – Structural parameters for species of cacti of Serra da Arara, São João do Cariri, Northeast Brazil. The respective values represent means for each parameter.

Species	Height (m)	Abundance	Diameter (cm)	Volume (m³)
Melocactus zehntneri	0.14	5	17.0	0.02
Pilosocereus pachycladus	8.1	53	14.8	10.7
Pilosocereus gounellei	1.3	41	6.1	0.18
Tacinga inamoena	0.33	21	3.7	0.01
Tacinga palmadora	1.7	434	4.5	1.3

(Moro *et al.* 2015). Some species of cacti easily survive with roots inserted in cracks of rocks (Zappi *et al*. 2011a), as is the case for *T. inamoena*, which is often found in inselbergs in the region, corroborating the present results that found the species to be associated with areas of greater rockiness (Lopes *et al*. 2017; Lopes-Silva *et al*. 2017). On the other hand, *P. gounellei*, for example, was positively correlated with deeper soils in the present study.

Differences in patterns of dispersion demonstrate that intraspecific patterns are also important for describing differences at community levels (Gaston *et al.* 2008), and for showing the limits established by the habitat filters to which these individuals are subjected (Kraft *et al.* 2015). The formation of groups along the elevation gradient (as evidenced by Morisita indices) reinforces the negative correlations between cactus abundance and elevation and slope (Gonçalves *et al*. 2016). For example, *P. gounellei* and *T. palmadora* have greater abundance and dominance in areas of plains and plateaus in the Caatinga (Parente *et al.* 2010; Araújo *et al*. 2012; Pereira *et al.* 2012). These species were also present in great abundance at lower elevations in the present study, precisely in areas of open Caatinga vegetation characterized by chronic anthropogenic disturbance (Lopes *et al.* 2017). It is worth noting that the clonal propagation capacity of *T. palmadora* may be directly influencing the abundance of this species, especially in areas with greater intensity of disturbances, such as where domestic animals walk or graze, which break cladodes and give rise to new individuals of the species (Ribeiro *et al*. 2015).

AAreas at the base of mountains in the Caatinga region are generally subjected to greater anthropogenic pressure, and even so *P. gounellei* and *T. palmadora* has greater abundance and aggregated distribution at the base of the mountain, along with their. It is worth noting, that the abundance of some species of cacti increases when their habitat experiences anthropogenic interference (Zappi *et a*l. 2011b). Corroborating Zappi *et al*. (2011b), our results also suggest that these species, especially *T. palmadora*, are benefit by the anthropogenic impacts. On the other hand, the restriction of *P. gounellei* at the base of the mountain, may be a restriction on the environmental conditions of the higher areas. *P. pachycladus* was uniformly distributed throughout the study area, even occurring in anthropized areas, not corroborating the results of Oliveira *et al.* (2020) that show the species is sensitive to disturbed places. *M. zehntmeri* was found at high levels in the study area, however, we cannot say that its occurrence is related to local environmental conditions, since the low n sample (five individuals) is insufficient to indicate a more consistent pattern.

It has been suggested that cacti species can be used as indicators of environmental heterogeneity and that the distributions of different species reflect edaphic gradients (Ferreira *et al.* 2016). The results presented here also indicate that cacti species can be used for the analysis of heterogeneity in the formation of microhabitats at small scales, with topographic factors (elevation, slope, soil depth, rockiness) being drivers of patterns of abundance and richness of species of Cactaceae. This variation in richness and abundance may also depend on the floristic arrays in which the cacti species are located, which serve as habitat filters (Kraft *et al.* 2015). In addition, the pattern of spatial dispersal of cacti may be related to topographic variables and also to the type of land use to which the plant communities are subjected (Lopes *et al.* 2017).

The results of the present study show that the cacti species can be used as indicators of environmental heterogeneity with different distribution patterns of composition along elevation gradients in the semi-arid region of Brazil. Cacti communities can be indicative of variation in microhabitats along an elevation gradient. The data presented here also show that the mountains of the Brazilian Caatinga represent important refuges for natural vegetation and, thus, are important for the conservation of local biodiversity, because the five sampled species corresponded to 50% of the total richness of cacti species present in this region. This importance is due to the fact that these mountains represent areas with distinct microenvironments that can provide shelter for different species of cacti. Thus, more studies of this nature are needed for a better understanding the factors that modulate the distribution of Cactaceas, and so, making decisions in relation to the conservation of these populations.

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References

Abreu MF, Pinto JRR, Maracahipes L, Gomes L, Oliveira EA, Marimon BS, Marimon Junior BH, Farias J & Lenza E (2012) Influence of edaphic variables on the floristic composition and structure of the tree-shrub vegetation in typical and rocky outcrop cerrado areas in Serra Negra, Goiás state, Brazil. Brazilian Journal of Botany 35: 259-272.

Almeida HA, Ramos MB, Diniz FC & Lopes SF (2020) What is the role of altitudinal variation in the stock and composition of litter? Floresta e Ambiente 27: 1-8.

Álvares CA, Stape JL, Sentelhas PC, Gonçalves JLM & Sparovek G (2014) Köppen's climate classification map for Brazil. Meteorologische Zeitschrif 22: 711-728.

Andrade MVM, Andrade AP, Silva DS, Bruno RLA & Guedes DS (2009) Levantamento florístico e estrutura fitossociológica do estrato herbáceo e subarbustivo em áreas de Caatinga no Cariri paraibano. Revista Caatinga 22: 229-237.

APG IV - Angiosperm Phylogeny Group (2016) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society 181: 1-20.

Araújo KD, Parente HN, Éder-Silva E, Ramalho CI, Dantas RT, Andrade AP & Silva DSS (2012) Estrutura fitossociológica do estrato arbustivo-arbóreo em areas contíguas de Caatinga no Cariri Paraibano. BGJ: Geosciences and Humanities research medium Uberlândia 3: 155-169.

Barbosa MRV, Lima IB, Lima JR, Cunha JP, Agra MF & Thomas WW (2007) Vegetação e Flora no Cariri Paraibano. Oecologia Brasilienses 11: 313-32.

Born J, Pluess AR, Burslem DFRP, Nilus R, Maycock CR & Ghazoul J (2014) Differing life history characteristics support coexistence of tree soil generalist and specialist species in tropical rain forests. Biotropica 46: 58-68.

Boulangeat I, Lavergne S, Van ESJ, Garraud L & Thuiller W (2012) Niche breadth rarity and ecological characteristics within a regional flora spanning large environmental gradients. Journal of Biogeography 39: 204-214.

Costa RC, Araújo FS & Lima-Verde LW (2007) Flora and life-form spectrum in area of deciduous thorn wood land (caatinga) in northeastern Brazil. Journal of Arid Environments 68: 237-247.

Fernandes MF, Cardoso D & Queiroz LP (2020). An updated plant checklist of the Brazilian Caatinga seasonally dry forests and woodlands reveals high species richness and endemism. Journal of Arid Environments 174: 1-8.

Ferreira PSMF, Lopes SF & Trovão DMBM (2016) Patterns of species richness and abundance among cactus communities receiving different rainfall levels in the semiarid region of Brazil. Acta Botanica Brasilica 30: 569-576.

Gaston KJ, Chown SL & Evans KL (2008) Ecogeographical rules: elements of a synthesis. Journal Biogeographic 35: 483-500.

Gonçalves PHS, Albuquerque UP & Medeiros PM (2016) The most commonly available woody plant species are the most useful for human populations: A meta-analysis. Ecological Applications. 26: 2228-2253.

Gurvich DE, Zeballos SR & Demaio PH (2014) Diversity and composition of cactus species along an altitudinal gradient in the Sierras Del Norte Mountains (Códoba Argentina). South African Journal of Botany 93: 142-147.

Hammer Ø, Harper DAT & Ryan PD (2001) Past: paleontological statistics software package for education and data analysis. Palaeontologia Electronica, vol. 4, issue 1, art. 4: 9p. Available at <http://palaeo-electronica.org/2001_1/past/issue1_01.htm>.

Kouba Y, Martinez-Garcia F, Frutos A & Alados CL (2014) Plant β-diversity in human-altered Forest ecosystems: the importance of the structural spatial and topographical characteristics of stands in patterning plant species assemblages. European Journal of Forest Research 133: 1057-1072.

Koch R, Almeida-Cortez JS & Kleinschmit B (2017) Revealing areas of high nature conservation importance in a seasonally dry tropical forest in Brazil: combination of modelled plant diversity hot spots and threat patterns. Journal for nature conservation 35: 24-39.

Kraft NJ, Adler PB, James EC, Fuller S & Levine JM (2015) Community phylogenetics and ecosystem functioning - community assembly coexistence and the environmental filtering metaphor. Functional Ecology 29: 592-599.

Lacerda AV, Barbosa FM & Barbosa MRV (2007) Estudo do componente arbustivo-arbóreo de matas ciliares na bacia do Rio Taperoá: uma perspectiva para a sustentabilidade dos recursos naturais. Oecologia brasiliensis 11: 331-340.

Lopes SF, Ramos MB & Almeida GR (2017) The role of mountains as refugia for biodiversity in Brazilian Caatinga: conservationist implications. Tropical Conservation Science 10: 1-12.

Lopes-Silva R F, Rodrigues JDS, Gomes-Silva F, Lucena DDS & Lucena MDFDA (2019). Composição florística de um inselberg no semiárido paraibano, nordeste brasileiro. Rodriguésia 70. doi: http://doi.org/10.1590/2175-7860201970079.

Lucena CM, Costa GM, Sousa RF, Carvalho TKN, Marreiros NA, Alves CAB, Pereira DD & Lucena RFP (2012) Conhecimento local sobre cactáceas em comunidades rurais na mesorregião do sertão da Paraíba (Nordeste Brasil). Biotemas 25: 281-291.

Mera AG, Orellana JAV, Perea EL, Cruz JC, De La Vera CT & Benavides FV (2012) Patrones de distribución de las comunidades de Cactáceas em lãs vertientes occidentales de los Andes peruanos. Caldasia 34: 257-275.

Martorell C & Peters E M (2005) The measurement of chronic disturbance and its effects on the threatened cactus *Mammillaria pectinifera*. Biological Conservation, 124: 199-207.

Méndez-Toribio M, Meave JA, Zermeño-Hernández I & Ibarra-Manríquez G (2016) Effects of slope aspect and topographic position on environmental variables disturbance regime and tree community attributes in a seasonal tropical dry forest. Journal of Vegetation Science 27: 1094-1103.

Moro MF, Lughadha EN, Araújo FS & Martins FR (2016) A phytogeographical metaanalysis of the Semiarid Caatinga domain in Brazilian. The Botanical Review 82: 91-148. <https://doi.org/10.1007/s12229-016-9164-z>

Moro MF, Silva IA, Araújo FS, Lughadha EN, Meagher TR & Martins FR (2015) The role of edaphic environment and climate in structuring phylogenetic pattern in seasonally dry tropical plant communities. Plos One 23: 1-18.

Oliveira-Filho AT, Cardoso D, Schrire BD, Lewis GP, Pennington RT, Brummer TJ, Rotella J & Lawin M (2013) Stability structures tropical woody plant diversity more than seasonality: insights into the ecology of high legume-succulent-plant biodiversity. South African Journal of Botany 89: 42-57.

Paraíba - Secretaria de Planejamento (1997) Plano diretor de recursos hídricos do estado da Paraíba: diagnóstico. Vol. 3. João Pessoa.

Paraíba - Secretaria Extraordinária de Meio Ambiente dos Recursos Hídricos e Minerais / SUDEMA - Superintendência de Desenvolvimento do Meio Ambiente (2000) Zoneamento Ecológico-econômico do estado da Paraíba: região do Cariri Ocidental. Estudos Hidrológicos, João Pessoa.

Parente HN, Araujo KD, Silva ÉÉ, Andrade AP, Dantas RT, Silva DS & Ramalho CI (2010) Parâmetros fitossociológicos do extrato arbóreo-arbustivo em áreas contíguas de caatinga no Cariri Paraibano. Revista Científica de Produção Animal 12: 138-141.

Pereira Junior LR, Andrade AP & Araújo KD (2012) Composição florística e fitossociológica de um fragmento de Caatinga em Monteiro-PB. Holos 6: 73-87.

Prado DE (2008) As caatingas da América do Sul. *In*: Leal IR, Tabarelli M, Silva JMC (eds.) Ecologia e conservação da Caatinga. 3ª ed. Ed. Universitária da UFPE, Recife.

R Core Team (2015) R: a language and environment for statistical computing. R Foundation for Statistical Computing Vienna. Available at <http://www.R-project.org/>.

Ramos MB, Diniz FC, Almeida HA, Almeida GR, Pinto AS, Meave JA, Lopes SF (2020) The role of edaphic factors on plant species richness and diversity along altitudinal gradients in the Brazilian semi-arid region. Journal Tropical Ecology.

Ribeiro EMS, Arroyo-Rodríguez V, Santos BA, Tabarelli M & Leal IR (2015) Chronic anthropogenic disturbance drives the biological impoverishment of the Brazilian Caatinga vegetation. Journal of Applied Ecology 52: 611-620.

Ricklefs RE (2015) Intrinsic dynamics of the regional community. Ecology Letters 18: 497-503.

Rito KF, Arroyo-Rodríguez V, Queiroz RT, Leal IR & Tabarelli M (2017) Precipitation mediates the effect of human disturbance on the Brazilian Caatinga vegetation. Journal of Ecology 105: 828-838.

Rocha EA & Agra MF (2002) Flora do Pico do Jabre Paraíba Brasil: Cactaceae Juss. Acta Botanica Brasilica 16: 15-21.

Rocha DSB & Amorim AMA (2012) Heterogeneidade altitudinal na Floresta Atlântica setentrional: um estudo de caso no sul da Bahia Brasil. Acta Botanica Brasilica 26: 309-327.

Rodal MJN & Nascimento LM (2002) Levantamento florístico da floresta serrana da Reserva Biológica de Serra Negra Itaparica-PE. Acta Botanica Brasilica 16: 481-500.

Rodrigues PMS, Schaefer CEGR, Silva JO, Ferreira Júnior WG, Santos RM & Neri AV (2018) The influence of soil on vegetation structure and plant diversity in different tropical savannic and forest habitats. Journal of Plant Ecology 11: 226-236.

Salas-Morales SH, Meave JÁ & Trejo I (2015) The relationship of meteorological patterns with changes in floristic richness along a large elevational gradient in a seasonally dry region of southern Mexico. International Journal of Biometeorology 59: 1861-1874.

Santos AC, Salcedo IH & Candeias ALB (2009) Relação entre o relevo e as classes texturais do solo na microbacia hidrográfica de Vaca Brava PB. Revista Brasileira de Cartografia 54: 86-94.

Silva FKG, Lopes SF, Lopez LC, Melo JIM & Trovão DMBM (2014) Patterns of species richness and conservation in the Caatinga along elevation gadients in a semiarid ecosystem. Journal of Arid Environments 110: 47-52.

Silva AC & Souza AF (2018) Aridity drives plant biogeographical sub regions in the Caatinga the largest tropical dry forest and woodland block in South America. PloS One 13: e0196130.

Silva JMC, Barbosa LCF, Leal IR & Tabarelli M (2017) The Caatinga: understanding the challenges. *In*: Silva JMC, Leal IR & Tabarelli M (eds.) Caatinga. The largest tropical dry forest region in South America. Springer International Publishing, Cham. Pp. 3-19.

Urbanetz C, Lehn CR, Salis SM, Bueno ML & Alves FM (2012) Composição e distribuição de espécies arbóreas em gradiente altitudinal Morraria do Urucum Brasil. Oecologia Australis 16: 859-877.

Velloso AL, Sampaio EVSB & Pareyn FGC (2002) Ecorregiões propostas para o bioma Caatinga. Associação Plantas do Nordeste, Instituto de Conservação Ambiental. The Nature Conservancy do Brasil, Recife.76p.

Zappi D, Taylor N, Larocca J & Calvente A (2011a) Domínios fitogeográficos. *In*: Silva SR (org.) Plano de ação nacional para a conservação das cactáceas. Brasília ICMBIO Série Espécies Ameaçadas 24: 31-39.

Zappi D, Taylor N & Santos MR (2011b) Conservação das Cactaceae no Brasil. *In*: Silva SR (org.) Plano de ação nacional para a conservação das cactáceas. Vol. 24. Brasília ICMBIO Série Espécies Ameaçadas 24: 29-31.

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