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A PHYTOGEOGRAPHICAL APPROACH TO THE SAVANNA FORMATIONS OF THE CEARÁ STATE, BRAZIL: BETA DIVERSITY PATTERNS AND CONSERVATION PERSPECTIVES

UMA ABORDAGEM FITOGEOGRÁFICA DAS FORMAÇÕES SAVÂNICAS DO ESTADO CEARÁ, BRASIL: PADRÕES DE DIVERSIDADE BETA E PERSPECTIVAS PARA A CONSERVAÇÃO

UN ENFOQUE FITOGEOGRÁFICO DE LAS FORMACIONES DE SABANA DEL ESTADO DE CEARÁ, BRASIL: PATRONES DE DIVERSIDAD BETA Y PERSPECTIVAS PARA LA CONSERVACIÓN

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ABSTRACT
The study of the SAVANNA formations in Ceará has long been limited to the sedimentary surfaces of the state. Recently, this knowledge expanded, giving rise to the term "savannas of the caatinga" for areas that exhibit cerrado species but are floristically more similar to the Crystalline Caatinga. Understanding how these areas interact is crucial for informing conservation policies, which currently have limited scope. Accordingly, this study aimed to investigate the interaction among these areas by analyzing their distribution, floristic aspects, beta diversity patterns, and coverage by Conservation Units (CU). For this purpose, 11 savanna formations were selected, and data were collected from field expeditions conducted between April 2012 and December 2023, as well as from articles, herbarium collections, and specialized databases (Flora e Funga do Brasil, SpeciesLink, and the Global Biodiversity Information Facility). The analyses revealed two distinct groups with similarity indices below 40%, indicating high beta diversity. The presence of *Qualea parviflora* as the most frequent species in eight areas was noteworthy, along with taxa new to science (*Borreria savannicola* and *Hexasepalum nordestinum*) restricted to these formations. Of these locations, Conservation Units (CU) protects only three, where environmental impacts are still observed. This finding underscores the complexity and challenges in effectively managing these ecosystems, emphasizing the need for improvements in conservation strategies to adequately include savanna formations on the conservation map of Ceará.
Keywords: Biogeography. Cerrado. Phytoecological Units.

RESUMO
O estudo das formações savânicas no Ceará limitou-se, por muito tempo, às superfícies sedimentares do estado. Recentemente, esse conhecimento expandiu-se, gerando o termo “savanas da caatinga” para aquelas áreas que apresentam espécies de cerrado, mas que são floristicamente mais similares à Caatinga do Cristalino. Compreender como essas áreas se relacionam é crucial

para fundamentar políticas conservacionistas, cuja abrangência é limitada. Diante disso, o presente trabalho objetivou investigar a interação entre essas áreas, analisando sua distribuição, aspectos florísticos, padrões de diversidade beta e cobertura por Unidades de Conservação (UC). Para isso, foram selecionadas 11 formações savânicas, cujos dados são provenientes de expedições de campo entre abril/2012 e dezembro/2023, artigos, coleção de herbários e bancos de dados especializados (Flora e Funga do Brasil, *SpeciesLink* e *Global Biodiversity Information Facility*). As análises revelaram dois grupos distintos, com índices de similaridade abaixo de 40%, o que indica alta diversidade beta. Destaca-se a presença de *Qualea parviflora* como a espécie mais frequente, presente em oito áreas, assim como táxons inéditos para a ciência (*Borreria savannicola* e *Hexasepalum nordestinum*) e restritos à essas formações. Desses locais, apenas três encontram-se resguardados por Unidades de Conservação, onde, mesmo assim, observam-se impactos ambientais. Tal constatação ressalta a complexidade e desafios na gestão efetiva desses ecossistemas, indicando a necessidade de aprimoramentos nas estratégias conservacionistas para incluir efetivamente as formações savânicas no mapa de conservação do Ceará.
Palavras-chave: Biogeografia. Cerrado. Unidades Fitoecológicas.

RESUMEN
El estudio de las formaciones de sabana en Ceará se limitó, durante mucho tiempo, a las superficies sedimentarias delestado. Recientemente, este conocimiento se ha ampliado generando el término “sabanas de caatinga” para aquellas áreas que tienen especies de cerrado, pero que florísticamente son más similares a la Caatinga Cristalino. Comprender cómo se relacionan estasáreas es crucial para apoyar las políticas de conservación, cuyo alcance es limitado. Ante esto, el presente trabajo tuvo como objetivo investigar la interacción entre estas áreas, analizando su distribución, aspectos florísticos, patrones de diversidad beta y cobertura por Unidades de Conservación (UC). Para ello, fueron seleccionadas 11 formaciones de sabana, cuyos datos provienen de expediciones de campo entre abril/2012 y diciembre/2023, artículos, colección de herbario y bases de datos especializadas (Flora y Funga do Brasil, SpeciesLink y Global Biodiversity Information Facility). Los análisis revelaron dos grupos distintos, con tasas de similitud inferiores al 40%, lo que indica una alta diversidad beta. Destaca como la especie más frecuente la presencia de Qualea parviflora, presente en ocho áreas, así como taxones nuevos para la ciencia (Borreria savannicola y Hexasepalum nordestinum) y restringidos a estas formaciones. De estas localidades, sólo tres están protegidas por Unidades de Conservación, donde, aun así, se observan impactos ambientales. Este hallazgo resalta la complejidad y los desafíos en el manejo efectivo de estos ecosistemas, indicando la necesidad de mejorar las estrategias de conservación para incluir efectivamente las formaciones desabana en el mapa de conservación de Ceará.
Palabras clave: Biogeografía. Grueso. Unidades Fitoecológicas.

INTRODUCTION

The Brazilian Caatinga, predominant in the Brazilian Northeast, stands out as the richest and most diverse core of Seasonally Dry Tropical Forests and Shrublands (FATSS), characterized by a remarkable environmental heterogeneity that harbors a rich variety of endemic taxa and genera (Fernandes; Cardoso; Queiroz, 2022; Silva; Leal; Tabarelli, 2017). This domain is surrounded by the Atlantic Forest and Cerrado, establishing with them a floristic-vegetational relationship widely studied but not completely elucidated (Andrade-Lima, 1981; Fernandes et al., 2022; Rizzini, 1997).

Throughout the entire extent of the Caatinga, it is possible to identify species characteristic of the two domains bordering it. These species establish themselves in disjointed areas that present environmental conditions and distinct physiognomies from those commonly observed for the Brazilian semiarid region (Bridgewater; Ratter; Ribeiro, 2004; Castro; Martins, 1999; Santos et al., 2007; Ratter; Bridgewater; Ribeiro, 2003).

In the case of the Cerrado, the largest, most biodiverse, and most threatened neotropical savanna, the Northeast is one of its three biodiversity supercenters (Castro; Martins, 1999; Myers et al., 2000). The floristic diversity of the northeastern cerrados goes beyond typical taxa widely distributed in the domain, also including locally abundant species but with distribution restricted to these areas (Castro; Martins; Fernandes, 1998; Castro et al., 2007; Vieira et al., 2019). This characteristic contributes to high beta diversity, which assesses species variation along an environmental gradient (Bridgewater; Ratter; Ribeiro, 2004; Castro; Martins, 1999).

In Ceará, areas with cerrado vegetation are among the 11 Phytogeological Units cataloged for the state, categorized as "exception areas" alongside forest formations of altitude marshes (Figueiredo, 1997; Moro et al., 2015). For a long period, scientific research in these environments focused on the state's extremes, encompassing cerrados established on the sedimentary surfaces of the Araripe Plateau and the Barreiras Formation (Costa; Araújo; Lima-Verde, 2004; Moro; Castro; Araújo, 2011; Ribeiro-Silva et al., 2012). Recently, this perspective has begun to change, with Nepomuceno et al. (2021) introducing the concept of "caatinga

savannas" to describe areas whose flora resembles more the Caatinga of Cristalino but still maintains typical species of the Cerrado's nuclear area.

As new SAVANNA formations are identified in the state, it becomes necessary to describe how these areas interact with each other and with the environment in which they are inserted. Such information underpins, for example, conservation policies, which, in defining areas for environmental protection, have ecological representativeness as a fundamental requirement (Santos; Cherem, 2023).

In Ceará territory, only 7.87% of the land is covered by some category of Conservation Unit (CU), with 92.4% of them being of Sustainable Use and 7.6% of Integral Protection (Gomes et al., 2022). Furthermore, there is an inadequate distribution of these CUs, which are concentrated in the wettest areas of altitude marshes, neglecting more arid ecosystems, such as the Cristallyne and Sedimentary Caatinga, the “Carnaubal”, and the “Cerrados” and “Cerradões”. These physiognomies comprise only 0.44% of the total protected area, making them particularly vulnerable to environmental impacts (Antogiovanni et al., 2020; Gomes et al., 2022).

Faced with this, the following questions have arisen: (i) with the discovery of new areas, how are the savanna formations distributed in the state? (ii) In their interaction, does the state beta diversity reflect the regional panorama described for Cerrado areas? (iii) What are the physical characteristics of the environments where these formations establish themselves? (iv) How is the coverage of these areas by Conservation Units?

In this scenario, this work aims to investigate the relationship that the savanna formations of Ceará have with each other, analyzing their distribution, floristic composition, beta diversity patterns, and the coverage of these locations by Conservation Units.

METHODS

Primary data from field expeditions conducted between April/2012 and December/2023 were used, along with secondary data from previously published works. Floristic surveys took place at the Professor Francisco José de Abreu Matos Herbarium (HUVA) of the Vale do Acaraú State University (UVA), with support from its associated projects, following the usual methodology (Mori et al., 1989; Peixoto; Maia, 2013). Table 1 details the locations selected for this study. Information regarding the physical aspects of each location followed the guidelines provided by Brandão and Freitas (2014), in addition to data from the Ceará Meteorology and Water Resources Foundation (FUNCEME), the Ceará Institute of Economic Research and Strategy (IPECE), and field observations.

Table 1. Savanna formations of Ceará selected for analysis. AC = Area code.

Sites	AC	Coordinates	Number of species	Reference
Papagaios	Sav_Papagaios	03°11’11”S, 40°44’35”W	110	Nepomuceno et al. (2021)
São Miguel	Sav_SM	03°21’32”S, 41°01’24”W	99	Nepomuceno et al. (2021)
Vereda dos Tomás	Sav_Veredas	03°13’33”S, 40°55’49”W	66	Nepomuceno et al. (2021)
Quilômetro 35	Sav_35	3°09'41.0"S, 40°46'15.2"W	102	Acervo HUVA
Bom Princípio	Sav_BP	03°11’51”S, 40°41’04”W	74	Nepomuceno et al. (2021)
Caracará	Sav_Caracará	3°42'33.8"S 40°06'47.5"W	85	Acervo HUVA
Fortaleza	Sav_Fortaleza	3º43’02”S, 38º32’35”W	126	Moro, Castro e Araújo (2011)
Serra de Ubatuba/Flores	Sav_SF	3°18'14.4"S, 41°10'35.0"W	60	Acervo HUVA + *SpeciesLink*

Sítio Palmeirinha	Sav_SP	4°17'55.3"S, 40°43'17.4"W	133	Acervo HUVA
Barbalha	Sav_Barbalha	07º24'S, 39º20'W	98	Costa, Araújo e Lima-Verde (2004)
Floresta Nacional do Araripe	Sav_Flona	07°23'50.22"S, 39°20'40.44''W	87	Ribeiro-Silva et al. (2012)

Fonte: os autores (2024).

In total, 11 areas were selected for analysis, with the classification of vegetation types in accordance with the proposal by Ribeiro and Walter (2008), as well as the concept of "savanna" used here to encompass all areas in the state that have typical Cerrado plant components, regardless of their arrangement in the landscape. Distribution maps of these areas were created in QGIS 3.28 Firenze (Rosas-Chavoya et al., 2022), and each location was placed within the context of the Phytogeological Units of Ceará, as defined by Figueiredo (1997) and Moro et al. (2015). For each area, information related to the number of genera and species per family, as well as the number of species per genus, was selected. It is worth noting that the studies chosen for analysis were required to have more than 60 species in their final floristic listing.

Angiosperm groups were classified according to the Angiosperm Phylogeny Group IV (APG, 2016), while the nomenclature of each taxon followed the Flora and Funga of Brazil (2024, constantly updated) and the Global Biodiversity Information Facility (GBIF, 2024, constantly updated). Both woody and non-woody strata were considered for analysis, with only native species remaining in the listings. Additionally, for a more accurate similarity analysis, species identified only at the genus level were disregarded. Taxa described with aff. or cf. were classified as belonging to the specified species (e.g., *Utricularia* cf. *gibba* → *Utricularia gibba*).

Due to listings published over 15 years ago, some species had their nomenclature updated. In order to standardize and incorporate the most recent nomenclature, the floristic lists were modified with the assistance of the PlantMiner algorithm, an online platform that performs automated queries to the Flora do Brasil database to identify possible spelling errors and nomenclatural legitimacy (Carvalho; Cianciaruso; Batalha, 2010).

To compute the similarity index between areas, the Sørensen-Dice Coefficient was chosen, which is suitable for studies involving presence-absence matrices (McCune; Grace; Urban, 2002). Its calculation is performed as follows

$$Sørensen - Dice = \frac{2 \times C}{S1 + S2}$$

This is twice the number of common species between two areas (C) divided by the sum of the species in each area (S1 and S2). The values range from 0 (completely different) to 1 (total similarity, with all species shared). The closer the coefficient is to 1, the lower the beta diversity (Ricklefs; Reyleya, 2016). This methodology is similar to that used by Bridgewater, Ratter, and Ribeiro (2004) for the Brazilian cerrados, Vieira et al. (2019) for northeastern cerrados, and Nepomuceno et al. (2021) for cerrado areas and other vegetation types. However, the first two studies only considered woody flora, while the latter also included herbaceous flora from Cristalino Caatinga and Restinga areas in their analyses.

To better present the results of the similarity analyses, an Unweighted Pair Group Method with Arithmetic Mean (UPGMA) was performed, a data clustering method (Rohlf, 1963). The presence-absence matrix was constructed using PAST 4.10 software (Hammer; Harper; Ryan, 2001). Another aspect analyzed was the frequency of species, expressed in numbers and percentage. In the classification used here, species present in more than 50% of

the areas were considered frequent. This definition is similar to that determined by Bridgewater, Ratter, and Ribeiro (2004) and Vieira et al. (2019).

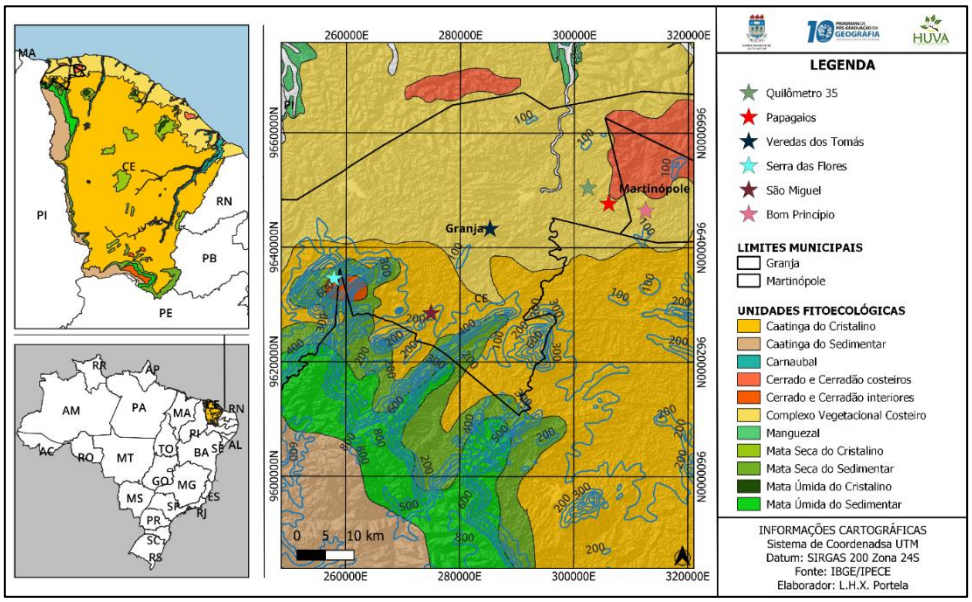
RESULTS AND DISCUSSION

Distribution of the savanna formations in the Ceará territory

Regarding the distribution of savanna formations in Ceará, they can be categorized into two types: those established at low altitudes (not exceeding 150 meters) and those situated at high altitudes (above 600 meters). These areas are characterized by different geological, geomorphological, soil, and climatic conditions, yet they share some typical species that aid in the identification of this vegetation type.

The areas of Papagaios, São Miguel, Veredas dos Tomás, and Quilômetro 35 belong to the municipality of Granja, while Bom Princípio is part of the municipality of Martinópole, Ceará (Map 1). Both municipalities are neighbors, which means that the areas are relatively close to each other. However, despite the proximity, there is no overlap between the areas, and the vegetation types are distinct (Nepomuceno et al., 2021).

Map 1. Savanna formations belonging to the municipalities of Granja and Martinópole.

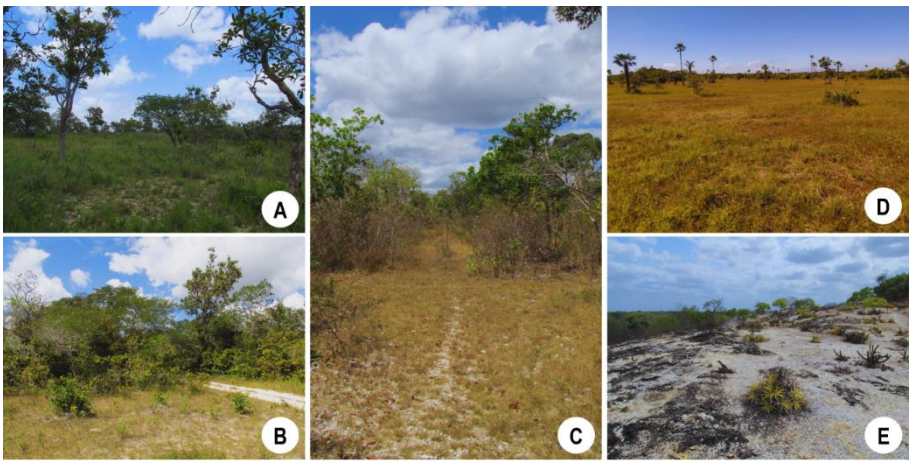


In the context of the phytogeological units of Ceará, four out of the five areas (Papagaios, Quilômetro 35, Vereda dos Tomás, and Bom Princípio) are located within the Coastal Vegetational Complex, which, in some parts of its extension, includes Coastal Cerrados and Cerradões (Figueiredo, 1997; Moro et al., 2015). These formations are directly associated with the sedimentary surfaces of the Barreiras Group, at low altitudes, where the predominant soils are sandy-clayey, such as Orthic Quartzarenic Neosols and Dystrophic Red-Yellow Argisols, with low natural fertility (Dantas et al., 2014). São Miguel, on the other hand, is located within the Crystaline Caatinga, also at minimal altitudinal levels, confirming the trend of interiorization of these vegetation formations (Ab'Saber, 2003). It is important to note that the savanna formation of Quilômetro 35 is being recorded for the first time in this study.

Out of the five areas mentioned above, four exhibit identifiable vegetation types according to Ribeiro and Walter (2008): Papagaios, Quilômetro 35, Vereda dos Tomás, and Bom Princípio. While Papagaios resembles a Typical Cerrado (Figure 1A), Vereda dos Tomás takes on the appearance of a Dense Cerrado (Figure 1B), and Bom Princípio transitions from

Dense Cerrado to Cerradão (Figure 1C) (Ribeiro; Walter, 2008). Quilômetro 35, despite being ecotonal with São Miguel (Nepomuceno et al., 2021), exhibits a vegetation type similar to a Cerrado Park (Figure 1D), where patches of tree vegetation are observed in specific points of the terrain, surrounded by a significant herbaceous layer (Ribeiro; Walter, 2008). On the other hand, São Miguel does not have a defined vegetation type, as the vegetation alternates with quartzitic rocky outcrops (Figure 1E) (Nepomuceno et al., 2021).

Figure 1. Savanna formations of Granja and Martinópole, northwest of Ceará, and their respective vegetation types. A – Papagaios; B – Veredas dos Tomás; C – Bom Princípio; D – Quilômetro 35; E – São Miguel. Photos: A-C and E: E.B. Souza; D: L.H.X. Portela.



In the same scenario but over granitic surfaces, we have the Caracará savanna in Sobral, established at the foot of the inselberg Serra do Barriga (Map 2). It is a caatinga savanna with patches of woody vegetation interspersed with a wide herbaceous layer, similar to a Typical Cerrado. However, during the rainy season, these patches form a continuous canopy, which is not typical of the vegetation type it resembles (Figure 2) (Ribeiro; Walter, 2008). This vegetation does not exceed 120 meters in altitude and is situated over Litholic Neosols and Luvisols, both characteristic of the Crystaline Caatinga (FUNCEME, 2018; Moro et al., 2015).

Map 2. Savanna formation located in the district of Caracará, Sobral, Ceará, at the foothills of the inselberg Serra do Barriga, over Crystaline Caatinga.

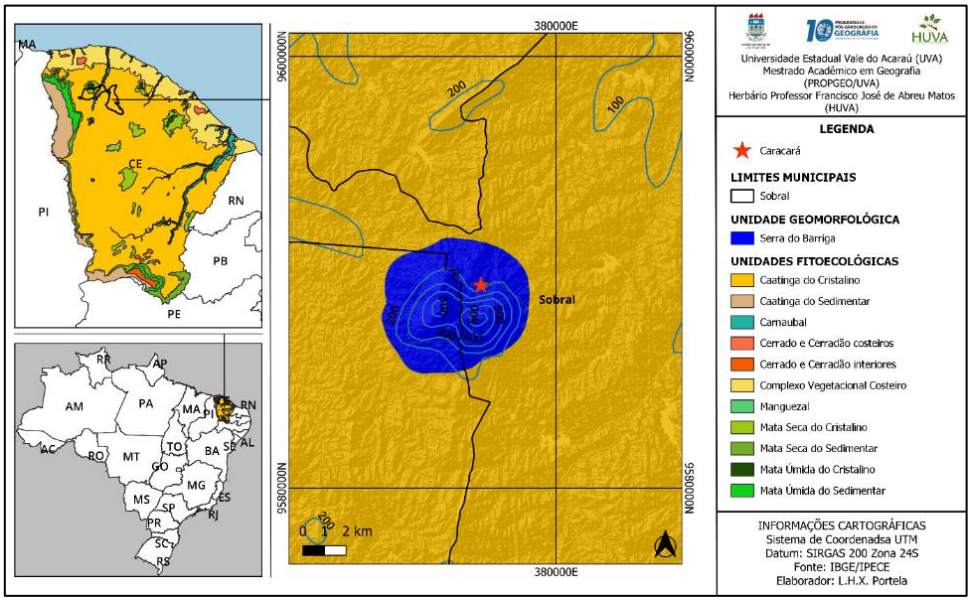
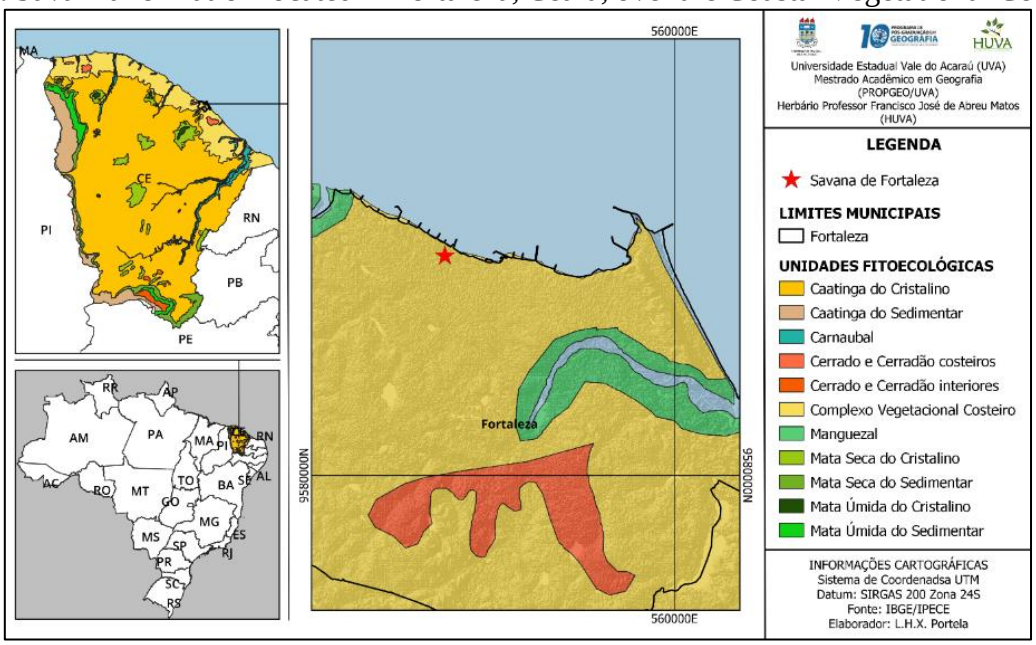


Figure 2. Savanna of Caracará, Sobral, Ceará. A – Vegetation type during the rainy season, with the inselberg Serra do Barriga in the background; B – Vegetation type during the dry season. Photos: L.H.X. Portela.

Still within the group of low-altitude savannas, there is the area studied by Moro, Castro, and Araújo (2011), in Fortaleza, Ceará (Map 3). Also situated within the context of the Barreiras Formation, over the Coastal Vegetational Complex, it does not exceed 20 meters in altitude and harbors vegetation types ranging from more open, resembling a Sparse Cerrado, to areas of Typical Cerrado and Dense Cerrado (Ribeiro; Walter, 2008).

Map 3. Savanna formation located in Fortaleza, Ceará, over the Coastal Vegetational Complex.



Moving on to the second category, there is the savanna formation described for the Serra de Ubatuba/Flores complex, a quartzitic massif adjacent to the Ibiapaba Plateau in the municipalities of Granja and Viçosa do Ceará, Ceará (França; Cabral, 1981) (Map 1).

Considered a relic area of extreme biological importance (Giulietti et al., 2003), the savanna formations there have been documented since the late 1970s (Figueiredo; Fernandes, 1987). Within the scope of the phytogeological units of Ceará, this vegetation belongs to the group of Interior Cerrados and Cerradões (Figueiredo, 1997; Moro et al., 2015), and it is the only known patch of Rocky Cerrado in Ceará, located on the plateau (above 700 meters in altitude) (Figure 3A).

Bordering this significant area of Rocky Cerrado is a zone of Typical Cerrado, established between 650-700 meters, which serves as a transition zone between the forest

formation of the slopes (belonging to the phytogeological unit of Wet Forests of the Crystaline) and the vegetation of the plateau (Figure 3B). It is worth noting that at higher altitudinal levels of the relief, there are also areas of Sparse Cerrado, interspersed with patches of humid forest.

Figura 3. Savanna formations of the Serra de Ubatuba/Flores, between Granja and Viçosa do Ceará. A – Rocky Cerrado; B – Typical Cerrado. Photos: L.H.X. Portela.

Over the sedimentary surfaces of the Ipu formation (Serra Grande Group, Parnaíba Basin), at elevations above 550 meters, lies an area adorned with savanna vegetation, situated within the district of Sítio Palmeirinha, Ipu, Ceará (Map 4). The prevailing vegetation type is Dense Cerrado, characterized by the presence of sizable trees in some sections (Figure 4).

This vegetation thrives on Red-Yellow Latosols, a characteristic soil type described for cerradões (Reatto et al., 2008). Notably, in conjunction with the savanna areas, there are outcrops of sandstone (Batista et al., 2020), fostering the growth of species adapted to this substrate, alongside other herbaceous and subshrub plants that flourish in rock crevices and the substrate formed by surface erosion.

The presence of savannas in the Ibiapaba region was initially documented by Figueiredo (1989), who delineated this vegetation type in isolated areas of Viçosa do Ceará and Guaraciaba do Norte. However, no floristic inventories are available for these locations, rendering the savanna of Sítio Palmeirinha, also being documented for the first time in this study, the inaugural floristic investigation for the region.

Map 4. Savanna formation of Sítio Palmeirinha, Ibiapaba Plateau, Ipu, Ceará.

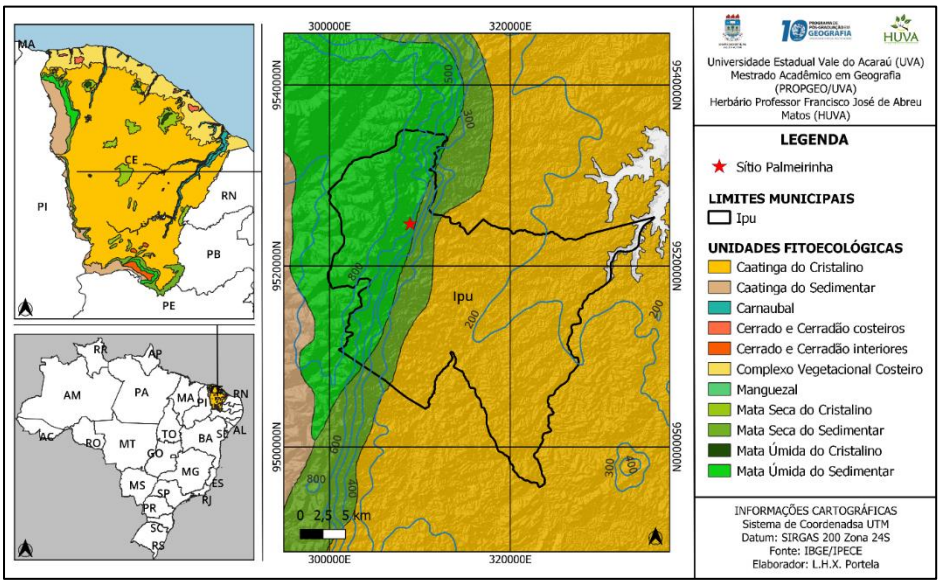


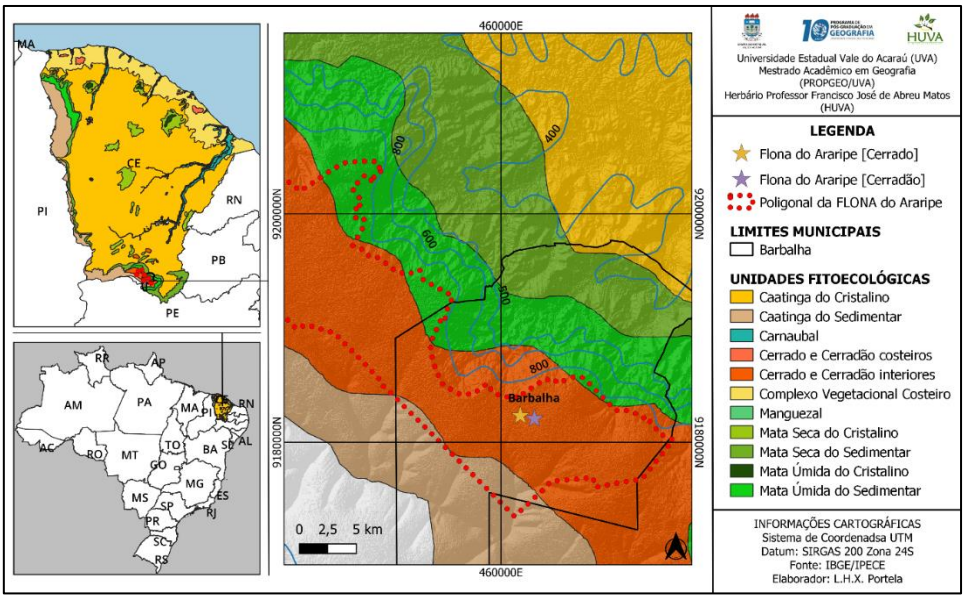
Figure 4. Savanna formation of Sítio Palmeirinha and its main physiognomies, Ibiapaba Plateau, Ipu, Ceará. A – Studied area during the rainy season, with Dense Cerrado in the background of the sandstone outcrops; B – Studied area during the dry season; C – Dense Cerrado area. Photos: L.H.X. Portela.

Lastly, we encounter the savannas nestled within the Chapada do Araripe, situated within the Araripe National Forest, one of the region's Conservation Units (UC) (Map 5). The "cerrados" of Araripe hold a longstanding recognition, fitting within the northeastern province of the domain outlined by Ratter, Bridgewater, and Ribeiro (2003).

The savanna formations within the Araripe National Forest are confined to the plateau of the chapada, covering an extensive area of 39 thousand hectares, with elevations ranging between 800 to 900 meters (Costa; Araújo; Lima-Verde, 2004; Ribeiro-Silva et al., 2012). Essentially, two primary physiognomies define this area: the Typical Cerrado and the Cerradão. These are sustained by sandstones and conglomeratic sandstones from the Cretaceous period, forming part of the Exu formation (Dantas et al., 2014).

The soils that develop over these sediments are of the dystrophic Red-Yellow Latosol type, characterized as sandy-clayey, susceptible to weathering, highly permeable and porous, friable, and of low natural fertility (Dantas et al., 2014). These characteristics resemble those found in the soils of the Central Plateau, the core area of the Cerrado (Reatto et al., 2008), thus justifying the presence of this vegetation type.

Map 5. Savanna formations of the Chapada do Araripe, within the context of the Araripe National Forest, Ceará.



Análises florísticas e biogeográficas

A total of 1041 individuals were cataloged across the 11 selected areas for analysis. Within this count, 575 species were identified, belonging to 310 genera and 92 families. Fabaceae exhibited the highest richness of genera (n=45) and species (n=97), followed by Asteraceae (19 genera and 27 spp.), Poaceae (17 genera and 25 spp.), Rubiaceae (16 genera and 30 spp.), and Apocynaceae and Lamiaceae (12 genera each and 19 and 17 spp., respectively).

Regarding genera with the highest species richness, Ipomoea L. was the most prominent with 11 species, followed by *Chamaecrista* (L.) Moench, *Mimosa* L., and *Senna* Mill. (nine spp. each), *Croton* L. (eight spp.), *Borreria* G.Mey., *Cyperus* L., *Fridericia* Mart. emend L.G. Lohmann, and *Sida* L. (seven spp. each), and *Combretum* Loefl., *Erythroxylum* L., *Ouratea* Aubl., and *Xyris* Gronov. ex L. (six spp. each). Notably, none of these genera were present in all analyzed areas, with those most frequently occurring listed in Table 2.

Among the most frequent species in the Ceará savanna formations, *Qualea parviflora* Mart. stood out as the most widespread, occurring in eight areas, followed by *Anacardium occidentale* L., *Chamaecrista flexuosa* (L.) Greene, *Curatella americana* L., *Myrcia splendens* (Sw.) DC., and *Ximenia americana* L. (each occurring in seven areas) (Table 3).

Of these species, *Qualea parviflora* was the most commonly found in northeastern cerrados, followed by *Anacardium occidentale* and *Curatella americana* (Bridgewater; Ratter; Ribeiro, 2004; Vieira et al., 2019), while *Qualea grandiflora* Mart. was documented as the most frequent species in the entire Cerrado domain (Ratter; Bridgewater; Ribeiro, 2003). Due to their high frequency, these species are considered oligarchic for the domain, alongside *Plathymenia reticulata* Benth. (Bridgewater; Ratter; Ribeiro, 2004).

Conversely, *Chamaecrista flexuosa*, *Myrcia splendens*, *Ximenia americana*, *Mimosa somnians* Humb. & Bonpl. ex Willd., *Pavonia cancellata* (L.) Cav., *Staelia virgata* (Link ex Roem. & Schult.) K.Schum., and *Stylosanthes angustifolia* Vogel fall

into the category of widely distributed species, capable of colonizing different types of vegetation (Flora e Funga do Brasil, 2024, constantly updated).

Agalinis hispidula (Mart.) D'Arcy, *Cuphea campestris* Mart. ex Koehne, *Hexasepalum gardneri* (K.Schum.) J.H.Kirkbr. & Delprete., *Himatanthus drasticus* (Mart.) Plumel, and *Senna trachypus* (Benth.) H.S.Irwin & Barneby exhibited high occurrence rates within Ceará's savanna formations, despite their absence from the lists of widely distributed species in the Cerrado by Ratter, Bridgewater, and Ribeiro (2003) and Bridgewater, Ratter, and Ribeiro (2004), as well as in the northeastern cerrados by Vieira et al. (2019). Consequently, these taxa were deemed characteristic of this particular vegetation type within the state.

Table 2. The most frequently documented genera for the Ceará savanna formations.

Genera	**Family**	**Frequency**	**Frequency (%)**
Chamaecrista	Fabaceae	9	81.8%
Croton	Euphorbiaceae	9	81.8%
Cyperus	Cyperaceae	9	81.8%
Mimosa	Fabaceae	9	81.8%
Myrcia DC. ex Guill.	Myrtaceae	9	81.8%
Sida L.	Malvaceae	8	72.7%
Byrsonima Rich. ex Kunth	Malpighiaceae	8	72.7%
Borreria	Rubiaceae	8	72.7%
Combretum	Combretaceae	8	72.7%
Hexasepalum Bartl. ex DC.	Rubiaceae	8	72.7%
Pavonia Cav.	Malvaceae	8	72.7%
Qualea Aubl.	Vochysiaceae	8	72.7%
Senega Spach	Polygalaceae	8	72.7%
Senna	Fabaceae	8	72.7%
Stylosanthes Sw.	Fabaceae	8	72.7%

Table 3. Species present in 50% or more of the analyzed areas. OL = Oligarchic species, according to Bridgewater, Ratter, and Ribeiro (2004); FCN = Frequently encountered in northeastern cerrados, as reported by Vieira et al. (2019); AD = Widely distributed (occurring in all or almost all Brazilian states), according to Flora e Funga do Brasil (2024, continuously updated); FFC = Frequently found in Ceará savanna formations.

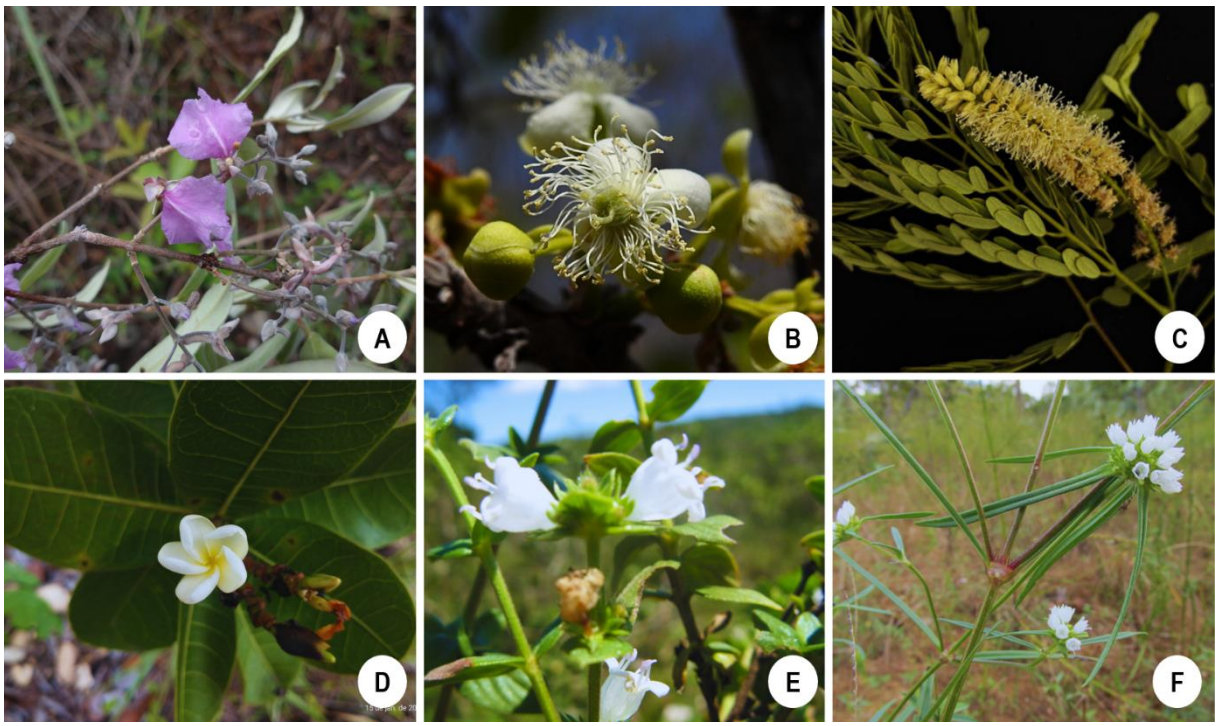
Species	**Family**	**Frequency**	**Frequency (%)**	**Classification**
Qualea parviflora	Vochysiaceae	8	72.7%	OL + FCN
Anacardium occidentale	Anacardiaceae	7	63.3%	OL + FCN
Chamaecrista flexuosa	Fabaceae	7	63.3%	AD
Curatella americana	Dilleniaceae	7	63.3%	OL + FCN
Myrcia splendens	Myrtaceae	7	63.3%	AD
Ximenia americana	Ximeniaceae	7	63.3%	AD
Agalinis hispidula	Orobanchaceae	6	54.5%	FFC
Cuphea campestris	Lythraceae	6	54.5%	FFC
Hexasepalum gardneri	Rubiaceae	6	54.5%	FFC
Himatanthus drasticus	Apocynaceae	6	54.5%	FFC
Mimosa somnians	Fabaceae	6	54.5%	AD
Pavonia cancellata	Malvaceae	6	54.5%	AD

Plathymenia reticulata	Fabaceae	6	54.5%	OL + FCN
Senna trachypus	Fabaceae	6	54.5%	FFC
Staelia virgata	Rubiaceae	6	54.5%	AD
Stylosanthes angustifolia	Fabaceae	6	54.5%	AD

Among the surveyed flora, 225 genera, 38 families, and 456 species were found to be restricted to one or two areas, a pattern consistent with the description not only for the overall Cerrado ecosystem (Bridgewater, Ratter, & Ribeiro, 2004) but also for the cerrados in northeastern Brazil (Vieira et al., 2019). Notable among these species are two endemics: *Hexasepalum nordestinum* Cabaña Fader & E.B. Souza (Rubiaceae) (Figure 5E), exclusive to Ceará and Piauí, where it inhabits the Cerrado Rupestre of Serra de Ubatuba/Flores (Cabaña-Fader et al., 2019); and *Borreria savannicola* E.B. Souza, Nepom. & L.M. Miguel (Rubiaceae) (Figure 5F), a recently described taxon endemic to Ceará's savanna formations (Souza et al., 2022).

The biogeographical analyses revealed low similarity among the areas, not exceeding 40% similarity. This aspect contributes to high beta diversity, indicating that the pattern described for the Brazilian and Northeastern cerrados is also reflected at the local level (Bridgewater; Ratter; Ribeiro, 2004; Vieira et al., 2019). Françoso et al. (2016) emphasized that while alpha diversity is higher in the core areas of the Cerrado, beta diversity tends to increase in the boundary zones of the domain due to the significant overlap of species occurring in these areas.

Figure 5. Species that define the savanna formations of Ceará. A – *Qualea parviflora*; B – *Curatella americana*; C – *Plathymenia reticulata*; D – *Himatanthus drasticus*; E – *Hexasepalum nordestinum*; F – *Borreria savannicola*. Photos: A and D: I.V. Nepomuceno; B-C-E-F: L.H.X. Portela.



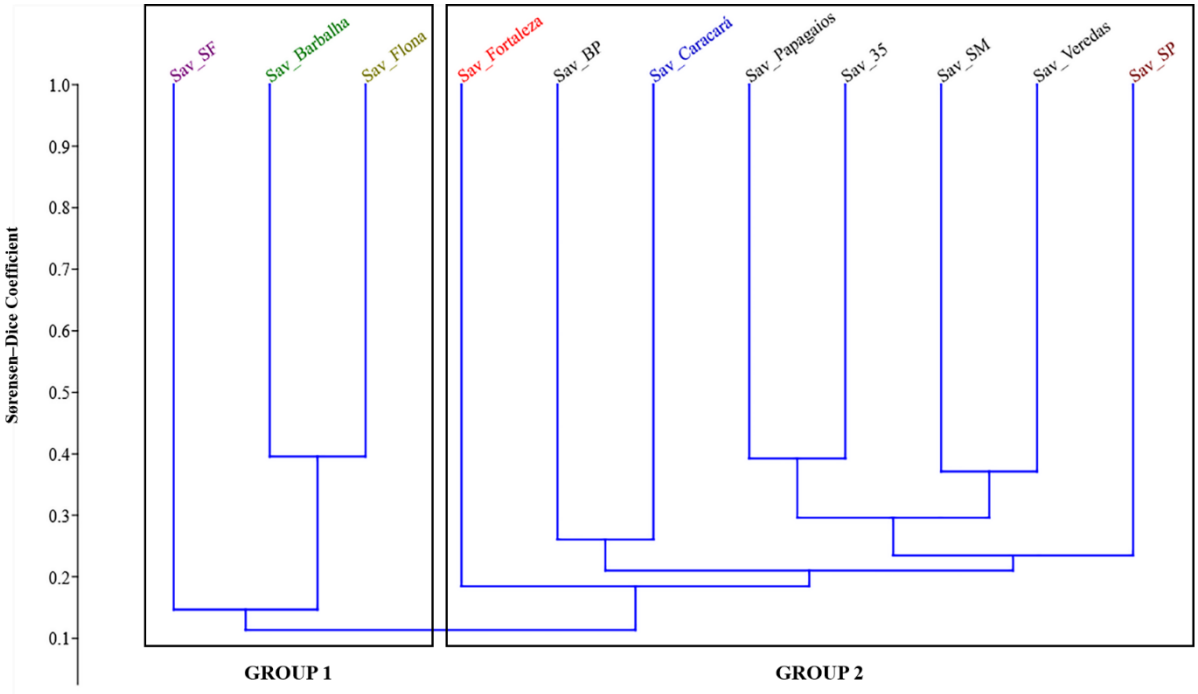
The UPGMA analysis, which exhibited a cophenetic correlation of 0.86, also revealed the existence of two groups: A, encompassing the savannas of the Araripe region and the Ubatuba/Flores Mountains; and B, which included all remaining areas (Figure 6). Group A

comprises three areas that traditionally form part of the interior cerrados and cerradões of Ceará (Figueiredo, 1997; Moro et al., 2015). It makes sense that the two savanna formations of Araripe formed such a distinct sister group, as they are not only contiguous but also have a flora more similar to that found in the core regions of the domain (Nepomuceno et al., 2021).

The presence of the Rupestrian/Typical Cerrado fragment of the Ubatuba/Flores Mountains in group A demands further analysis, this time in a broader context, at least initially, within the northeastern cerrados. One of the aspects that make this fragment interesting is the presence of *Vellozia tubiflora* (A.Rich.) Kunth, a typical plant of these environments found uniquely in this location in Ceará, along with significant populations of other families characteristic of the Cerrado, such as Eriocaulaceae (Giulietti et al., 2002; Ribeiro; Walter, 2008; CRIA, 2024, constantly updated).

Group B is exclusively formed by the caatinga savannas, where four subgroups are observed: the first composed of the Caracará and Bom Princípio formations; the second comprising the Papagaios and Quilômetro 35 formations; the third associating the São Miguel and Veredas dos Tomás formations; and the fourth encompassing the Fortaleza and Sítio Palmeirinha areas.

Figure 6. Hierarchical clustering of the 11 analyzed savanna formations in Ceará, using the Sorensen-Dice coefficient. The code for each area is detailed in Table 1.



It's understandable that the formations of Fortaleza and Sítio Palmeirinha stand out from the other subgroups, as they are the locations with the most distinct physical characteristics. The area studied by Moro, Castro, and Araújo (2011) is indeed part of the Coastal Vegetational Complex, whose associated "cerrados" have a particular floristic composition not only compared to the Central Plateau but also to the "northeastern cerrados" (Castro, 1994; Castro; Martins, 1999).

On the other hand, the Dense Cerrado of Sítio Palmeirinha is located on the sedimentary surfaces of the Ibiapaba Plateau, under geomorphological, edaphic, and climatic conditions different from other caatinga savanna areas. However, this formation alternates with continuous areas of Dry Forest of the Sedimentary, which share the same edaphic preferences (Moro et al., 2015).

Moro (2013) highlighted that the dry forests occurring in Ibiapaba share a considerable number of species with sedimentary caatinga areas, thus being a physiognomic subtype of it. Therefore, the savanna formation of Sítio Palmeirinha, despite being located on different physical aspects, also fits into the proposal of Nepomuceno et al. (2021).

Lastly, the three remaining subgroups of group B were the caatinga savannas located at lower altimetric levels. The four areas belonging to the municipality of Granja (Papagaios, Quilômetro 35, São Miguel, and Veredas dos Tomás) form two well-defined groups, confirming what Felfili and Felfili (2001) stated: the closer the areas are, the more similar they tend to be.

The savanna formations of group B reinforce the existence of caatinga savannas as a vegetation group rich in species and physiognomies, capable of integrating the map of Phytogeographical Units of Ceará. This aspect contributes to reinforcing both the provincialism of the "northeastern cerrados," proposed by Ratter, Bridgewater, and Ribeiro (2003) and reinforced by Vieira et al. (2019), and the heterogeneity of the Caatinga (Fernandes; Cardoso; Queiroz, 2022). The presence of new species, recently described for science, and restricted to these areas (Borreria savannicola and Hexasepalum nordestinum) opens the door to broader studies that may or may not be associated with existing theories about the interaction between the Cerrado flora and adjacent environments (Pennington; Richardson; Lavin, 2006; Ratter et al., 2003; Rizzini, 1997).

Conservation of the savanna formations of Ceará: what has been done?

A high beta diversity combined with a variety of physiognomies and high levels of endemism have led the Cerrado to be classified as one of the 200 ecoregions worldwide whose conservation should be prioritized (Olson; Dinerstein, 2002). However, despite the proven importance of its ecosystem services, this domain and all its associated physiognomies are neglected by conservation policies (Overbeck et al., 2022).

This neglect partly stems from legislation. Overbeck et al. (2022) emphasize that although the Forest Code (Brazil, 1965) has been replaced by the Native Vegetation Protection Law (Law No. 12,651/2012), its text maintains a continuous emphasis on the word "forest," implying that only this type of vegetation deserves actual protection. Moreover, the fact that the Caatinga, the Cerrado, and the Pampa are not legally considered national heritage, like the Amazon and Atlantic forests, influences public perception and, consequently, their conservation, resulting in extensive unprotected areas undergoing intense conversion processes from natural areas to agriculture (Overbeck et al., 2022; Sano et al., 2020).

Regarding the Cerrado and the Caatinga, the two domains whose vegetation is addressed in this study, conservation-related data are similar. The first domain has only 8.3% of its territory protected by Conservation Units (CU), corresponding to 388 areas, of which 264 (68.29%) are Sustainable Use and 124 (31.71%) are Integral Protection (Santos; Cherem, 2023). In turn, only 8% of the total Caatinga territory is legally protected by some form of CU, with only 1.3% of these being Integral Protection (Teixeira et al., 2021). The lack of ecological representativeness is also evident, with some ecosystems being more covered than others.

These values are lower than those stipulated by the International Union for Conservation of Nature (IUCN) (2020), which determines that at least 15% of terrestrial areas and 7% of seas and oceans should be allocated for territorial protection. Moreover, another issue is observed: the lack of ecological representativeness of CUs. Arruda et al. (2008) highlight that many protected areas are poorly located, not encompassing a variety of physiognomic characteristics due, for example, to inadequate size. This renders them incapable of effectively protecting the natural heritage of a given region.

In the state of Ceará, this lack of representativeness is evident when protected areas predominantly safeguard the state's wettest regions (Cristalino and Sedimentary Wetlands), to the detriment of the driest ones (Gomes et al., 2022). In the case of the locations analyzed here, only three are protected under some form of CU.

The two Araripe areas were studied within the context of the Araripe National Forest, a Sustainable Use CU, while the Sítio Palmeirinha area, in the Ibiapaba Plateau, is within the limits of the Bica do Ipu Environmental Protection Area (APA). The remaining eight areas are without legal protection, making them vulnerable to various unsustainable anthropogenic impacts.

It should be noted that even legally protected areas are not exempt from negative impacts. The Araripe National Forest, for example, suffers from fires resulting from agriculture in the surrounding areas (MMA, 2006; Rodrigues, 2020), affecting native vegetation areas and all their associated elements, in addition to the predatory extraction of Caryocar coriaceum (pequi), abundant in the local savanna formations (Almeida, 2014).

However, both in the Management Plan and in practice, the Araripe National Forest exhibits landscape representativeness, where different physiognomies are covered within its boundaries (MMA, 2005). This effectively protects, for example, Antilophia bokermanni (Araripe manakin), an endemic and endangered bird species whose life area is restricted to the moist forest areas of the slopes (Girão and Silva; Linhares, 2011).

Still, within the Ibiapaba-Araripe context, the Bica do Ipu APA, a CU still without a management plan, presents environmental impacts ranging from the disposal of various wastes to deforestation and wildfires due to unsustainable agriculture and predatory mining (Lopes; Claudino-Sales, 2019). Actions for guidance and environmental education with the population dependent on the CU about its importance are not often carried out due to the reduced number of employees, affecting the achievement and effectiveness of its objectives (Lopes; Claudino-Sales, 2021).

On the other hand, the Serra das Flores, with its savanna formations and other associated vegetation types, is in the process of integration into the Carnaúbas State Park (PEC). This Integral Protection CU was created by State Decree No. 28,154, of February 15, 2006, covers approximately 10,005 hectares, and is located in the municipalities of Granja and Viçosa do Ceará.

The objective is to transform it into the Serra das Flores State Park, maintaining its category and expanding its boundaries by about 3,000 hectares (Ceará, 2023). Such a redefinition would encompass the Rupestrian and Typical Cerrados of the plateau, as well as the forest formations of the slopes, honoring the categorization of this area as a Montane Ecological Refuge and its extreme biological importance (Giulietti et al., 2002).

Moro, Castro, and Martins (2011) proposed the creation of a Relevant Ecological Interest Area (ARIE), another category of CU, in the savanna formation studied by them in Fortaleza, Ceará. The authors justified their proposal based on the richness and floristic diversity that the site possessed in a small space, uniting Cerrado species present in the core area or only in the enclaves and Caatinga.

Building on Moro, Castro, and Araújo's (2011) proposal and considering the progress made regarding the integration of the Serra das Flores into the Carnaúbas State Park, it is crucial to focus on the Ceará savanna formations that are not yet protected. The caatinga savannas, by blending floristic elements of the Cerrado and the Caatinga, should be seen as priority areas for conservation. Once protected, these areas would shelter species belonging to two of the domains neglected by public conservation policies, as well as all associated adjacent elements.

CONCLUSION

The results unveiled three new areas with savanna formations in the state of Ceará: Quilômetro 35, Caracará, and Sítio Palmeirinha. Among these, the first two are located at lower altitudinal levels, while the latter integrates the "cerrados" of the Ibiapaba-Araripe complex, filling in the gaps of floristic data for this vegetation in the Ibiapaba Plateau.

The floristic similarity indices among these areas demonstrate a high beta diversity, reinforcing the observation of this diversity pattern not only at the regional level but also at the state level. *Qualea parviflora* stands out as the most frequent species, occurring in eight studied areas, while *Borreria savannicola* and *Hexasepalum nordestinum* are taxa unprecedented to science, confined to these formations.

The UPGMA cluster analysis indicated two main groups, corroborating the existence of caatinga savannas in the territory of Ceará. The correlation between savanna formations and different soil types, from Quartzarenic Neosols to Red-Yellow Latosols and Litholic Neosols, suggests a possible contribution of edaphic factors to floristic dissimilarities among the areas. However, it is emphasized the need for more comprehensive studies of the physical components for a better understanding of these correlations.

Despite the attributes that reinforce the need for protection, some form of Conservation Unit (CU) safeguards only three out of the 11 analyzed areas. The realization that even those safeguarded are not immune to environmental impacts highlights the complexity and challenges in the effective management of these ecosystems. Efforts have been made to include these vegetative formations on the conservation map of Ceará; however, the irregular distribution and low landscape representativeness of protected areas indicate the need for improvements in the basis of these conservation strategies.

As future perspectives, it is crucial to advance studies in these areas, considering not only floristic aspects but also physical, socioeconomic, and faunistic elements. The promotion of integrated research emerges as a necessity to obtain a more comprehensive view of these ecosystems, providing essential support for decision-making in conservation policies. Therefore, it is fundamental to direct efforts towards the implementation of practical strategies aimed at the effective protection of these areas, considering not only the maintenance and expansion of existing Conservation Units but also the mitigation of present environmental impacts. This can be achieved through raising awareness in society regarding the importance of these ecosystems and seeking partnerships among governmental agencies, non-governmental organizations, and local communities.

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