International Journal Semiarid

THE CAATINGAS DOMAIN: CONSIDERATIONS FROM A COMPARATIVE CARTOGRAPHY

Lucas Costa de Souza Cavalcanti
Associate Professor at the Department of Geographical Sciences, Federal University of Pernambuco
https://orcid.org/0000-0001-9096-138X
lucas.cavalcanti@ufpe.br

Riclaudio Silva Santos
PhD student in Geography at the Federal University of Pernambuco - UFPE
https://orcid.org/0000-0001-5219-8002
riclaudio.silva@ufpe.br

Resumo
Este trabalho teve como objetivo discutir aspectos relevantes da diferenciação das potencialidades paisagísticas semiáridas do Brasil em diferentes níveis. A discussão partiu de uma leitura comparada de mapas à luz de conceitos da estrutura das paisagens. A leitura comparada dos mapas evidenciou a ausência de consenso principalmente relacionada aos limites ocidentais do Domínio e a consideração das áreas de exceção como parte da Caatinga. Algumas dessas diferenças surgiram em função da natureza das propostas e da preocupação com a precisão cartográfica.
Palavras-chave: Geografia; Paisagens; Semiárido Brasileiro.
ABSTRACT
This work aimed to discuss relevant aspects of the differentiation of semi-arid landscape potential in Brazil at different levels. The discussion started from a comparative reading of maps in the light of concepts of the structure of landscapes. The comparative reading of the maps evidenced the absence of consensus mainly related to the western limits of the Domain and the consideration of the areas of exception as part of the Caatinga. Some of these differences arose due to the nature of the proposals and the concern with cartographic accuracy.
Keywords: Geography; Landscapes; Brazilian semiarid.

INTRODUCTION

The study of Brazilian natural formations owes much to the pioneering work of Aziz Ab'Saber. His comments on the spatial variability of landscapes at different scales provide a basic and didactic reference for the comprehension of the landscape potential of our country (AB'SABER, 2007; AB'SABER, 1984).

The concept of nature domain (landscape domain) is introduced by Ab'Saber (2007, p.11-12), being defined as:

> (...) a spatial set of a particular order of territorial magnitude - from hundreds of thousands to millions of square kilometers in land area - where there is a coherent scheme of relief features, soil types, vegetation forms and climatic-hydrological conditions.

Each domain manifests itself in a main area, which the São Luiz`s Geographer called a core area, varying laterally from transition zones, sort of abruptly, to another core area. This transition is usually associated with changes in the water and/or thermal regime, affecting the vegetation in aspects such as floristic (plant species composition), phenological (changes throughout the year), and structural (height, density, life forms, etc.).

Inside the core areas, it is possible to identify intradomain variations that configure local or sub-regional landscapes as a result of the water regime, relief characteristics, superficial materials, and/or land use. In these spaces, the vegetation may present one or more distinct aspects, usually its structure and/or phenology. Frequently, the floristics vary, but always within the spectrum of common species and/or endemic to the domain, for example the rocky slopes, where cacti and bromeliads predominate.

Otherwise, intra-domain variations may be such, that the plant species composition, its structure, and phenology reflect more expressively another domain.

These spaces are known as exception areas, one example is the altitude swamps in the Northeast, where remnants of the Atlantic Forest occur in the middle of the Caatinga. Sometimes, these areas are considered relicts of past climatic conditions, but whose geoenvironmental configuration allowed their maintenance until the present day.

These four concepts of units (core areas, transition zones, intra-domain variations, and exception areas) constitute the scope of a discussion about landscape structure (Fig. 1). Within this context, one of the challenges for landscape cartography is the construction of a taxonomic system of landscapes that considers these concepts.

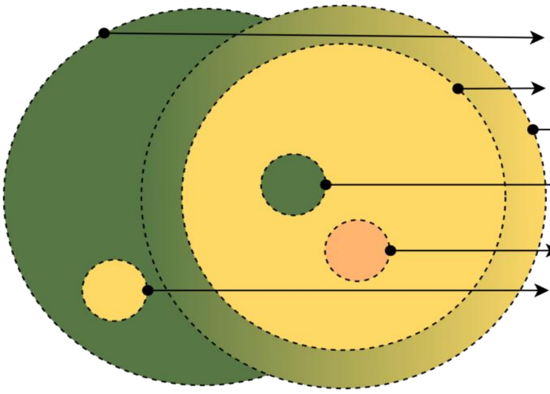

Figure 1: Concepts of landscape structure
Source: the authors.

In dealing with this issue, the Russian geographer Anatole Isachenko (1973) suggests distinguishing landscapes from two major lines of information. The first, of bioclimatic nature, seeks to distinguish the reflection of climatic variables in vegetation. The second emphasizes its geomorphological evolution. For Isachenko, landscapes would be defined by the crossing of bioclimatic (which he calls "zonal") and geomorphologic (or "azonal") units.

Isachenko (1973, p.232-233) suggests using two bioclimatic units: zones and subzones. Although he largely considers climatic variables to identify such units, he suggests that, for delimiting purposes, potential vegetation is the best resource. For zone definition he adopts the following criteria:

1) Qualitative analysis of as many bioclimatic indexes as possible. The goal is defining nuclei and smooth and abrupt transitions;

2) Delineation of a general system of bioclimatic units, considering the differences that were observed;

3) Define the borders among the units one by one, by considering: a) the climatic and biogeographical history, b) the atmospheric systems and/or active air masses and their seasonal rhythm c) examining the reflex of climatic conditions on geochemical, geomorphological, pedological and biogeographical processes.

Also according to the same author, the best method for differentiating the zones would be mapping the landscape units and their subsequent grouping (upscaling method). He points out, however, that some typical landscapes of one zone can occur in another zone, especially when they are located near its limits, marking a transition.

The transitions would mark subzones, whose identification would be based not only on the interpenetration of attributes from adjacent zones, but also on the increasing and/or decreasing variability in bioclimatic variable values.

Recently, different authors have put aside a fully qualitative approach in the interpretation of the units (CASTILLO-RODRIGUEZ et al, 2010; SOTO; PINTÓ, 2010; ERIKSTAD et al, 2015; VANTEEVA, 2019; BRAZ et al, 2020). This is particularly due to the increasing availability of bioclimatic variables with constantly higher resolution (big data). In these works, multivariate statistics have been applied to help in the decision of the relevant variables.

It turns out that many of the available variables tend to respond in similar ways. The application of sorting techniques such as Principal Component Analysis (PCA) or Non-Metric Multidimensional Scaling (NMDS) have been used to reduce the number of variables of greatest relevance alone.

However, statistics have their own limitations. Despite the ease of applying a Principal Component Analysis, Khoroshev (2018) defends that it is not the best technique for all cases because it assumes linear relationships between variables. Here, we believe that statistics, indexes, and other quantitative elements should be considered, but not exclusively. Qualitative analysis needs to permeate the whole process of mapping landscape units.

This work intends to discuss relevant aspects of the differentiation of the semi-arid landscape potentialities of Brazil in different scales. For this, a comparative map reading will be used. Methodological details are presented at the end, in Appendices A, B and C.

How far does the Caatinga Domain reach?

From a phytogeographical point of view, the Caatingas occur as part of dry forest and/or shrub formations that extend from Argentina to Mexico. These formations happen in isolation from each other and work more as nuclei of endemism, sharing some species, but showing low floristic similarity between the nuclei (LINARES-PALOMINO, OLIVEIRA FILHO, PENNINGTON, 2011).

Different delimitations for the Caatinga have already been proposed. In this paper, we will compare three delimitations (FIG 2): the one by Olson et al (2001) modified by Fernandes et al (2020), which we will refer to as UEFS, being the product of the efforts of researchers from the State University of Feira de Santana; the proposal of ecoregions by Velloso, Sampaio; Pareyn (2001), which will be referred to as SNE, because it resulted from a meeting of the Sociedade Nordestina de Ecologia. In addition, the recent revision of the limits of Brazilian biomes by IBGE (2019) will also be considered, which from now on will be called IBGE.

Out of the three maps examined, the IBGE map has, without a doubt, the boundaries defined with a higher level of detail. Both the SNE and UEFS maps have more generic and smoothed contours, indicating that they adopted less detailed reference bases. This characteristic will be considered in the following discussion.

It is notable that all proposals admit a Caatinga nucleus that extends from northern Minas Gerais to northern Piauí. This area also includes part of the states of Alagoas, Bahia, Ceará, Paraíba, Pernambuco, Rio Grande do Norte and Sergipe. Despite the recognition of the spaces dominated by the Caatingas, there are many areas "in dispute". These divergences occur most clearly in the west, at the transition to the Cerrado. In addition, areas associated with high altitudes and/or exposed to humid winds can also be observed. Finally, less significantly, there are also disagreements regarding the eastern and northern limits.

Next, these differences will be compared considering the occurrence of species listed as endemic to the Caatinga (FERNANDES et al, 2020). The endemism was gathered from a global biodiversity data system (Cf. Appendix A).

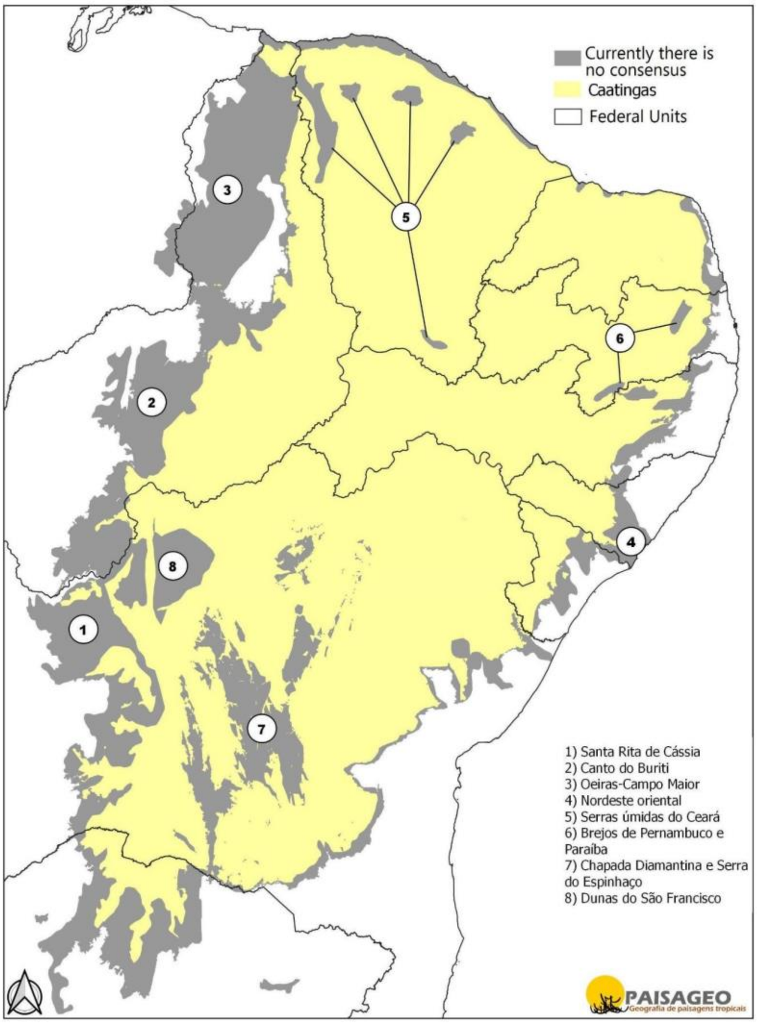

Figure 2: Different limits attributed to the Caatingas
Source: the authors.

International Journal Semiarid

In Figure 3, it is possible to see that the species listed as endemic are distributed in a subtropical extension area, concentrated, though, in the intertropical region and with a nucleus in northeastern Brazil. For the Caatinga, there is not yet a study that differentiates pure endemic species (pure endemism) from those that manifest near endemism.

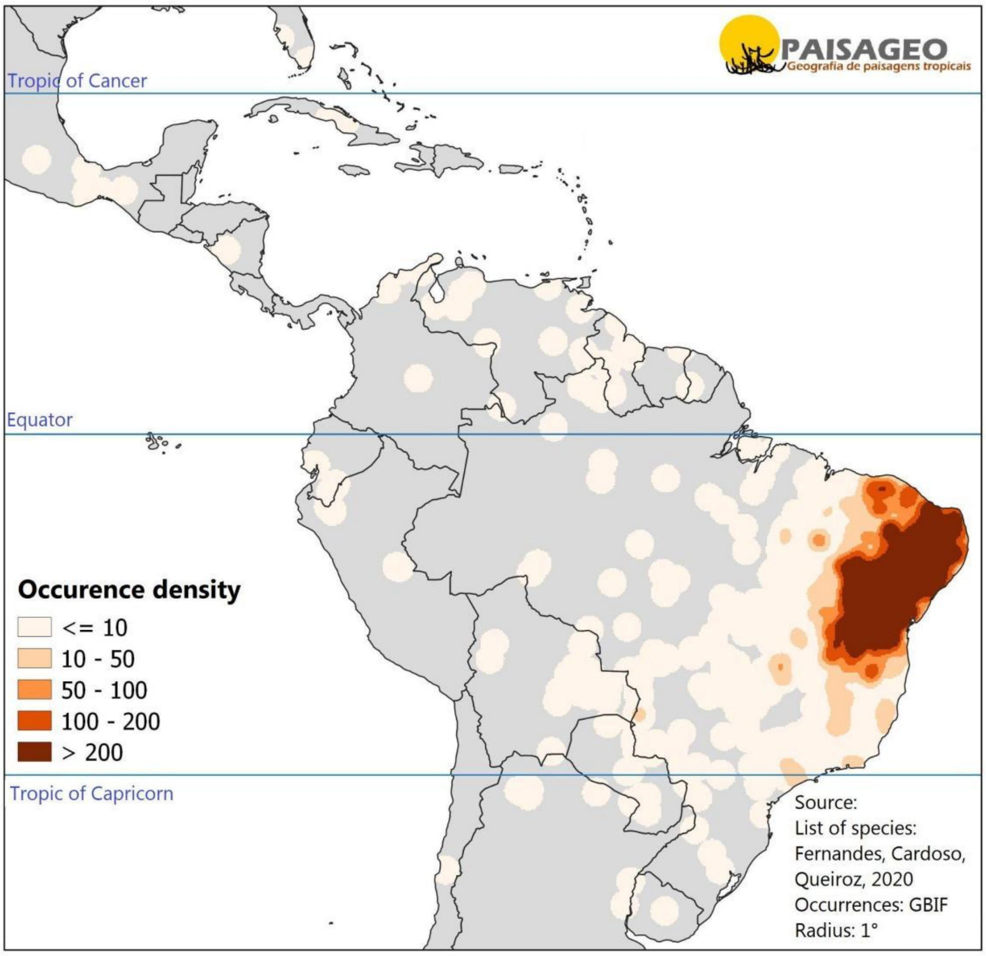

Figure 3: Occurrence of species listed as endemic for the Caatinga.
Source: the authors.

In addition, a measure of the intra-annual variability of the vegetation will be used (FIG. 4). This measure was determined from the vegetation variation coefficient using remote sensing and geoprocessing (Cf. Appendix B).

The strong seasonality is a fundamental characteristic of the Caatingas, from which comes its own etymology, meaning "white forest" or "forest that looks white". In this sense, the phenology of the leaf system can be a key element for the mapping of vegetation in the Brazilian semi-arid region.

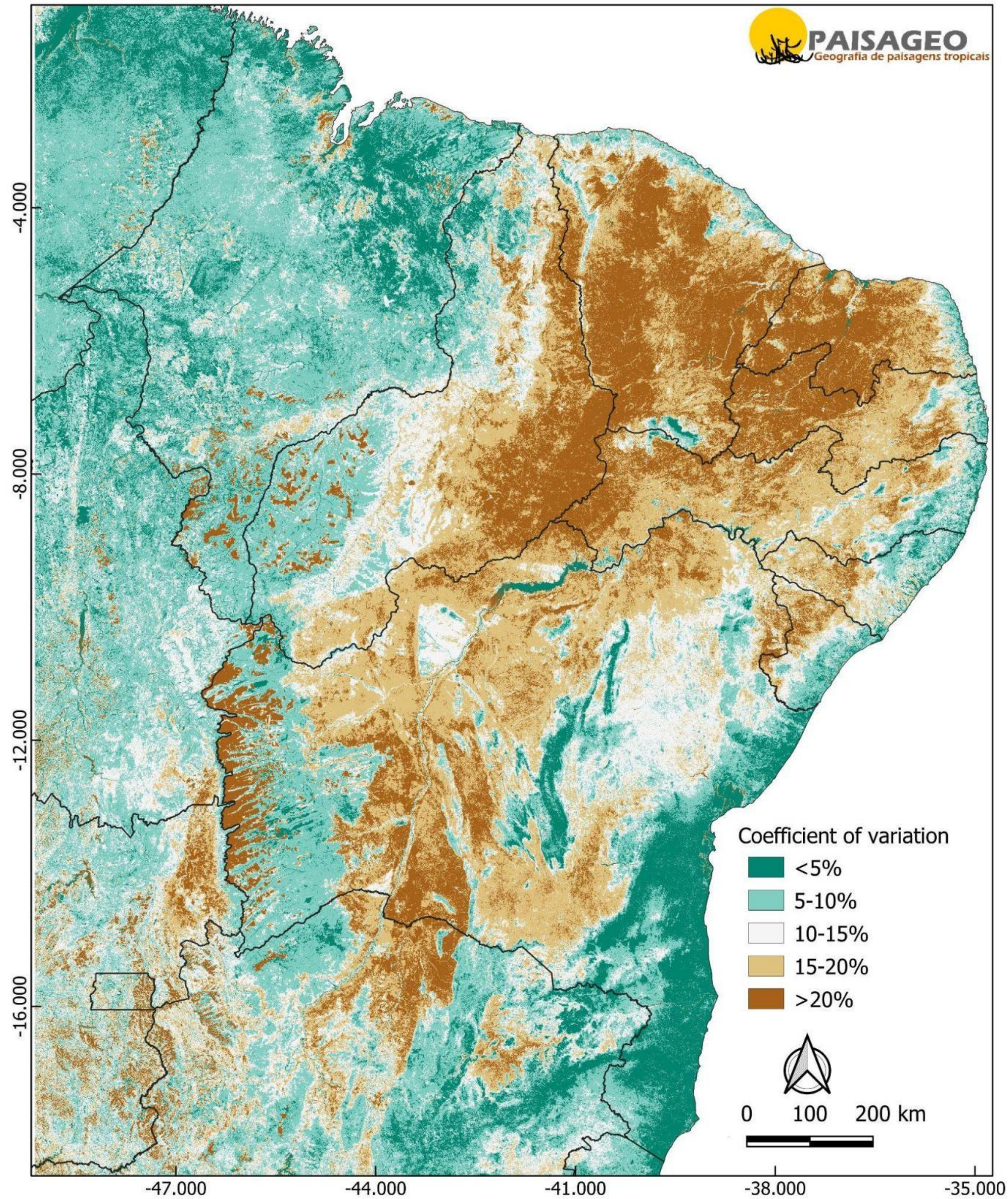

Figure 4: Coefficient of intra-annual variation of the vegetation.
Source: the authors.

The phenology refers to the intra-annual variability of vegetation attributes, such as the timing of growth and leaf fall, the stages of blooming and fruiting. Traditionally, vegetation classifications incorporate primarily the phenology of the foliar system, adopting qualifiers such as "evergreen", "seasonal", "deciduous", etc. In this work, a summary of phenology is represented by the coefficient of vegetation variation.

The three limits we are considering (UEFS, IBGE and SNE) strongly concur with areas of coefficient of variation (CV) >10%. These areas manifest greater intra-annual variability of the vegetation, in other words, greater change from the wet to the dry season. An interesting detail is that in areas where there is consensus about the predominance of Caatingas, the CV is often >15%.

Both Cerrado and Atlantic Forest areas, as well as exception areas, can be recognized for showing a CV < 10%. Some examples include the northeastern portion of the Chapada do Araripe, the eastern portion of the Chapada Diamantina, the brejos of Pernambuco and Paraíba, as well as the humid hills of Ceará.

Additionally, the land use is well outlined with areas of CV>20%, coinciding with agricultural areas on flat tops, whether in the extreme west of Bahia (Chapadões do São Francisco), in a small part of Tocantins or in the southern portions of Piauí and Maranhão, evidencing the MATOPIBA. On the other hand, the irrigated fruit-growing pole of Petrolina-Juazeiro is visible as a 5-10% CV spot.

In the following sections, we will consider the exception areas within and outside the Caatinga Domain (FIG. 2, cases 5 to 8). At this stage, we will examine the limits proposed in light of the available data, beginning with the areas of dispute. In the south, the differences seem to be more associated with the digitization effort of creating the archive.

In the southwest, the limit of the Domain is clearly marked by the contour of the depression of the medium São Francisco river along with the border of the Chapadões do São Francisco (or Chapadas do Oeste Baiano). In these areas, the transition appears to be easier to observe. The top of the Chapadões has Cerrado vegetation (Forested Savannah and Savannah - Park), according to the IBGE.

Differences in Santa Rita de Cássia and surroundings

A divergence in the maps appears to the west, in the region of Santa Rita de Cássia and surroundings (in Bahia). Both the IBGE and UEFS maps do not consider the area as Caatinga, while the SNE map does. This seems to be a significant difference.

One of the highlights in the landscape of Santa Rita de Cássia is the presence of buritis paths along the Preto River, an affluent of the São Francisco River. This feature suggests a Cerrado area. Nevertheless, the map in Figure 3 points to CV<10% only alongside the river. In the adjacent areas, the CV is always greater than 10%.

Also, the record of Caatinga endemic species in the city suggests that the paths of the Preto River are associated with the presence of its channel, rather than the climate. Some endemic species of Caatinga, according to Fernandes et al (2020), include: S*enna trachypus*, *Indigofera blanchetiana*, *Mimosa ophthalmocentra*, *Adenocalymma candolleanum*, *Heteropterys trichanthera*, *Arachis dardani*, *Annona leptopetala*, among others.

Furthermore, it is well known that there is a region of common occurrence of dry forests and savannas (DEXTER et al, 2018). In this sense, and considering that the vegetation map of IBGE indicates several spots of Contact with Savanna/Steppic Savanna for this location, it is suggested that the area should be better classified as part of the transition zone. This should include all the continuous spaces that are outside the limits of biomes and eco-regions, but which contain a CV >10%, endemic species and/or spots of Steppic Savannah and/or Contact with Steppic Savannah.

The Surroundings of Canto do Buriti

This region was included as Caatinga by UEFS and IBGE, but not by SNE. The CV shows significant portions for the 5-10%, 10-15% and 15-20% classes. There are some endemic occurrences, such as: *Ditaxis desertorum, Calliandra macrocalyx, C. ulei and C. spinosa, Mansoa paganuccii, Senna cearensis, Cnidoscolus urniger, Dalbergia cearensis, Trischidium molle and Adenocalymma candolleanum*. Due to the low density of records and the CV values <10%, it is suggested to include this area as a transition zone.

Discordances of Oeiras and Campo Maior

Another significant discordance occurs around Oeiras (PI) and continues until Campo Maior. Near Oeiras, the limit proposed by IBGE is projected to the west beyond the UEFS limit. The IBGE definition, however, coincides with a CV >10% and there is an occurrence of Caatinga endemic species.

Going north to Campo Maior (PI), Fig. 3 shows an extension of CV >10%. However, IBGE (2019) does not consider this region to be part of the Caatinga biome, despite the fact that several spots on IBGE's own vegetation map indicate the occurrence of Steppic Savannah. Endemic occurrences include: *Pilosocereus gounellei, Arachis dardani, Croton blanchetianus, Piptadenia retusa, Indigofera blanchetiana, Adenocalymma candolleanum, and Mimosa nothopteris.*

The UEFS map indicates a large isolated spot of Caatinga near Campo Maior. However, the CV is highly fragmented. The occurrences of endemism are registered in fragments with a CV<10%. It is understood that there was a generalization of the botanists from Feira de Santana. It is possible to include the range Oeiras-Campo Maior as part of the Domain and the spot of UEFS as part of the transition zone, but the floristic composition still needs to be examined more carefully.

Divergences in the Eastern Northeast

Looking at the eastern limits of the Caatinga Domain, we find a series of divergences notably shown by the UEFS map, especially in relation to the IBGE map and less strongly to the SNE map. These spaces include the proximities of the city of Alagoinhas and extensions somehow wide along the valleys of the Itapicurú (BA), Vaza-Barris, Japaratuba, and São Francisco rivers (SE/AL) and further north, around the valleys of the Siriji (PE) and Curimataú (RN) rivers.

These areas are distinguished by a great spatial variability of the CV, mostly originated from fragmentation due to the use of the land in regions of old and intense occupation, making them difficult to classify.

EXCEPTION AREAS

The concept of exception areas refers to landscapes that differ from what would be expected for a specific climate context. Ab'Saber (2007, p.15) outlines a typology of these areas that can be summarized as of: cyme, slope, pé de serra and riverside (of humid valleys and parallel rivers typical of the yazoo type).

Medeiros and Cestaro (2019) demonstrated that the identification of brejos de altitude in Northeastern Brazil involves the understanding of different theories that aim to determine the origins and evolution of these exceptional areas. The investigation of these areas is usually anchored in systemic, morphoclimatic, and phytogeographic approaches, and it can also relate different approaches simultaneously.

In this way, among the terms used to designate the brejos de altitude, according to each geomorphological context of their formation/evolution or ecological characteristics, it can be highlighted, Brejo (Ab'Saber, 1999), Residual Elevations, Inselbergs and Residual Massifs, Chapadas, Residual Plateaus (PRATES et al., 1981; GUERRA e GUERRA, 1997; CORRÊA, 1997), Position Monadnocks (CORRÊA, 2003), Structural Massif, Tectonic Massif, Granitic Massif (GURGEL, 2012), Sedimentary Matrix Massif (Residual Massif) (GOIS et al., 2019).

According to Freire (2007) it is the particular dynamics, among the natural elements, with emphasis on the elements of biogeography and ecology, that determine the exception areas. For Medeiros and Cestaro (2019) these areas are characterized by orography as a climate determining factor, which provide differentiated local conditions within the semi-arid environment, allowing the simultaneous occupation between Caatinga and Atlantic Forest species.

Góis et al. (2019) emphasize, among the common features observable in brejos, the presence of Acrisols (Argissolos), usually a soil type associated with wetter environmental contexts, in addition to the abundant occurrence of feldspar in the rocks of these environments.

In general, regarding the consensus of the authors, we highlight the concept that the brejos de altitude have distinct pluviometric conditions from the semi-arid environment in which they are located, directly affecting the development of the other elements of these landscapes. Another aspect in common to the brejos de altitude is their hypsometric characteristic, generally reaching heights above 550 meters.

Among the maps compared in this study, the IBGE map, due to the nature of its approach, does not consider the exception areas. SNE does not emphasize specific exception areas, and the UEFS removes some of them, by considering them as not being Caatinga.

In the state of Ceará, a group of hills with rainforest formations, associated with the orographic effect of altitude and/or exposure was classified by UEFS as not being Caatinga. The CV map registered values of <10% in the northern portion of the Serra da Meruoca Hills and in the eastern portion of the Uruburetama and Ibiapaba Hills, and more expressively on the Baturité Hill. In all cases, the median altitude was always above 600m. It is worth mentioning that there are several smaller hills and fragments in the interior of the hills mentioned above, with median altitudes in a range of 400-600 meters, but always with less spatial expression.

In the far south of Ceará, the Chapada do Araripe presents Cerrado fragments, but with a record of Caatinga endemic species, clearly configuring a vegetational contact, in conformity with the IBGE vegetation map classification. However, these fragments of CV<10% are concentrated in the high portion in the Northeast of the Chapada, with a median altitude above 800 meters.

The brejo de altitude and exposição are located in Alagoas, Pernambuco and Paraíba, and are associated with the Borborema Plateau. The median altitude is generally higher than

600 meters, with the exception of the exposure areas closer to the coast, that present a median higher than 400 meters, such as the Brejo de Areias, in Paraíba.

Another point of debate is related to the Chapada Diamantina. This is a group of highlands structured in very old metassedimentary rocks, located in the central area of Bahia. This area has a very particular endemism to the point that the UEFS map does not consider the area as Caatinga. However, the IBGE and SNE do. However, IBGE and SNE do. From the list of species considered endemic to Caatinga, 231 have registered occurrences in the areas of Chapada Diamantina with a CV<10%. In this sense, it is easier to consider this space as a Caatinga of altitude.

It is worth mentioning that the areas showing a CV <10% occur preferentially above 600 meters and almost always on the eastern side of the highlands, which receive the trade winds from the ocean, especially in the Sincorá and Jacobina Hills. The eastern portion generally shows a CV>10%, as occurs in the case of Boqueirão da Onça and the Bacia de Irecê.

Beyond the exception areas of orographic influence, the UEFS map brings the suggestion that the São Francisco dunes would be an exception area, of arenaceous influence, not being considered as Caatinga. This proposition diverges from the IBGE and SNE maps, respectively. These extensive fields of dunes and sand mantles occur on the left shore of the São Francisco river between the cities of Barra and Pilão Arcado (both in Bahia). Despite the UEFS proposition, it was observed that 71 species included in the list of endemics study of Fernandes et al's (2020) are registered for the dunes of the São Francisco River. Therefore, it is considered that the area is better classified as an internal variant than an exception area.

In order to finalize the discussion regarding the exception areas, it was decided to include the saline plains (SUDENE, 1989) that occur under the semi-arid climate in the northern coast of the Northeast, where the rivers are in valleys structured on geological faults that affect the Bacia Potiguar (COSTA et al, 2020). In this context, the influence of marine salinity is so strong that the riverside vegetation is dominated by mangrove species, varying even according to the salinity content (COSTA; ROCHA; CESTARO, 2014). The presence of the mangrove configures, therefore, an area of exception, even though the dimensions are not very expressive in the context of the Caatinga Domain.

Apart from the limits of the Caatingas Domain, areas of dry formations occur with less expression. The main one is the Vale do Jequitinhonha, in Minas Gerais. This is a region with a precipitation index of less than 1000 mm/year, an aridity index of less than 0.5 and a CV>10%, showing many occurrences of endemic plants of the Caatinga.

Internal Variations

Now that the areas of discordance between the maps have been examined, let us look for explanations for the CV map variations that reflect internal differences in the Caatinga.

The first case to be observed is the extensive CV area from Feira de Santana to Monte Santo. It embraces mainly the Paraguaçu river basin and, to a lesser degree, the Itapicurú basin. The distribution of precipitation throughout the year seems to be the answer for this pattern (FIG. 5). In this region, the rains are not concentrated within just for a few months, as is the case in the drier areas of the Brazilian Semiarid. Observing the rainy season (Cf. Appendix C), it is noted that it represents less than 40% of the annual precipitation. In this regard, it is possible to consider the possibility of a different phenological response due to the better distribution of rainfall.

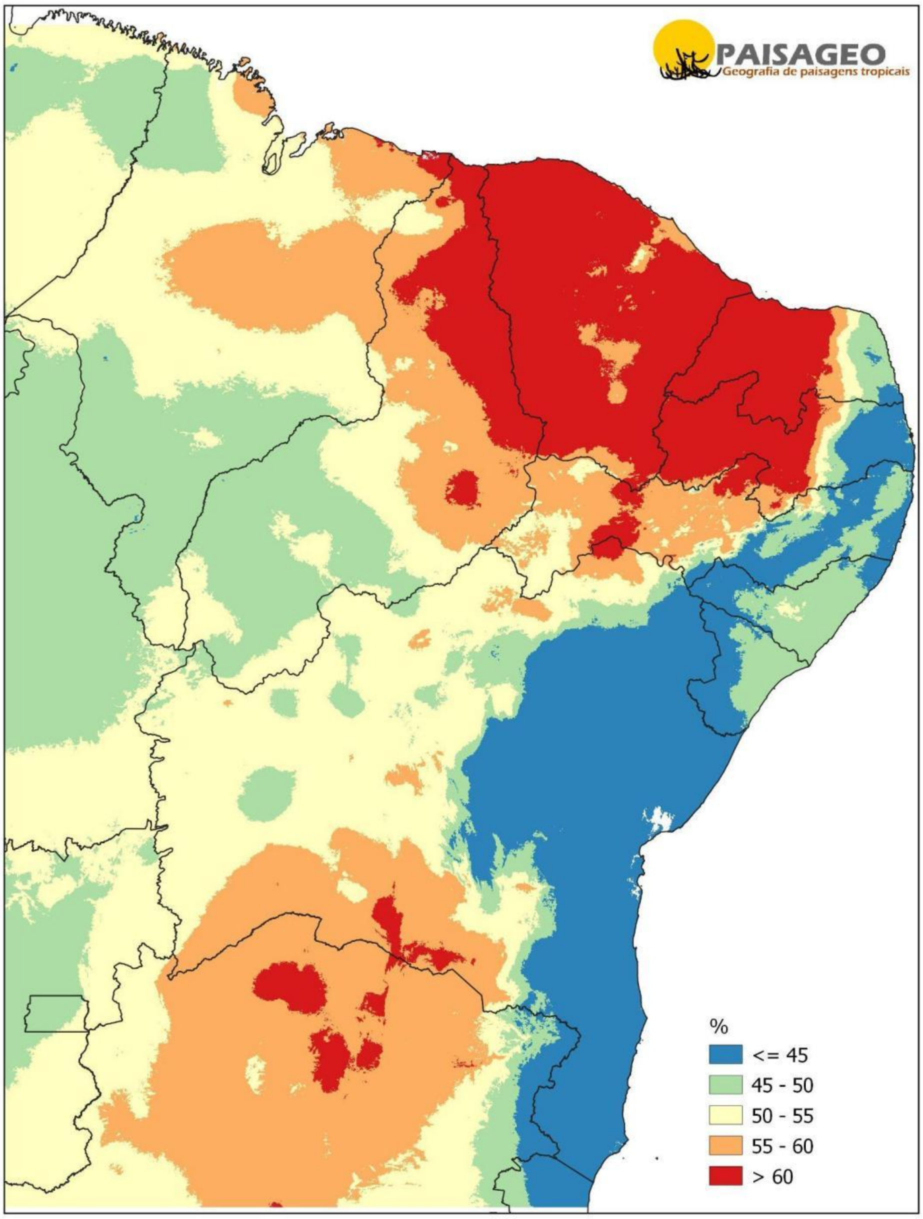

Figure 5: Contribution of the rainy season to the annual precipitation.
Source: the authors.

Queiroz et al. (2017) highlight floristic variations in the Caatinga Domain in the following contexts: crystalline rocky basement (Caatinga of the crystalline), in environments of sedimentary rocks, especially those of a sandy nature (Caatinga of sedimentary areas) and within these two contexts there are also special environments, which are related to differentiated altitudes, aquatic environments, karstic environments, dunes and rocky outcrops.

The Caatinga of the crystalline is present mostly at the Depressão Sertaneja, in environments of igneous and metamorphic rocks and is presented as deciduous caatinga with thorns, with predominance of trees and small bushes, in shallow and stony soils. Non-woody species are predominant in these environments; however, exceptions can be found along the channels of the main rivers, due to the fact that they are the environments of sediment deposition that allow for the formation of deeper soils, in combination with a greater water supply (QUEIROZ et al., 2017).

In terms of aquatic environments, there are few examples for the Brazilian semiarid region, with a predominance of intermittent rivers, the São Francisco River and the Parnaíba River are the main nuclei of the aquatic flora of the Caatinga, which consists a total of about 227 species of plants, distributed in 136 genera and 54 families (BFG, 2015).

The Caatinga of arenaceous sedimentary areas on the other hand is associated with sedimentary basin environments, and is known to be associated with a floristic unit distinct from that found in the Caatinga of the crystalline. In continental dune environments some vegetation cycles, such as blooming and leaf loss, are not so strongly controlled by precipitation distributions throughout the year, these dune environments of the São Francisco River stand out for the high number of endemic species (ROCHA; QUEIROZ; PIRANI, 2004).

It is also evident that while stony soils predominate in the crystalline environments, in the context of the arenaceous sedimentary Caatinga, deeper arenaceous soils predominate, resulting in the development of different species of Caatinga flora.

In karstic relief environments, in contrast, the differentiated soils and the greater water supply allow for the development of what is known as arboreal Caatinga, composed of larger trees with forest physiognomies, outstanding among these environments are the Chapada Diamantina and the southern portion of the Caatinga in the state of Minas Gerais (QUEIROZ et al., 2017).

PERSPECTIVE FOR LANDSCAPE MAPPING

Based on the differences discussed throughout this paper, it is possible to sketch a typology of the landscapes of the Caatinga Domain. Four main groups are highlighted: Native Areas (core), Exception Areas, Transition Areas, and Internal Variants (FIG 6).

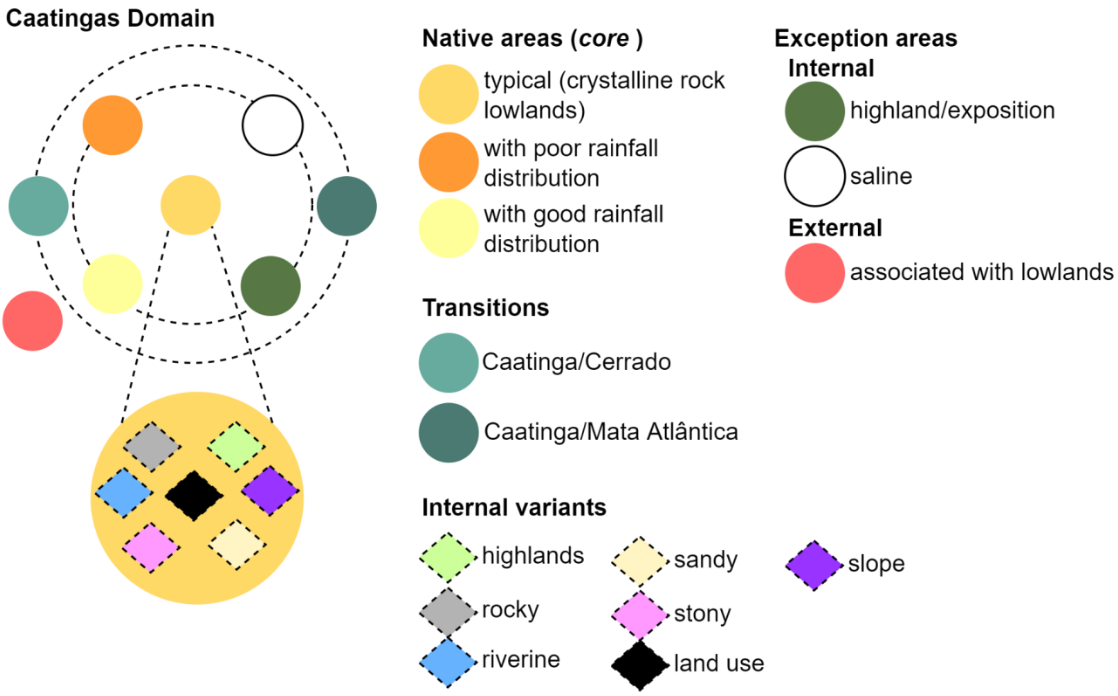

Figure 6: Sketch of the main differences observed in the Caatinga.
Source: the authors.

Native Areas are those defined by a semi-arid climate (with an aridity index between 0.2 and 0.5), dominated by caatingas. The Exception areas are classified according to their occurrence as intradominal and extradominal. In the first case, the areas occur in the interior of the Caatingas Domain, and are mainly associated with the orographic effect of altitude and/or exposure on the climate, which varies from dry sub-humid to humid. Besides these, it is worth mentioning the areas of saline influence (saline plains). In the second case, caatinga species occur in a context of strong seasonality outside their Domain, generally associated with depressions on the land, which affect the climate, reducing the contribution of precipitation.

Transition zones can be classified according to the floristic domain to which they transit: Caatinga/Cerrado or Caatinga/Atlantic Forest. IIn these areas, it is usual the occurrence of spots with intense seasonality in a climatic context that is also transitional, with a gradual increase of precipitation.

Lastly, the internal Variants manifest changes especially in structure, phenology or, at times, floristic variations but within the spectrum of the Caatingas. These areas are differentiated by several factors, such as: proximity to water bodies (even if they are intermittent), excessive stoniness, excessive sand, rocky outcroppings, steep relief, altitude, and the land use.

FINAL REMARKS

The comparative reading of the maps showed the absence of a consensus mainly related to the western limits of the Domain and the consideration of the exception areas as part of the Caatinga. Some of these differences arose due to the nature of the proposals and the concern with cartographic precision.

The use of the coefficient of variation of the vegetation showed good visual correlation with the exception areas and with the limits of Caatinga proposed mainly by IBGE, as well as showing internal variations. Additionally, there is a possible correlation between the phenological response with the intra-annual variability of the precipitation, especially in terms of its concentration or distribution.

A charter of the Brazilian semi-arid landscapes that considers all of these variations is still to be constructed. This work gathered some brief reflections based on the comparative reading of maps. The blend of qualitative and quantitative criteria seems to be an appropriate path to follow.

Acknowledgments

The authors wish to thank CNPq for providing the funds for project 437004/2018-0 and CAPES for providing scholarship.

REFERENCES

AB'SABER, A.N. **Domínios de natureza no Brasil: potencialidades paisagísticas.** São Paulo: Ateliê Editorial. 4ed. 2007.

AB'SABER, A.N. Ecossistemas continentais. **Relatório da Qualidade do Meio Ambiente.** Brasília, 1984.

AB'SABER, A.N. Nordeste sertanejo: a região semiárida mais povoada do mundo. **Revista Estudos Avançados**, São Paulo, v.13, n.36, p. 7-59, 1999.

BFG – The Brazil Flora Group. Growing knowledge: an overview of seed plant diversity in Brazil. **Rodriguésia**, 66, p. 1085–1113. 2015.

BRAZ, A. M.; OLIVEIRA, I. J. de; CAVALCANTI, L. C. de S.; ALMEIDA, A. C. de; CHÁVEZ, E. S. ANÁLISE DE AGRUPAMENTO (CLUSTER) PARA TIPOLOGIA DE PAISAGENS. **Mercator**, Fortaleza, v.19, e19011, 2020. ISSN: 1984-2201

CASTILLO-RODRÍGUEZ, M.; LÓPEZ-BLANCO, J.; MUÑOZ-SALINAS, E. A geomorphologic GIS-multivariate analysis approach to delineate environmental units, a case study of La Malinche volcano (central México). **Applied Geography**, 30, p. 629-638, 2010. DOI: 10.1016/j.apgeog.2010.01.003

CORRÊA, A.C.B. História geomorfológica dos compartimentos elevados do Planalto da Borborema, NE do Brasil: a perspectiva da etchplanação. **Revista de Geografia**, Recife, v. 20, n. 1, p. 16-24, 2003.

CORRÊA, A. C. B. **Mapeamento geomorfológico de detalhe do maciço da Serra da Baixa Verde, Pernambuco: estudo da relação entre a compartimentação geomorfológica e a distribuição dos sistemas geoambientais.** Dissertação (Mestrado). Universidade Federal de Pernambuco, Programa de Pós-Graduação em Geografia. Recife. 1997.

COSTA, D.F.S.; ROCHA, R.M; CESTARO, L.A. Análise Fitoecológica e Zonação de Manguezal em Estuário Hipersalino. **Mercator**, Fortaleza, v. 13, n. 1, p. 119-126, jan./abr. 2014.

COSTA, L.R.F.; MAIA, R.P.; BARRETO, L.L.; SALES, V.C.C. Geomorfologia do Nordeste Setentrional Brasileiro: uma proposta de classificação. **Revista Brasileira de Geomorfologia.** v.21. n1. 2020. p.185-208.

DEXTER, K.G. et al. Inserting Tropical Dry Forests Into the Discussion on Biome Transitions in the Tropics. **Frontiers in Ecology and Evolution.** 2018.

DIDAN, K.. 2015. MOD13Q1 MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006. NASA EOSDIS Land Processes DAAC. https://doi.org/10.5067/MODIS/MOD13Q1.006

ERIKSTAD, L.; UTTAKLEIV L. A.; HALVORSEN, R. Characterisation and mapping of landscape types, a case study from Norway. **Belgeo**, 3, 2015. DOI: 10.4000/belgeo.17412

FERNANDES, M.; CARDOSO, D. QUEIROZ, L.P. An updated plant checklist of the Brazilian Caatinga seasonally dry forests and woodlands reveals high species richness and endemism. **Journal of Arid Environments.** v.174, March 2020.

FICK, S.E.; HIJMANS, R.J. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. **International Journal of Climatology** 37 (12). 2017. p.4302-4315.

FREIRE, L. M. **Paisagens de Exceção: problemas ambientais no município de Mulungu, Serra de Baturité – Ceará.** 2007. 134f. Dissertação (Mestrado em Geografia) – Universidade do Estado do Ceará, Fortaleza, 2007.

GBIF.org (13 October 2021) GBIF Occurrence Download https://doi.org/10.15468/dl.kjdhwx

GOIS, L. S. de S.; MONTEIRO, K. de A.; SANTOS, J. E. B. dos.; FALCÃO, A. de M. UMA REVISÃO DOS BREJOS DE ALTITUDE DO NE DO BRASIL. In: PINHEIRO, L. de S.; GORAYEB, A. (Org.). **Geografia Física e as Mudanças Globais**. 1 ed. Fortaleza: Editora UFC, 2019. IBSN: 978-85-7282-778-2

GORELICK, N., HANCHER, M., DIXON, M., ILYUSHCHENKO, S., THAU, D., & MOORE, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment.

GUERRA, A.T.; GUERRA, A.J.T. **Novo dicionário Geológico-Geomorfológico.** Rio de Janeiro: Bertrand Brasil, 1997. 652 p.

GURGEL, S.P.P. **Evolução Morfotectônica do Maciço Estrutural Pereiro, Província Borborema.** Tese (Doutorado em Geodinâmica e Geofísica) – Universidade Federal do Rio Grande do Norte, Natal. 2012.

IBGE. **Biomas e sistema costeiro-marinho do Brasil : compatível com a escala 1:250 000.** Rio de Janeiro: IBGE. 2019. 164p.

ISACHENKO, A.G. **Principles of Landscape Science and Physical Geographic Regionalization.** Melbourne. 1973. 311p.

KHOROSHEV, A.V. **Organização multiescalar da paisagem geográfica.** LITRES. 2018. 412p. (em russo).

KING, L.C.A geomorfologia do Brasil Oriental. **Revista Brasileira de Geografia**. Rio de Janeiro, v. 18, n. 2, p. 147-265, 1956.

LINARES-PALOMINO, R. OLIVEIRA-FILHO, A.T.; PENNINGTON, T. Neotropical Seasonally Dry Forests: Diversity, Endemism, and Biogeography of Woody Plants. In:

DIRZO, R. et al. (eds.) **Seasonally Dry Tropical Forests: Ecology and Conservation.** 2011. p.3-21.

MEDEIROS, J. F. de.; CESTARO, L. A.; AS DIFERENTES ABORDAGENS UTILIZADAS PARA DEFINIR BREJOS DE LATITUDE, ÁREAS DE EXCEÇÃO DO NORDESTE BRASILEIRO. **Sociedade e Território** – Natal. Vol. 31, N. 2, p. 97-119, Jul./Dez. de 2019. ISSN: 2177-8396

OLSON,D.M.; DINERSTEIN, E.; WIKRAMANAYAKE, E.D.; BURGESS, N.D. et al. Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. **BioScience,** Volume 51, Issue 11, November 2001, p.933–938,

PRATES, M.; GATTO, L.C.S.; COSTA, M.I.P. Geomorfologia. In: BRASIL. Ministério das Minas e Energia. Secretaria Geral. **Projeto RADAMBRASIL. Folhas SB. 24/25 Jaguaribe/Natal: geologia, geomorfologia, pedologia, vegetação e uso potencial da terra.** Rio de Janeiro, 1981. p. 301-348.

QGIS.org, 2021. **QGIS Geographic Information System.** QGIS Association. http://www.qgis.org

QI J., KERR Y., CHEHBOUNI, A., 1994. External factor consideration in vegetation index development. **Proc. of Physical Measurements and Signatures in Remote Sensing**, ISPRS, 723-730.

QUEIROZ, L. P. de.; CARDOSO, D.; FERNANDES, M. F.; MORO, M. F.; Diversity and Evolution of Flowering Plants of the Caatinga Domain. In: SILVA, J. M. C. da.; LEAL, I. R.; TABARELLI, M. (org.). **Caatinga: The Largest Tropical Dry Forest Region in South America.** Editora Springer. 482 p, 2017.

ROCHA, P. L. B.; QUEIROZ, L. P.; PIRANI, J. R. Plant species and habitat structure in a sand dune field in the Brazilian Caatinga: a homogeneous habitat harbouring an endemic biota. **Rev Bras Bot.** 27, (4): p, 739–755. 2004.

SOTO, S.; PINTÓ, J. Delineation of natural landscape units for Puerto Rico. **Applied Geography,** 30, p. 720-730, 2010. DOI: 0.1016/j.apgeog.2010.01.010

VANTEEVA, Y. V.; RASPUTINA, E. A.; SOLODYANKINA, S. B. Geoinformation mapping of lanscape on the example of the Primorskiy Ridge (Baikal region), **Geodesy and Cartography**, Vol. 80, N. 12, p. 20-30, 2019. DOI: 10.22389/0016-7126-2019-954-12-26-36

Appendix A - Density of Endemism

To evaluate the density of endemism, we initially downloaded, (using an R script), the species listed in the Fernandes, Cardoso, and Queiroz (2020) checklist. A total of 38,136 occurrences were obtained from the Global Biodiversity Information Facility (GBIF, 2021). Only those species marked as "Preserved Specimen" and having coordinates were considered. After the download and pre-treatment, the file was imported into QGIS (2021) to generate a heat map with a radius of 1°.

Appendix B - Coefficient of Variation

In order to make the variation coefficient map of the vegetation, images from the MODIS sensor, product MOD13Q1 (DIDAN, 2015) were used. Initially, the monthly median was determined for the bands 1 and 2 for the time period 2001-2020. Then, the second version of the improved soil-adjusted vegetation index (MSAVI2) was calculated (QI et al, 1994). This index was chosen because it constitutes an improvement of SAVI by replacing the arbitrary adjustment factor. These procedures were performed on the Google Earth Engine platform (GORELICK et al, 2017). With the monthly MSAVI2, the coefficient of variation (CV) was calculated. The choice of the CV intervals was based on the slicing of histogram by the Quartile method. The values were rounded up. The series statistics were calculated in the QGIS.

To evaluate the predominant altitude in each vegetation fragment, the coefficient of variation classes of <5% and 5-10% were vectorized. In addition, the median altitude for each fragment was calculated. When writing the comments, we used the toponymy from the topographic maps available in the Brazilian Army's Geographic Database (available at: https://bdgex.eb.mil.br/bdgexapp/mobile/).

Appendix C - Rainy Season Contribution

The rainy season contribution in the annual precipitation amount, was obtained by the formula "BIO16*100/BIO12", in which BIO12 is the annual precipitation and BIO16, the rainy season precipitation. Both QGIS raster calculator and variables from WorldClim (FICK; HIJMANS, 2017) were used.