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Changes in vegetation coverage with emphasis on the identification of *cerrado* patches in a topographic profile of the semi-arid region from Pernambuco – Brazil

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Abstract
The semi-arid Northeast is one of the least known Brazilian regions in terms of vegetative diversity since claims of there being few plants endemic to the Caatinga are unjustly propagated. However, although this biome has suffered a lot through anthropic action, it presents a great diversity of vegetational types, including disjunctions of other biomes in exceptional areas, such as humid *brejos de altitude*, which are present as isolated patches in the landscape of the semi-arid Northeast. Thus, in this study, an analysis was made to differentiate the vegetation coverage along a topographic profile, in a spatial transect of the southern *Agreste* region of Pernambuco, comprising portions of the municipalities of Águas Belas, Iati and Saloá, through 10 plots established along this topographic profile. Application of the Normalized Difference Vegetation Index (NDVI) showed the variation of values as a function of the topography, revealing that in depression areas, where drier caatinga is observed, the lowest value of NDVI was obtained (0.18). On the other hand, in the areas of higher relief, where montane forests and *cerrado* develop, the highest values were found (0.49), thus showing the influence of topography on the distribution of humidity and vegetational features.

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INTRODUCTION

The establishment of *cerrado* patches in the semi-arid Northeast is primarily due to altitude. In a preliminary study on the identification of a *cerrado* patch in the municipality of Saloá, southern *Agreste* of Pernambuco - Brazil, which coincides with the spatial transect selected for this study, Santos et al. (2014) associate this patch with the phytophysiognomy of *cerrado senso stricto*. Ribeiro and Walter (2008) point out that low, tortuous, leaning individuals with irregular and twisted branches are found in this environment. Thus, these patches can be interpreted as fragments that, due to variations in the topographic gradient and soil factors, form an ecotone area, interconnecting different soil and vegetation features. In this sense, they require unique strategies for the conservation of these remnants, as well as for the recovery of degraded areas.

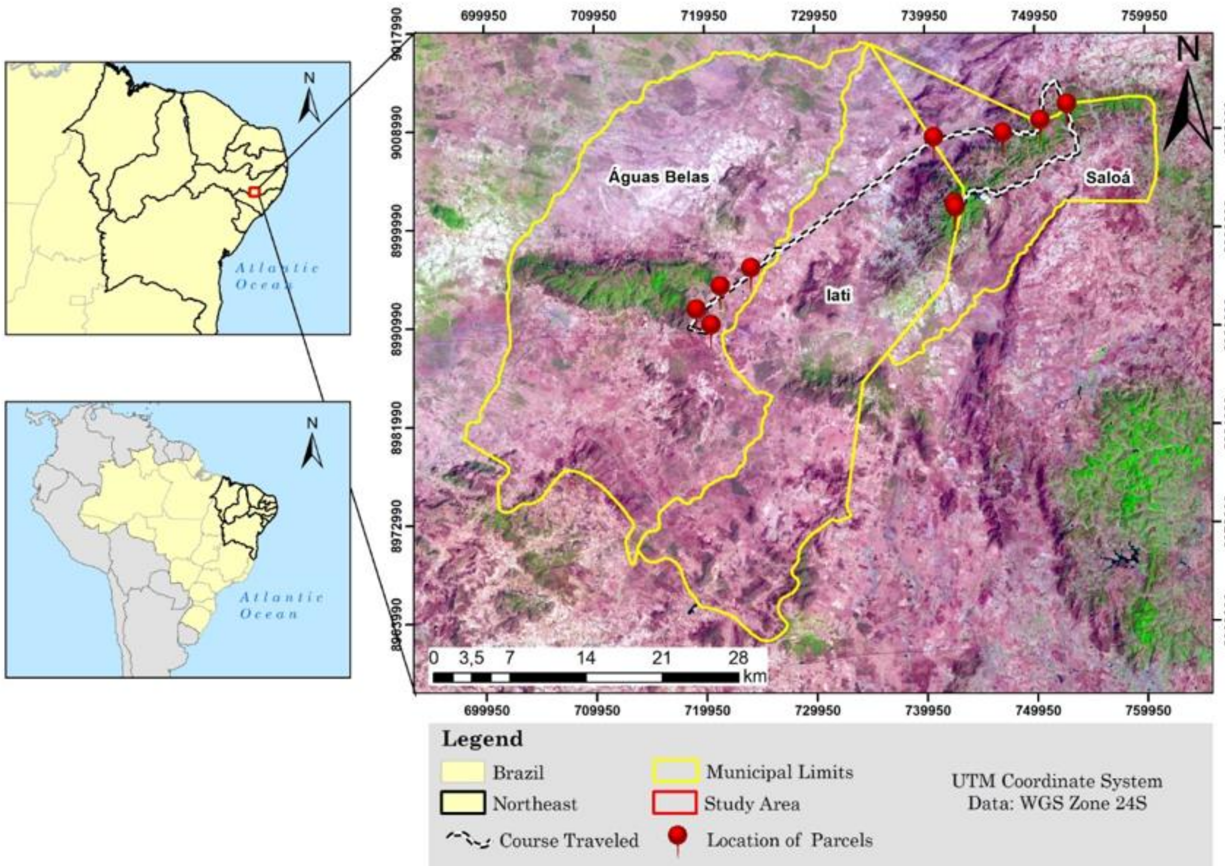
Therefore, the objective of this study was to identify and characterize the change in vegetation along the topographic profile in areas of transition between the semi-arid and *Agreste* regions of southern Pernambuco, to identify the floristic composition of the *cerrado* enclave that occurs at the top of the Brejo de Saloá, comprising portions of the municipalities of Águas Belas, Iati and Saloá.

MATERIAL AND METHODS

Study area

The area is comprised of the municipalities of Águas Belas, Iati and Saloá, which are part of the southern Agreste of Pernambuco (Map 1). The municipalities of Águas Belas and Iati are part of the geomorphological unit of the Interplanaltic Depression of Alto Ipanema, while the municipality of Saloá is located in the Pernambuco - Alagoas Structural Summit (CORRÊA et al., 2010).

Map 1. Location of the study area, municipalities of Águas Belas, Iati and Saloá, State of Pernambuco - Brazil.



Source: Authors.

Fieldwork methodology

Expeditions were made in July 2013. The methodological procedure applied follows the recommendations of IBGE (2012). The sampling technique adopted was Stratified Randomization, which consists of stratifying a given forest area (population) into homogeneous subpopulations (strata), based on the interpretation of aerial photographs or another remote sensing.

For a better operationalization of field procedures, a complementary methodological technique was selected to adapt to the objectives and conditions presented by the study, namely Rapid Ecological Assessment (REA) (SOBREVILLA; BATH, 1992), which allows for quick qualitative data collection but requires prior analysis of the study area. The REA method is based on a previous understanding of the research area, making use of databases, aerial photographs, remote sensing images, and maps, so that field procedures can be defined. Species are collected for identification and deposition in herbaria, and the physical characteristics of the area are noted. Subsequently, all data extracted in the field are treated to provide tools for an analysis of the spatial information. Thus, the REA can generate succinctly a description of the vegetation, perform georeferencing of the vegetation patches, analyze the conservation status of the study area, as well as generate a list of species collected. This method is considered flexible, presents speed, ease usage and data analysis, and allows the study to be conducted with a reduced team of researchers.

Combining the two methodological techniques described in the spatial transect selected for this study, 10 plots of 30 × 30 m were established. These were allocated where significant changes in the vegetation composition as well as in the topographic gradient could be evaluated. It should also be noted that the plots were installed in places where the vegetation was minimally preserved. As a result of these requirements, the plots were not equidistant, which allowed for the research to document the nuances found along the landscape profile. The 10 plots installed among the municipalities can be seen in Map 1 and their locations with respective georeferencing are shown in Table 1.

Table 1. Georeferenced coordinates, altitude and municipality of the parcels established for the elaboration of the topographic profile.

Parcels	Latitude	Longitude	Altitude	Municipality
1	9.12426° S	36.99365° W	408 m	Águas Belas
2	9.11148° S	37.00602° W	457 m	Águas Belas
3	9.09237° S	36.98561° W	396 m	Águas Belas
4	9.07695° S	36.96050° W	394 m	Águas Belas
5	8.96851° S	36.80968° W	508 m	Iati
6	8.96523° S	36.75299° W	747 m	Saloá
7	8.95476° S	36.72229° W	965 m	Saloá
8	8.94136° S	36.70044° W	997 m	Saloá
9	9.02343° S	36.79278° W	1090 m	Saloá
10	9.02673° S	36.79199° W	1052 m	Saloá

Source: Authors.

The plots were distributed to perform botanical collections, to contemplate the dominant species in each selected environment. After the collections, the specimens were taken to the herbarium to be identified and deposited and to test the hypothesis of the variation of vegetation structure along the topographic profile, as well as the occurrence of a *cerrado* patch at the top of this profile. Also, photographic records were made to distinguish plant physiognomies, and georeferencing of collection sites was performed using a GPS receiver.

Normalized difference vegetation index (NDVI) and its techniques

The NDVI is simple, easy to implement and can be effective in predicting surface properties when the vegetation canopy is not too dense or too sparse.

The NDVI is obtained through the equation:

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

Wherein NIR and R are spectral two-way reflectance factors (ratio of the radiance of the target on the surface to the radiance of a conservative, Lambertian surface) at the wavelengths of the visible (red, R) and near-infrared (NIR), respectively (MYNENI et al., 1995). These are the surface reflectance ranges in near-infrared (0.8 μm to 1.1 μm) and visible (red – 0.6 μm to 0.7 μm) (ASRAR et al., 1984).

To obtain the NDVI in the spatial transect analyzed, images of the TM sensor (Thematic Mapper) were used, which are onboard the Landsat 5 satellite, acquired from the Brazilian National Institute of Space Research - INPE. The images used for this study were obtained on December 10, 2013.

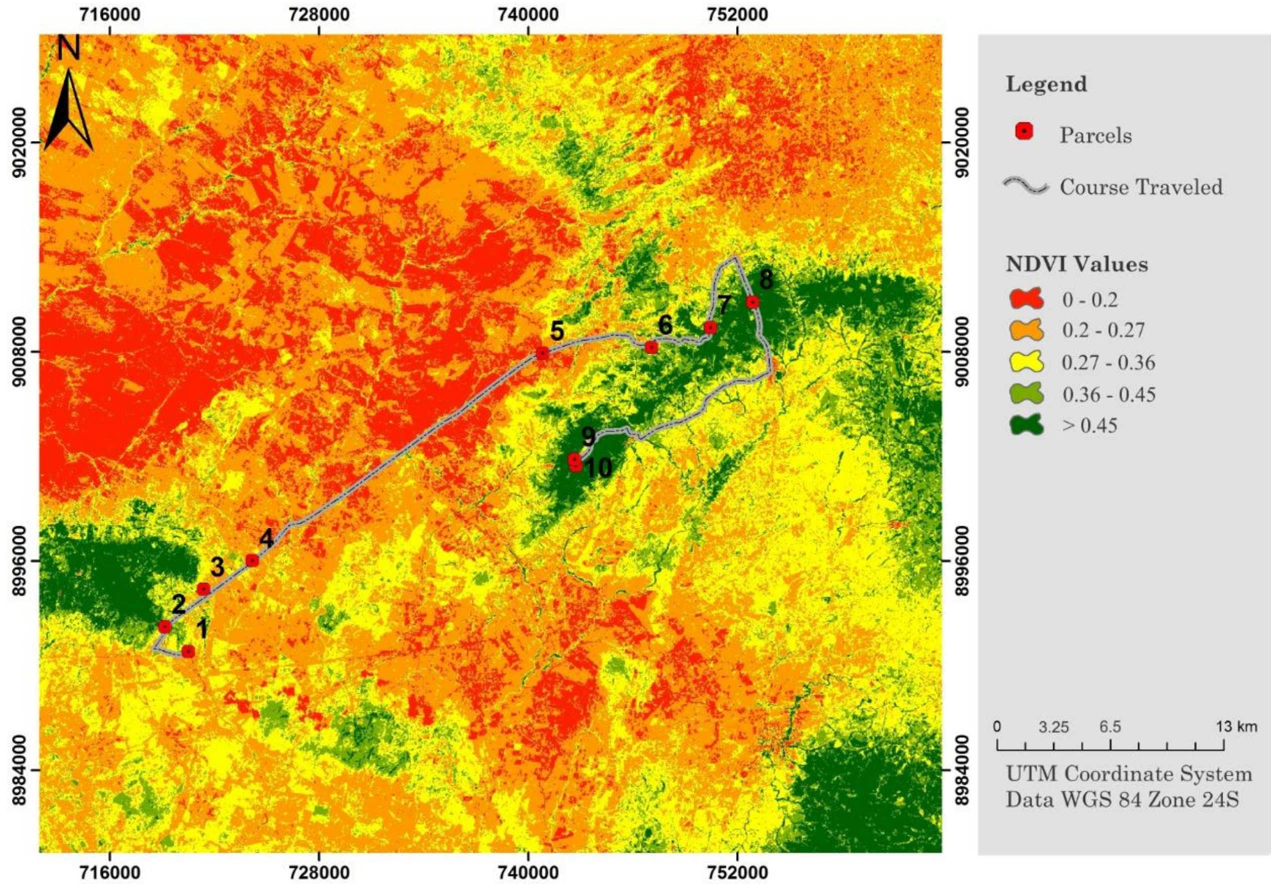
The images were stacked and orthorectified. Geometric correction (orthorectification) was performed by image-image comparison. This correction procedure takes one image whose geometry has already been corrected as a reference to correct another image. This step is of fundamental importance since the images obtained have distortions concerning the terrain. Image processing was performed using the ERDAS Imagine version 9.3 program licensed at the Geoprocessing and Remote Sensing Laboratory - SERGEO of the Geographic Sciences Department of UFPE, with the Model Maker tool.

RESULTS AND DISCUSSION

Applications of the Normalized Difference Vegetation Index (NDVI)) and Topographic Profile

From the analysis of the NDVI vegetation index (Map 2), it was possible to perform a series of correlations from the data collected.

Map 2. Normalized difference vegetation index (NDVI), indicating points 1-10 that represent the plots installed in the study area.



Source: Authors.

We made comparisons of the NDVI values found in our study with other works, especially those examining the *cerrado*. In a study carried out in the municipality of Santa Rita do Passa Quatro, state of São Paulo, on the differentiation of *cerrado* physiognomies using the vegetation index, Bitencourt et al. (1997) found the following values: for the physiognomy *campo sujo* the NDVI from 0.02 to 0.20; *campo úmido* from 0.02 to 0.20; *campo cerrado* from 0.20 to 0.26; *cerrado sensu stricto* from 0.26 to 0.38; *cerrado sensu stricto* tending to *cerradão* from 0.38 to 0.44; *cerradão* from 0.44 to 0.55 and *mata mesófila* from 0.44 to 0.55.

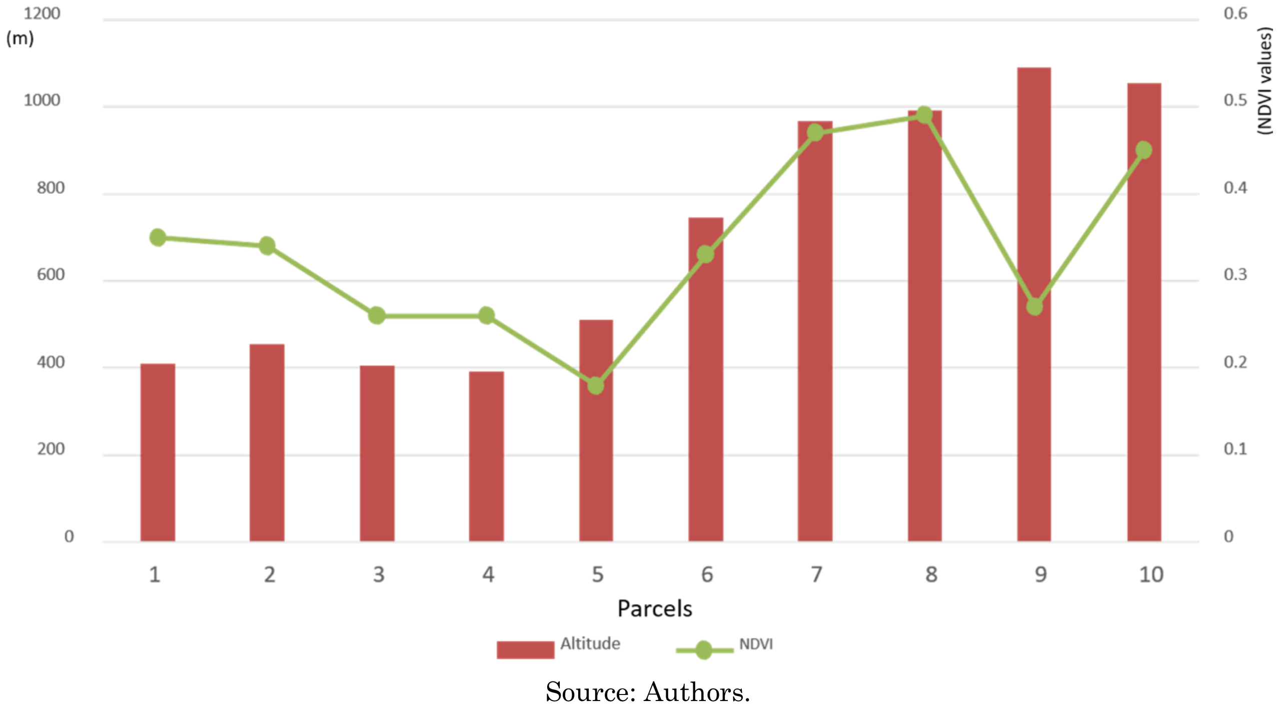
Carvalho Junior et al. (2008), in a study on savanna pattern classifications using the vegetation index in Chapada dos Veadeiros, state of Goiás, found NDVI values for both dry and rainy periods in the following *Cerrado* features: for the *cerrado denso* environment a mean NDVI value of 0.8 was found for the rainy period and 0.62 for the dry period; for the predominantly *campo* environment, a value of 0.60 for the rainy period and 0.35 for the dry period; in the environment composed of the *cerrado ralo* or *cerrado rupestre*, values of 0.60 for the rainy season and 0.4 for the dry season.

The values of NDVI found for the *cerrado* patch at the top of the Brejo de Saloá, represented by plots 9 and 10, were similar to those found in areas of *cerrado*, including the areas of *cerrado* in central Brazil.

However, it is necessary to emphasize that the variation of the vegetation index values can be explained by the difference in floristic diversity and structural complexity in each physiognomy, because the correlations among the herbaceous, shrubby and arboreal strata of the *cerrado* trigger important variations in biophysical parameters (ASNER; WARNER, 2003). Thus, the standardization of a certain physiognomy of the cerrado or other biome according to the values obtained through the NDVI is limited, because such determination depends on several parameters such as climate, vegetation type, land use and soil exposure, among other aspects.

A very relevant analysis is the interpretation of the vegetation density values obtained from the NDVI, compared with the altimetry values of all ten plots studied (Graph 1).

Graph 1. Altitude and NDVI values per plot in the study area, municipalities of Águas Belas, Iati and Saloá, southern *Agreste* of Pernambuco - Brazil.



Source: Authors.

The detailed and individualized correlation by parcel explains, among other aspects, the oscillations contained in the correlation of the NDVI values with the altitude values, and the influence of other physical factors. Parcel 1 corresponds to a transect in the municipality of Águas Belas, and has an altitude of 408 m.a.s.l. The area is covered by a fragment of dense arboreal caatinga located on a slope. For this area, the NDVI had a value of 0.35, a relatively high index, mainly because it is inserted in the Sertaneja Depression, where the dominant vegetation is a drier caatinga. However, the high value can be explained because the position of this plot was relatively close to the Brejo de Águas Belas, with higher humidity than the surrounding caatinga, favoring the formation of dense arboreal caatinga vegetation, with higher density values than other plant formations.

The second parcel is also located in the municipality of Águas Belas, at an altitude of 457 m.a.s.l. The plot was established in an area of dense, shrubby caatinga. However, the area is influenced by agropastoral activities. The NDVI for this plot is 0.34, relatively high for the pattern of the Sertaneja Depression. It can be explained by the proximity to the Brejo de Águas Belas, as in the case of the first plot, as well as by the density of the local shrubby caatinga itself.

The third parcel was also installed in the municipality of Águas Belas at an altitude of 396 m.a.s.l. The plant formation of the site analyzed is caatinga, with a marked presence of vegetative, shrubby and herbaceous structures. Regarding the NDVI, this plot presented a value around 0.26, which can be explained by the very physiognomy of the vegetation that does not show high density. These variations are probably observed due to the decrease in humidity to the first two plots. Although there is no microclimatic study for the area, it is possible to infer this premise, since the humidity reflects directly on the density of the vegetation.

Still in the municipality of Águas Belas, the fourth parcel was also installed. This point has an altitude of 394 m.a.s.l., which does not vary significantly from the previous plots. The NDVI for this area was 0.26, which is not high, a reflection of the vegetation coverage, a notably spaced arboreal caatinga.

In the municipality of Iati the fifth plot was installed, at an altitude of 508 m.a.s.l. The physiognomy of the vegetation cover remained as typical caatinga of a dry environment, where a shrubby stratum prevails. The vegetation of this environment is widely spaced and suffers a lot with the agropastoral activity in the region, presenting several degraded areas. This fact influenced the NDVI, which registered the lowest value to all plots (0.18), revealing that in this environment the vegetation is not very dense.

The sixth plot was installed in the municipality of Saloá, where the altitude reached 747 m.a.s.l. and a marked difference in the physiognomy of the vegetation was noted. The vegetation cover of the area is predominantly arboreal, with some elements of the caatinga and *cerrado*, presenting itself as a formation of montane forest. Concerning the NDVI, it had a value of 0.33. Theoretically, this plot should have a higher NDVI than the others. However, according to records of the vegetation, it is configured as a transitional area, comprising features of *cerrado* and caatinga. Thus, it presents areas of more widely spaced vegetation, explaining the low NDVI, when compared to plots 1 and 2. Nóbrega et al. (2012) studied the lichen *Parmotrema andinum*, collected in this same area, for bioprospection and biotechnology. This species was only registered for the *cerrado* of the Brazilian Central-west region until then, which corroborates our findings.

The seventh parcel was established in the municipality of Saloá. The altitude recorded for this point was 965 m.a.s.l., which has a decisive impact on the configuration and development of the vegetation cover. It is a formation of montane forest, standing out in its exuberance and arboreal size. The density and exuberance of the vegetation cover are reflected in the NDVI, which had a value of 0.47 for this plot.

The eighth parcel was established in the municipality of Saloá, with an altitude of 997 m.a.s.l. The vegetation cover of the area analyzed is characterized as a mixture between shrubby and tree layers, drawing attention to its exuberance and high density, responsible for the highest value of NDVI found, 0.49. The area has an ecotonal character, presenting species typical of montane forest, caatinga and *cerrado*. However, in the upper parts of the profile, the soil becomes increasingly sandy (quartz sands), which facilitates the penetration and percolation of water. In the uppermost parts of the *brejo* there is greater humidity, however, a soil that facilitates percolation can promote drought-like conditions, which is typical of edaphic *cerrados*.

The last two plots (9 and 10) deserve an integrated analysis because they are the same environment. These plots were installed at the top of the topographic gradient, in the municipality of Saloá, with altitudes of 1090 and 1052 m.a.s.l., respectively. The vegetation of these plots represent a true disjunction of the *cerrado*, with species typical of that biome, whose altitude added to high humidity, a mild climate and soil characteristics, provide conditions for such a patch of *cerrado* to establish itself in that environment. However, not only do *cerrado* species occur in this area, but elements of the caatinga are also present, forming an ecotonal environment. The terrestrial lichens of the Cladoniaceae family, which occur naturally on sandy soils of climatic and edaphic *cerrado* (PEREIRA et al., 2019), including in the Amazon, have also been recorded in this area (MOTA-

FILHO et al., 2007). This evidence, together with new data from the NDVI analysis, reinforce the idea that this is an ecotonal area resulting from the conjunction of the action of physical factors on a topographic profile variation between a dry and semi-arid depression and a humid, elevated area in the interior of the semi-arid Northeast (SANTOS et al., 2014). As such, the only relevant difference between these two plots is that the value of the NDVI of plot 9 (0.27), is below what is expected for the environmental conditions of the area. However, this is explained by clearings present in the plot, exposing the sandy soil, making the value of this index decrease. For plot 10, the value of NDVI was 0.45, returning to the pattern of the area.

Regarding the classification of the *Cerrado* patch found at the top of the Brejo de Saloá, it is important to observe two parameters mentioned by Ribeiro and Walter (2008). The first one concerns the physiognomy, defined by the structure and dominant forms of growth. The other criterion concerns the physical factors of the environment and also the floristic composition. In this sense, the enclave of *cerrado* found in the study area fits in the physiognomy of a *cerrado senso stricto*, due to its structure, as well by its floristic composition because species such as *Stigmaphyllon paralias*, *Tocoyena formosa*, *Tibouchina multiflora*, *Lantana camara*, and *L. canescens*, among others, have been collected, which are part of the flora of the *cerrado senso stricto*, and have been cited in the literature (BASTOS; FERREIRA, 2010; MEDEIROS, 2011; MENDONÇA et al., 2008; RIBEIRO; WALTER, 2008).

The sector where the *cerrado* enclave is located, at the top of the topographical profile, is quite differentiated from the portion of the Sertaneja Depression, mainly regarding climatic conditions and the floristic composition of the vegetation cover. In this sense, in the lower portion of the topographic profile, species such as *Poincianella pyramidalis*, *Piptadenia stipulacea*, *Jatropha molissima*, among others typical of the caatinga biome, have been collected (PRADO, 2003).

The establishment of *cerrado* patches inserted in the semi-arid domain finds an explanation in the Refuge Theory (HAFFER, 1969). In this sense, Troppmair (2006) highlights that refuges are areas that can be forest or not, where a biota is established in relatively restricted environments, surrounded by different geo-environmental conditions, causing the impediment of its expansion.

According to the Refuge Theory, due to a series of glaciations that occurred in the Quaternary, the vegetative dynamics of Brazil went through phases of forest retraction and expansion, changing the position of the caatingas and *cerrados* (AB'SABER, 2005). Due to the alternation between dry and humid climates in the tropical regions, Conti and Furlan (2003) cite that the Brazilian geobotanical set is the result of the expansion and retraction of forests, *cerrados* and caatingas, triggered during periods of climate change.

In the transition between the Pleistocene and Holocene, 18 to 12 thousand years B.P., the climatic conditions made the caatingas occupy a much larger area than they do today, extending into the domains of the *cerrado* and Amazonian biomes. During this drier period of expansion of the caatinga, the areas where the *cerrado* vegetation is found became refuges; in some places, the caatinga has remained as strongholds (SILVA, 2011). Thus, the Refuge Theory explains the *cerrado* found at the top of the Brejo de Saloá.

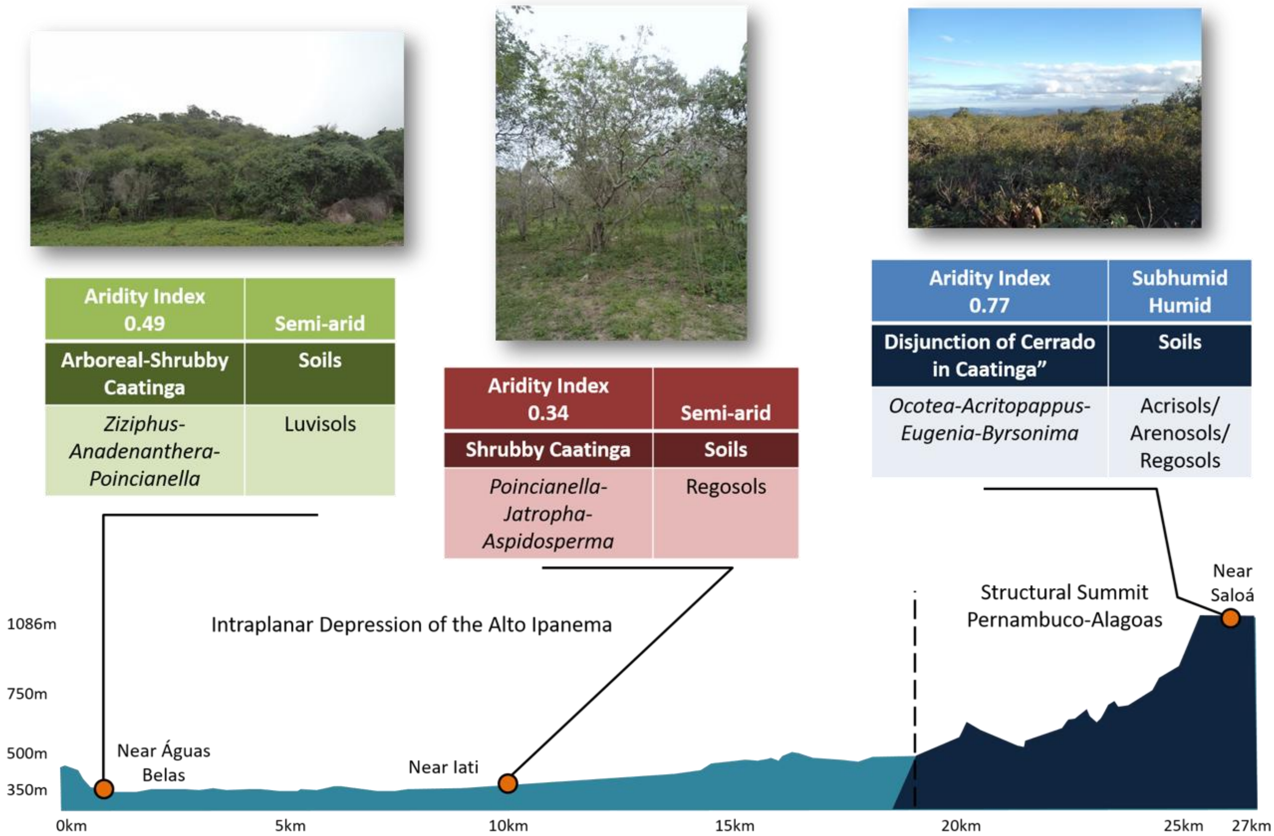
To explain the occurrence of a typical vegetation from another phytogeographic province, Ab'Sáber (2005) used the principle of the enclave, or residual relict. In this context, Brejo de Saloá can be considered as one enclave, since the vegetation cover, considered as *cerrado*, is surrounded by another domain of a completely different nature and composition. This author also adds that for the establishment of these species in these locations, possible corridors would have existed at some time, probably at the geological moment when the climate was favorable for the expansion of such vegetation.

On the dynamics of expansion and retraction of the *cerrado* and caatinga during the Quaternary, Silva (2011) comments that, after the period of retraction of the caatinga, due to climate fluctuations and with a more humid climate, these conditions led the *cerrado* to expand. Thus, the author adds that the enclaves of *cerrado* found outside its domain (Central Brazil), are refuges, interpreted as testimonies of paleoenvironments.

Moreover, it is also noteworthy the occurrence of lichens from the Cladoniaceae family, which are common in coastal sandy areas, in the Amazonian *cerrado* (*senso lato*) and in the central Brazilian *cerrado* (*senso stricto*). In a study of the lichen species *Cladonia verticillaris*, Buril et al. (2010) made collections of this species in two areas of *cerrado*, in the coastal tablelands of Alhandra (Paraíba) and in the *cerrado* that occurs in the Brejo de Saloá (Pernambuco). The authors corroborated that this species occurs in phytophysiognomically similar areas, but climatically and geographically distinct ones, including by tracing its genetic profile. This fact corroborates our indications of the establishment of the *cerrado* patch in Saloá, and that in those climatic conditions, lichens can be a bioindicator of *cerrado* environments. In other regions of the planet, especially boreal ones, Cladoniaceae occur in acid soils of *Pinus* spp. forests (PIZNAK; BAKOR, 2019).

This study becomes more comprehensive and enlightening as the proposed spatial transect is analyzed by drawing a physiographic overview of the landscape transect. In this sense, it cover aspects of the relief units, soils, and the different vegetation coverages involved in this process of vegetation differentiation along the topographic profile. These features can be seen in Figure 1, which shows the different environmental aspects of the area studied. The georeferenced coordinates, used for the elaboration of the Landscape Profile of Figure 1, are shown in Table 1. The spatial distribution of the points (plots) along the municipalities is represented in Map 1.

Figure 1. Landscape Profile between Águas Belas and Saloá.



Source: Authors.

Thus, through groupings of environmental characteristics, such as vegetation types, aridity index, soil types and relief units, it was possible to establish a schematic profile of how the different plant formations are distributed along the topographic gradient.

Figure 2 shows a mosaic with photographs of the plots along the whole landscape profile (plots 1 to 10).

Such vegetational formations vary from the typical caatinga of dry environments, to environments where physical conditions favor the development of montane forest, and culminating in the *cerrado* enclave at the top of the Brejo de Saloá.

Figure 2. Mosaic with photographs of parcels 1 to 10.

Source: Authors.

FINAL CONSIDERATIONS

Along the selected spatial transect, which extends from the Interplanaltic Depression of the Alto Ipanema, in the municipalities of Águas Belas and Iati, to the Pernambuco – Alagoas Structural Summit, where the municipality of Saloá is located, there was a variation in the structure and composition of the vegetation cover. Therefore, due to several influences of environmental factors, especially the variation of humidity along the topographic profile, a true vegetational mosaic has become established and developed. This mosaic includes the following: caatinga, typical of dry environments, which is sometimes densely shrubby, in other places it is sparsely shrubby; arboreal caatinga, which develops in a humid environment; montane and high-altitude forests; in addition to a *cerrado* enclave where local conditions are favorable.

Analysis using NDVI has proven to be very effective in differentiating vegetation density levels, especially when the values obtained are compared with the altitudinal values of the land. In this way, it helps to differentiate the vegetation cover patterns, which when associated with local physical factors, can explain the variation in the vegetation mosaic, especially in the establishment of patches of edaphic *cerrado*.

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REFERENCES

AB'SABER, A. N. **Os Domínios de Natureza no Brasil:** potencialidades paisagísticas. São Paulo: Ateliê Editorial, 3ª edição, 159 p. 2005.

ASNER, G. P.; NEPSTAD, D.; CARDINOT, G.; RAY, D. **Drought stress and carbon uptake in an Amazon forest measured with spaceborne imaging spectroscopy.** PNAS, v. 101, n. 16, pp. 6039–6044. 2004. https://doi.org/10.1073/pnas.0400168101

ASNER, G. P.; WARNER, A. S. **Canopy shadow in Ikonos satellite observations of tropical forest and savanas.** Remote Sensing of Environment, v. 87, p. 521-533, 2003. https://doi.org/10.1016/j.rse.2003.08.006

ASRAR, G.; FUCHS M.; KANEMASU, E. T.; HATFIELD, J. L. **Estimating absorbed**

photosynthetic radiation and leaf area index from spectral reflectance in wheat. Agronomy Journal, v. 76, pp. 300–306. 1984. https://doi.org/10.2134/agronj1984.00021962007600020029x

BASTOS, L. M.; FERREIRA, I. M. **Composições fitofisionômicas do bioma Cerrado: Estudo sobre o subsistema de Vereda.** Espaço em Revista, v.12, p.99-108, 2010. Available at: https://www.revistas.ufg.br/espaco/article/view/17656 Accessed: May 10, 2015.

BITENCOURT, M. D.; MESQUITA Jr., H. N.; MANTOVANI, W.; BATALHA, M. A.; PIVELLO, V. R. 1997. **Identificação de fisionomias de cerrado com imagem índice de vegetação.** Pp. 316-320. In: L. L. Leite. & C. H. Saito (orgs.). **Contribuição ao Conhecimento Ecológico do Cerrado**. Editora Universidade de Brasília, Brasília. 1997.

BURIL, M. L. L.; MARTINS, M. C. B.; PEREIRA, E. C. G.; SILVA, N. H. **Estudo comparativo da fração fenólica da imobilização em sistema de fluxo contínuo de *Cladonia verticillaris* (Raddi) FR. (Ascomycota: Lecanoromycetes) de duas ÁREAS DISTINTAS DE CERRADO.** In: 61° Congresso Nacional de Botânica. Manaus, Amazônia, Brasil. 2010.

CARVALHO JÚNIOR, O. A.; SAMPAIO, C. S.; SILVA, N. C.; COUTO JÚNIOR, A. F.; GOMES, R. A. T.; CARVALHO, A. P. F.; SHIMABUKURO, Y. E. **Classificação de Padrões de Savana Usando Assinaturas Temporais NDVI do Sensor MODIS no Parque Nacional Chapada dos Veadeiros**. Revista Brasileira de Geofísica. Vol. 26 (4). p. 505-517, 2008. https://doi.org/10.1590/S0102-261X2008000400010

CONTI, J. B.; FURLAN, S. A. **Geoecologia: O Clima, os Solos e a Biota**. In: ROSS, J. S. (Org.). Geografia do Brasil. 4. ed. 1 reimp. São Paulo: Editora da Universidade de São Paulo. 2003.

CORRÊA, A. C. B., TAVARES, B. A. C., MONTEIRO, K. A., CAVALCANTI, L. C. S., LIRA, D. R. **Megageomorfologia e Morfoestruturas do Planalto da Borborema.** Revista do Instituto Geológico, n.31. São Paulo. p.35-52. 2010. https://doi.org/10.5935/0100-929X.20100003

HAFFER, J. **Speciation in Amazonian Forest Birds. Science**, vol. 165, n. 3889. P. 131-137. 1969. https://doi.org/10.1126/science.165.3889.131

IBGE. **Manual técnico da vegetação brasileira: sistema fitogeográfico, inventário das formações florestais e campestres, técnicas e manejo de coleções botânicas, procedimentos para mapeamentos.** 2a ed. IBGE-Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, 275p. 2012. Available at: https://uc.socioambiental.org/sites/uc/files/2019-12/liv63011.pdf. Accessed: May 10, 2019.

MEDEIROS, J. de D. **Guia de campo: vegetação do Cerrado 500 espécies.** Ministério do Meio Ambiente/SBF, Brasília. 2011.

MENDONÇA, R. C.; FELFILI, J. M.; WALTER, B. M. T.; SILVA JÚNIOR, M. C.; REZENDE, A. V.; FILGUEIRAS, T. S.; NOGUEIRA, P. E. **Flora Vascular do Cerrado**. Pp. 289-556. In: S. M. SANO; S. P. ALMEIDA (eds). **Cerrado: ambiente e flora. Planaltina**, EMBRAPA-CPAC. 2008.

MOTA FILHO, F. O.; PEREIRA, E. C. G., LIMA, E. S., SILVA, N. H., FIGUEIREDO, R. C. B. **Influência de poluentes atmosféricos em Belo Jardim (PE) utilizando *Cladonia verticillaris* (líquen) como biomonitor**. Química Nova, vol. 30, No. 5, pp. 1072-1076, 2007. https://doi.org/10.1590/S0100-40422007000500004

MYNENI, R. B.; HALL, F. G.; SELLERS, P. J.; MARSHAK, A. L. **The interpretation of spectral vegetation indexes**. IEEE Transactions on Geoscience and Remote Sensing, v. 33, pp. 481–486. 1995. https://doi.org/10.1109/36.377948

NOBREGA, N. A.; RIBEIRO, S. M. A.; PEREIRA, E. C.; MARCELLI, M. M.; MARTINS, M. C. B.; FALCÃO, E. P. S.; GUSMÃO, N. B.; SILVA, N. H. **Produção de compostos fenólicos a partir de células imobilizadas do líquen *Parmotremaandinum* (Müll. Arg.) Hale e avaliação de atividade antimicrobiana**. Acta Botanica Brasilica, vol. 26 num. 1: pp. 101-107. 2012. https://doi.org/10.1590/S0102-33062012000100012

PEREIRA, E. C.; SANTOS, L. P.; SILVA, A. K. O.; SILVA, R. F.; SILVA, N. H.; BURIL, M. L. L.; MARTINS, M. C. B.; SANTIAGO, R.; VICENTE, C.; LEGAZ, M. E. Interaction of Cladoniaceae lichens with Quartzarenic Neosols in Northeastern Brazil: a mini review. Revista Brasileira de Geografia Física, vol. 12 num. 06: pp. 2302-2312. 2019.

PIZNAK, M.; BACKOR, M. **Lichens affect**

boreal forest ecology and plant metabolism. South African Journal of Botany, v.124, pp. 530 – 539. 2019. https://doi.org/10.1016/j.sajb.2019.06.025

PRADO, D. E. **As Caatingas da América do Sul**. In.: LEAL, I. R.; TABARELLI, M. (Eds.) **Ecologia e Conservação da Caatinga**. Editora Universitária: UFPE. 2003.

RIBEIRO, J. F.; WALTER**,** B. M. T. **As principais fitofisionomias do bioma cerrado**. In: SANO, S. M.; ALMEIDA, S. P de. (Ed.) **Cerrado: ambiente e flora**. Brasília: EMBRAPA, v.1, p.152-212. 2008.

SANTOS, L. S.; SILVA, H. P. B.; PEREIRA, E. C. G. **Cerrado em área disjunta em brejo de altitude no agreste pernambucano, brasil.** Boletim Goiano de Geografia. v.34, n.32, p.337-353. 2014. https://doi.org/10.5216/bgg.v34i2.31735

SILVA, M. L. **A Dinâmica de Expansão e Retração de Cerrados e Caatingas no Período Quaternário: Uma Análise Segundo a Perspectiva da Teoria dos Refúgios e Redutos Florestais.** Revista Brasileira de Geografia Física. v.4, p.57-73. 2011. https://doi.org/10.26848/rbgf.v4i1.232642

SOBREVILLA, C.; BATH, P**. Evaluación ecológica rápida: un manual para usuarios de América Latina y el Caribe.** Washington, The Nature Conservancy. 1992.

TROPPMAIR, H. **Biogeografia e Meio Ambiente**. 7. ed. Rio Claro: Divisa. 2006. Available at: http://www.icmbio.gov.br/portal/images/stories/imgs-unidades-coservacao/naturezaemfoco.pdf Accessed: June 17, 2016.