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Structure and Spatial Variability of Plant Formations in Savanna

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ABSTRACT

The objective of this study was to evaluate the structure and spatial variability of vegetation in savanna area (Brazilian Cerrado). The plots were placed in Sparse Cerrado - T1; Typical Cerrado - T2 and Dense Cerrado - T3. A plot of 20 x 500 m was delimited in each area, which was subsequently subdivided into 10 subplots of 20 x 50 m, where individuals with diameter at breast height (DBH) ≥ 10 cm were sampled. A total of 684 individuals were sampled in T1, 475 in T2 and 453 individuals in T3. There was no statistical difference for diameter at breast height (DBH), analyzed by the Tukey test ($p < 0.05$). For the subplots, the T2 plot showed homogeneity for the mean values of DBH (m). The diameter classes showed similar trends for all experimental plots, indicating self-regenerating communities. The spherical model was the one that best fitted the data, with different scales of spatial variability, greater spatial continuity for T3 (a = 210 m), and smaller spatial continuity for the T2 plot (a = 120 m). The scaled semivariograms adjusted to the spherical model showed different degrees of spatial dependence, demonstrating spatial continuity for all sample plots and subplots.
Keywords: Brazilian savanna. Vegetation structure. Geostatistical. Spatial continuity.

Estrutura e Variabilidade Espacial de Formações Vegetais no Cerrado

R E S U M O

O objetivo deste estudo foi avaliar a estrutura e variabilidade espacial da vegetação em área com savana (Cerrado). As parcelas foram implantadas em Cerrado Esparso - T1; Cerrado Típico - T2 e Cerrado Denso - T3. Em cada área foi delimitada uma parcela de 20 x 500 m, que posteriormente foi subdividida em 10 subparcelas de 20 x 50 m, onde foram amostrados indivíduos com diâmetro à altura do peito (DAP) ≥ 10 cm. Um total de 684 indivíduos foram amostrados em T1, 475 em T2 e 453 indivíduos em T3. Não houve diferença estatística para o diâmetro à altura do peito (DAP), analisado pelo teste de Tukey ($p < 0,05$). Para as subparcelas, a parcela T2 apresentou homogeneidade para os valores médios de DAP (m). As classes de diâmetro apresentaram tendências semelhantes para todas as parcelas experimentais, indicando comunidades autorregenerativas. O modelo esférico foi o que melhor se ajustou aos dados, com diferentes escalas de variabilidade espacial, com maior continuidade espacial para T3 (a = 210 m) e menor continuidade espacial para a parcela T2 (a = 120 m). Os semivariogramas escalonados ajustados ao modelo esférico apresentaram diferentes graus de dependência espacial, demonstrando continuidade espacial para todas as parcelas e subparcelas amostrais.
Palavras-chave: Savanna brasileira. Estrutura da vegetação. Geoestatística. Continuidade espacial.

Introduction

Savanna is a xeromorphic vegetation, which in known as Cerrado Brazil (IBGE, 2012), and originally covered an area of approximately 2 million km^2 (Sano et al., 2010), occupying about 22% of the Brazilian territory (Parente et al., 2021). Currently, approximately 50% of the original area of Savanna has been removed or modified by anthropic action (Soares Filho et al., 2014; Strassburg et al., 2017), mainly for agricultural use. This kind of impact may take the lost of diversity in vegetation species (Silva et al., 2022).

In the Brazilian Savanna, the studies about vegetation usually involve floristic and phytosociological surveys that assess the structure of plant community (Mews et al., 2011), providing information that characterizes the distribution and heterogeneity of species across the landscape (Morais et al., 2019; Silva and Siqueira, 2020; Siqueira et al., 2022). The knowledge of floristic diversity and phytosociological surveys are important to support the conservation of natural resources, self-regeneration, and elaboration of preservation plans (Morais et al., 2021). Freire et al. (2022) found significant floristic richness even in anthropic fragments, which is important to maintenance of ecological process in Piauitinga River sub-Basin. Then, floristic and structural studies make possible to know the forest conservation status and the phytosociological pattern of forest formations (Santos Neto et al., 2023).

Although the studies about vegetation dynamic, phytosociological and taxonomic aspects are common in areas of Savanna (Mews et al., 2011; Morais et al., 2019; Silva et al., 2019), the plant community can also be characterized by the spatial distribution of individuals (Neves et al., 2010), making it possible to evaluate the different scales of spatial variability across the landscape (Silva and Siqueira, 2020; Gholami et al., 2021; Siqueira et al., 2022). Neves et al. (2010) described different scales of spatial variability for the tree, and shrub strata, which, according to these authors, was caused by the characteristics of each plant fragment. For Gholami et al. (2021), the spatial variability of tree component can be described with greater or lesser spatial continuity, which is caused by the characteristics of the tree stratum such as density and species coverage.

Therefore, the hypothesis of this study was that the different vegetal formations of Savannah of Parque Estadual do Mirador present different scale of spatial variability. Thus, the aim of this study was to evaluate the structure and spatial variability of vegetation in savanna area.

Material and methods

The study was carried out in the Parque Estadual do Mirador (PEM), located in State of Maranhão, Brazil, in the geographical coordinates: 06° 18' 51" S and 45° 53' 04" W (Figure 1A). PEM is an integral conservation unit with a total area of 766,781 ha, with an Aw type climate (humid tropical), an average annual rainfall of 1.183 mm, and an average temperature ranging from 24 °C (winter) to 32 °C (summer).

In the present study, three experimental plots were delimited in the period from 07/21/2017 to 07/30/2017, in wooded Savannas that differ by the arboreal size in: Sparse Cerrado (T1), Typical Cerrado (T2), and Dense Cerrado (T3), according to Ribeiro and Walter (2008). T1 corresponds to 33.50% of the total area of PEM (Figure 1A), with sparse vegetation, trees around 3 m high, and a three density of 0.396 ha^{-1}. The vegetal formation in T2 represents 33.97% of the PEM area, with a predominance of shrub-tree extract, and three density of 0.467 ha^{-1}. In turn, T3 corresponds to 26.36% of the PEM, with an arboreal size around eight meters high and three density of 1,605 ha^{-1}.

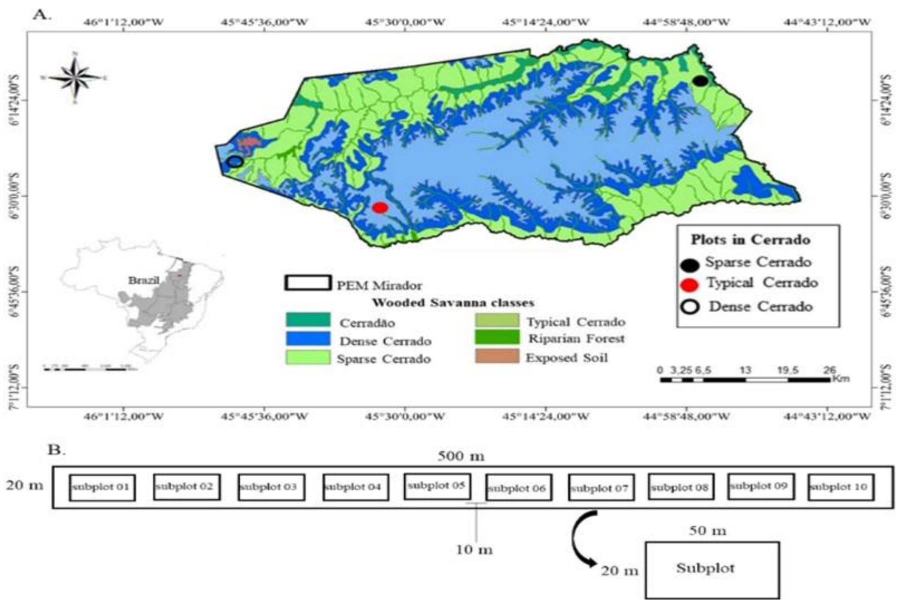

Figure 1. Location of the Parque Estadual do Mirador (PEM), Maranhão, Brazil

The parameter diameter at breast height [DBH (m)], estimated from the trees present in the experimental plots, were estimated based on the plot's method. For this, the plots of 20 x 500 m (1 ha) were subdivided into 10 subplots of 20 x 50 m (0.1 ha), which were set with a spacing of 10 m (Figure 1B). All shrub-tree individuals with DBH ≥ 10 cm in the plots were measured and georeferenced; from this, the diametric classes were stablished, with an amplitude of 0.4 m

(Morais et al., 2019). The natural vegetation in PEM is Savanna, which is known in Brazil as Cerrado (IBGE, 2012), and is subdivided into four vegetation formations: Savanna Forest, Savanna Wooded, Savanna Park and Savanna Grassy-Woody (IBGE, 2012).

The individuals found with flowers or fruits at the time of phytosociological sampling were collected, herborized and identified using the Angiosperm Phylogeny Group classification system, totaling 24 species: Anacardiaceae (*Anacardium occidentale* L. and *Tapirira guianensis* Aubl.); Apocynaceae (*Hancornia speciosa* Gomes and *Himatanthus* sp); Caryocaraceae (*Caryocar coriaceum* Wittm.); Chrysobalanaceae (*Hirtella glandulosa* Spreng. and *Hirtella ciliata* Mart. & Zucc.); Combretaceae (*Combretum* sp.); Conaraceae (*Connarus suberosus* Planch.); Dilleniaceae (*Curatella americana* L.); Fabaceae (*Albizia procera* (Roxb) Benth., *Dimorphandra mollis* Benth., *Parkia platycephala* Benth., *Plathymenia reticulata* Benth., *Stryphnodendron coriaceum* Benth., *Tachigali subvelutina* Benth. and *Vatairea macrocarpa* [(Benth. Ducke)]; Melastomataceae (*Mouriri elliptica* Mart.); Myrtaceae (*Eugenia sonderiana* Berg.); Opiliaceae (*Agonandra brasiliensis* Miers ex Benth); Vochysiaceae (*Salvertia convallariodora* A.St.-Hil., *Vochysia gardneri* Warm., *Qualea grandiflora* Mart. and *Qualea parviflora* Mart.).

The following statistical parameters were determined: mean, standard deviation, coefficient of variation (CV%), asymmetry and kurtosis. The normality of data was tested using the Kolmogorov-Smirnov test (D-KS - $p < 0.01$). CV values (%) were classified as low ($CV \leq 12\%$), median ($CV = 12\text{-}60\%$) and high ($CV \geq 60\%$), according to Warrick and Nielsen (1980). The statistical difference for DBH (m) between plots and subplots were determined by Tukey test ($p < 0.05$).

The spatial variability of data was assessed with aim of geostatistic tools, considering the assumptions of the intrinsic hypothesis through the construction of a semivariogram γ (h) of a spatially distributed variable (Vieira, 2000 - Eq. 1):

$$y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (1)$$

where:

y(h) - value of semivariogram estimation for the distance h;

x - measure of separation of vector h;

h - distance between measurements; and,

N(h) - number of observations, separated by the distance h.

The data were adjusted to a mathematical model (Gaussian, exponential or spherical), by means of cross-validation, considering the values of adjustments corresponding to the parameters of the nugget effect (C_0), structural variation (C_1), and reach (a, m), according to Vieira (2000). Scaled semivariograms were constructed, allowing comparing the patterns of spatial variability between variables (Silva et al., 2018). The advantage of the scaled semivariogram is that several semivariograms can be drawn on the same graph, otherwise, the scales on the semivariance axis would be different. When grouping the semivariograms, similar spatial variability of the relevant variables was observed. Spatial dependence was determined by the spatial dependency index (SDR, %) classified as strong ($SDR \leq 25\%$), moderate ($SDR > 25$ to $< 75\%$), and weak ($SDR \geq 75\%$), according to Cambardella et al. (1994), Eq. 2:

$$SDR = \left(\frac{C_0}{C_0 + C_1}\right) * 100 \quad (2)$$

where:

SDR - spatial dependency ratio;

C_0 - nugget effect; and,

C_1 - structural variance.

Results and discussion

A total of 1,612 shrub-tree individuals were sampled in the three physiognomies (Table 1): 684 (Mean = 0.37A) in T1; 475 (Mean = 0.37A) in T2, and 453 (Mean = 0.37A) in T3; and there was no statistical differentiation by the Tukey test ($p < 0.05$ - Table 1). Statistical differentiation was observed for the subplots corresponding to T1 and T3 (subplot 01 - 0.52A; subplot 03 - 0.28B; subplot 08 - 0.33B; subplot 09 - 0.30B; subplot 10 - 0.31B and subplot 30 - 0.66A). The occurrence of greater abundance of shrub-tree individuals in T1 plot (684 individuals) reflects the presence of individuals with smaller diameters (between 0.1-0.4 m). Ribeiro and Walter (2008) described that the Sparse Cerrado is characterized by individuals with shorter and sparse size, smaller canopy and vegetation cover, aspects confirmed in the present study. The presence of 475 individuals in T2 indicates that it is an intermediate formation between T1 and T3, where occurs individuals common to both environments (IBGE, 2012; Siqueira et al., 2022).

Table 1. Descriptive statistics for diameter at breast height (DBH) in physiognomies of Cerrado in the Parque Estadual do Mirador, Maranhão, Brazil

	N		Mean	Variance	SD	CV (%)	Skewness	Kurtosis	D-KS*
				T1 – Sparse Cerrado					
Plot	684	1 ha	0.37A	0.09	0.30	80.35	2.47	8.80	0.181Ln
Subplot 01	42	0.1 ha	0.52A	0.13	0.36	69.05	1.16	1.39	0.144n
Subplot 02	67		0.42AB	0.12	0.35	84.48	2.21	6.03	0.170n
Subplot 03	103		0.28B	0.07	0.26	93.08	2.35	6.09	0.213Ln
Subplot 04	61		0.37AB	0.06	0.24	66.48	1.21	1.09	0.126n
Subplot 05	71		0.37AB	0.08	0.28	76.04	1.73	3.52	0.143n
Subplot 06	68		0.40AB	0.13	0.37	91.68	3.05	11.47	0.206Ln
Subplot 07	59		0.41AB	0.08	0.29	69.93	1.58	2.21	0.153n
Subplot 08	125		0.33B	0.10	0.31	95.02	3.65	18.63	0.203Ln
Subplot 09	76		0.30B	0.05	0.22	73.82	1.98	5.49	0.185Ln
Subplot 10	44		0.31B	0.04	0.20	66.02	1.79	3.69	0.177n
				T2 - Typical Cerrado					
Plot	475	1 ha	0.37A	0.05	0.24	63.88	2.44	9.29	0.153Ln
Subplot 11	47	0.1 ha	0.41A	0.05	0.23	55.88	1.39	2.31	0.202n
Subplot 12	41		0.45A	0.08	0.28	63.37	1.41	1.93	0.186n
Subplot 13	39		0.34A	0.03	0.18	52.72	1.56	3.29	0.118n
Subplot 14	59		0.39A	0.06	0.25	64.81	1.55	2.53	0.158n
Subplot 15	27		0.38A	0.03	0.18	47.50	1.16	1.81	0.170n
Subplot 16	72		0.32A	0.05	0.22	69.42	4.08	23.27	0.182n
Subplot 17	65		0.31A	0.02	0.16	53.57	2.28	8.66	0.126n
Subplot 18	41		0.45A	0.10	0.32	70.65	3.26	14.62	0.218n
Subplot 19	49		0.39A	0.05	0.23	60.76	1.53	2.15	0.179n
Subplot 20	41		0.34A	0.08	0.28	82.28	2.71	9.73	0.231n
				T3 - Dense Cerrado					
Plot	453	1 ha	0.37A	0.07	0.26	72.02	2.14	6.75	0.155Ln
Subplot 21	41	0.1 ha	0.29B	0.02	0.16	56.75	1.92	5.27	0.150n
Subplot 22	64		0.29B	0.02	0.16	54.97	1.37	1.85	0.173n
Subplot 23	29		0.35B	0.06	0.26	73.39	1.73	2.08	0.244n
Subplot 24	46		0.32B	0.06	0.24	76.47	1.25	0.87	0.185n
Subplot 25	58		0.41B	0.07	0.28	67.55	2.03	6.52	0.126n
Subplot 26	49		0.34B	0.06	0.25	74.39	1.33	1.28	0.197n
Subplot 27	64		0.39B	0.08	0.29	73.16	1.88	5.15	0.146n
Subplot 28	49		0.39B	0.06	0.24	61.71	1.25	1.14	0.170n
Subplot 29	33		0.27B	0.03	0.18	66.78	1.42	1.43	0.215n
Subplot 30	27		0.66A	0.21	0.46	69.50	1.66	2.09	0.206n

N - Individuals number; SD - Standard deviation; CV (%) - Coefficient of variation; D-KS* - Kolmogorov-Sminorv normality test - 0.01%. Ln- lognormal e n- normal

There was less abundance of individuals (453 individuals) in T3, justified by the occurrence of trees with larger size, which provide greater shading, thus preventing the development of lower strata (Ribeiro and Walter, 2008). Although there are particularities in each plant formation, other factors can affect the abundance and distribution of plant species in Cerrado, such as altitude (Pessoa et al., 2021), soil (Silva and Siqueira, 2020; Siqueira et al., 2022), climate (Peixoto et al., 2020) and degree of human exploitation (Rios et al., 2018).

The data presented high CV values for the three experimental plots (values > 60%), according to the Warrick and Nielsen (1980). However, T2 presented four subplots with median CV values (subplots 11, 13, 15 and 17). While T3 showed two subplots with median CV (subplots 21 and 22). The diameter at breast height data showed lognormal frequency distribution in T1, T2 and T3, based on the Kolmogorov-Smirnov test [D-KS ($p < 0.05$)]. Regarding the subplots, T2 and T3 presented normality of data (Table 1).

There was no statistical differentiation by the Tukey test ($p < 0.05$) for the mean values of DBH between the plant formations (Table 1), however, there was statistical differentiation for this parameter in the subplots in T1 and T3, showing heterogeneity for these formations (Table 1). The homogeneity of DBH values in T2 is possibly caused by the specific characteristic of this area, where occurs the presence of shrub and tree individuals common in T1 and T3 (Ribeiro and Walter, 2008; IBGE, 2012), corroborating the lower CV value (%).

The high CV values corresponding to the subplots in T1 (Table 1), describe the greater heterogeneity of DBH values in this plot, since there are also greater variations in the number of individuals between the sub-plots. On the other hand, the presence of median CV values for the subplots in T2 and T3 is indicative of the low variation of DBH within these subplots, compared to T1 (Table 1).

The individuals were distributed in diametric classes from the definition of amplitude of 0.4 m (Figure 2). This occurred in T1 (8 classes of diameter - Figure 2A), T2 (7 diameter classes - Figure 2D), and T3 (6 diameter classes - Figure 2G). Only the histograms with largest number of diameter classes were presented. There was a higher concentration of individuals in the first diametric class (DBH = 0.1-0.4 m - Figures 2B, C, D, E, F, H and I) in all plots. However, it is important to highlight that T2 presented the lowest standard deviation value (Table 1), indicating that the system has the least internal variation in relation to DBH in this plot.

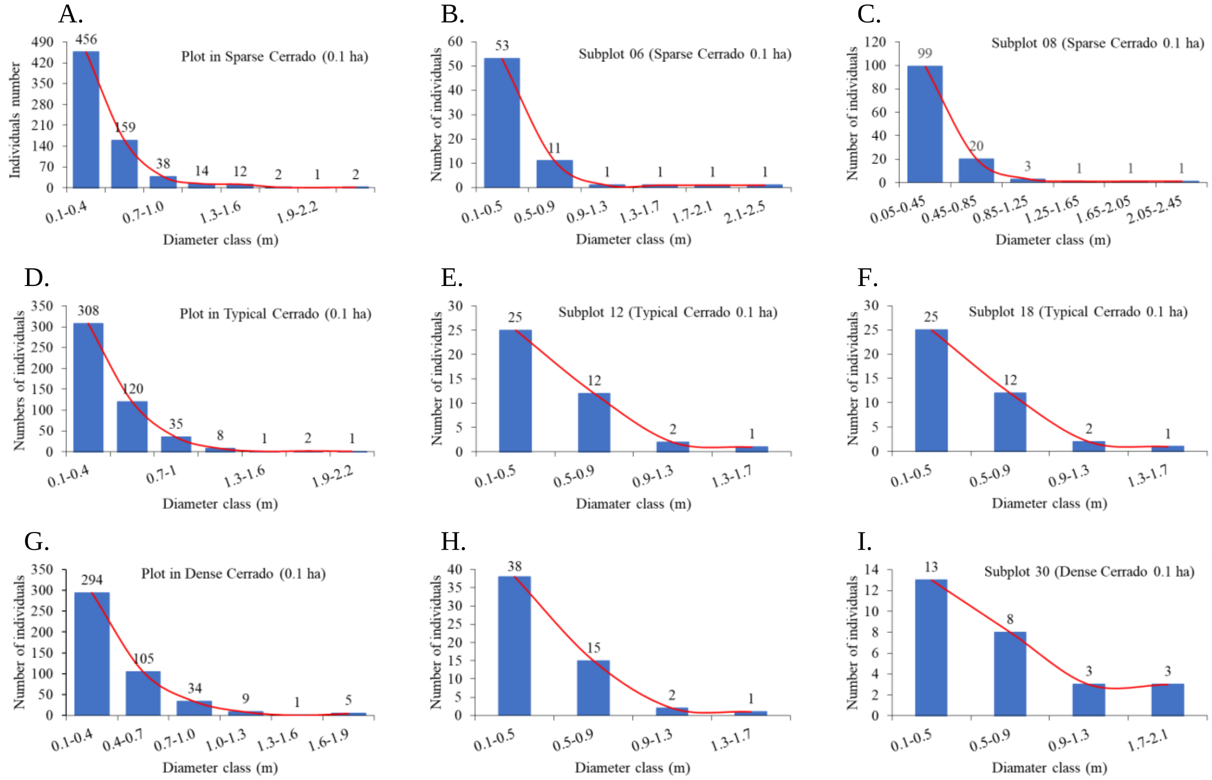

Figure 2. Frequency distribution of diameter classes corresponding to individuals sampled in Cerrado phytophysiognomies in the Parque Estadual do Mirador, MA. (A) Plot in T1, (B) Subplot 06 in T1, (C) Subplot 08 in T1, (D) Plot in T2, (E) Subplot 12 in T2, (F) Subplot 18 in T2, (G) Plot in T3, (H) Subplot 25 in T3, and (I) Subplot 30 in T3.

The high CV values corresponding to the subplots in T1 (Table 1), describe the greater heterogeneity of DBH values in this plot, since there are also greater variations in the number of individuals between the sub-plots. On the other hand, the presence of median CV values for the subplots in T2 and T3 is indicative of the low

variation of DBH within these subplots, compared to T1 (Table 1).

The distribution of DBH in diametric classes showed that there is a greater number of individuals with diameters between 0.1-0.4 m, suggesting the same trend for all plant formations. The greater number of individuals allocated to the first classes describes that the plant community presents an inverted "J" trend, indicating a balance between the recruitment rate and mortality in the community (Pessoa et al., 2021). Inverted "J" trend is commonly described in preserved communities, where mortality and recruitment rates are stabilized (Santos et al., 2017), thus, young individuals replace adults in the population balancing the plant community (Oliveira Filho; Ratter, 2002). The distribution pattern observed in this study was registered by Lima et al. (2020) in studies in savanna, indicating continuous recruitment and self-regeneration in the communities.

The presence of individuals with largest diameters was recorded from T3 (DBH = 1.6-1.9 m), whereas in T1, only two individuals had DBH = 2.2-2.4 m. Although there are structural differences between the Cerrado physiognomies, these differences are more pronounced in areas such as T1 and T3 (Oliveira Filho; Ratter, 2002; Ribeiro and Walter, 2008; Siqueira et al., 2022), compared to areas such as T2. The different levels of shading, caused by the density of individuals in plant formation, which can define the succession of species in the landscape, is another factor that differentiates areas such as T1 and T3 (Pessoa et al., 2021).

The spherical model was the one that best characterized the spatial variability for most of the data, in terms of plots and subplots, except the subplot 07 in T1, which fitted the Gaussian model (Table 2). T2 showed four subplots with pure nugget effect (PNE - subplot 12, 14, 18 and 19), followed by plot T3 (subplots 22, 23 and 28) and T1 (subplot 05 and 09).

Table 2. Adjustment parameters of semivariograms for plots and subplots in the Parque Estadual do Mirador, Maranhão

		Modelo	C_0	C_1	a (m)	R^2	SDR %
			T1 - Sparse Cerrado				
Plot	1 ha	Spherical	0.06	0.03	130	0.99	61.85
Subplot 01	0.1 ha	Spherical	0.03	0.11	8	0.99	21.42
Subplot 02		Spherical	0.04	0.10	10	0.99	28.57
Subplot 03		Spherical	0.06	0.02	9	0.98	73.17
Subplot 04		Spherical	0.02	0.55	11	0.98	26.66
Subplot 05		PNE					
Subplot 06		Spherical	0.03	0.07	8	0.99	30.00
Subplot 07		Gaussian	0.01	0.06	9	0.99	23.17
Subplot 08		Spherical	0.02	0.13	9	0.99	18.23
Subplot 09		PNE					
Subplot 10		Spherical	0.01	0.04	8	0.99	20.00
			T2 - Typical Cerrado				
Plot	1 ha	Spherical	0.05	0.01	120	0.99	83.33
Subplot 11	0.1 ha	Spherical	0.04	0.03	10	0.99	53.33
Subplot 12		PNE					
Subplot 13		Spherical	0.01	0.02	13	0.98	36.58
Subplot 14		PNE					
Subplot 15		Spherical	0.01	0.02	12	0.98	25.64
Subplot 16		Spherical	0.01	0.05	11	0.98	14.49
Subplot 17		Spherical	0.01	0.04	12	0.99	20.00
Subplot 18		PNE					
Subplot 19		PNE					
Subplot 20		Spherical	0.01	0.08	11	0.99	17.52
			T3 - Dense Cerrado				
Plot	1 ha	Spherical	0.5	0.3	210	0.98	62.50

Subplot 21	0.1 ha	Spherical	0.01	0.03	10	0.98	36.17
Subplot 22		-- PNE ------------------------------------					
Subplot 23		-- PNE ------------------------------------					
Subplot 24		Spherical	0.01	0.03	10	0.99	38.77
Subplot 25		Spherical	0.03	0.05	10	0.98	37.50
Subplot 26		Spherical	0.01	0.07	10	0.99	16.66
Subplot 27		Spherical	0.04	0.13	11	0.98	23.52
Subplot 28		-- PNE ------------------------------------					
Subplot 29		Spherical	0.01	0.01	12	0.98	34.48
Subplot 30		Spherical	0.01	0.26	10	0.99	3.70

C_0 - Nugget effect; C_1 - Structural variance; a (m) - Range; R^2 - Determination coefficient; SDR (%) - Spatial dependence ratio; PNE - Pure nugget effect

The highest range value corresponded to T3 (a = 210 m), followed by T1 (a = 130 m), and T2 (a = 120 m), thus evidencing the existence of different ranges of variability space for the tree component (Vieira, 2000). When studying the structure of a vegetation, Neves et al. (2010) described the occurrence of greater spatial continuity for the tree strata, compared to the lower strata (herbaceous and shrub). When studying a tree vegetation, Gholami et al. (2021) described the spatial continuity over long distances (a = 3110 m), possibly caused by the specific characteristics of elements present in the sampling area (topography, edaphic properties, and climate), which are components that define the spatial scale gradient of tree strata. Different range values were observed in the subplots (Table 2), and the variations between the range values were from 8 to 11 m for the sub plots in T1; from 11 to 13 m in T2, and from 10 to 12 m in T3, indicating that DBH along had different ranges of variability along the plots, mainly in areas such as T1 (Neves et al., 2010). The range values are indicative of the maximum distance at which a variable is spatially correlated and is an important parameter in the assessments involving geostatistics tools (Vieira, 2000).

The spatial dependence was considered low in T2 (SDR = 83.33%), median in T1 (SDR = 61.85%) and T3 (SDR = 62.50%), as shown in Table 2. In T1 subplot, SDR values were considered median (SDR = 25-75%) in four subplots, and high (SDR = 0-25%) in four subplots. In T2, three subplots presented median SDR (subplot 11, 13 and 15) and three presented high SDR (subplot 16, 17 and 20). In T3, four subplots showed median SDR (subplot 21, 24, 25 and 29), and three subplots showed high SDR (subplot 26, 27 and 30), as shown in Table 2.

As to the subplots, in the vegetation formations, the spatial dependence values ranged from high (SDR ≤ 25% - Table 2) to moderate (SDR = 25-75%), according to Cambardella et al. (1994), indicating that the spatial dependence vary according to the vegetable composition present in study. Thus, according to Cambardella et al. (1994), the strong spatial dependence may reflect the intrinsic characteristics of a variable, while the spatial dependence considered as median may be an indication of less variability of the data.

The scaled semivariograms corresponding to the variables that showed spatial dependence are shown in Figure 3. The scaled semivariograms for the T1, T2 and T3 plots were adjusted to the spherical model, with a reach value of 130 m (Figure 3A) and moderate spatial dependence (SDR = 72.38%). The subplots showed different scales of spatial variability, with ranges ranging from 10 m (in T2 and T3) to 9 m (in T1 - Figures 3B, C and D). The values of spatial dependence (SDR%) were considered median in the subplots in T1 (SDR = 33.33% - Figure 3B) and in T3 (SDR = 43.85% - Figure 3D); in T2, were elevated (SDR = 23.07% - Figure 3C).

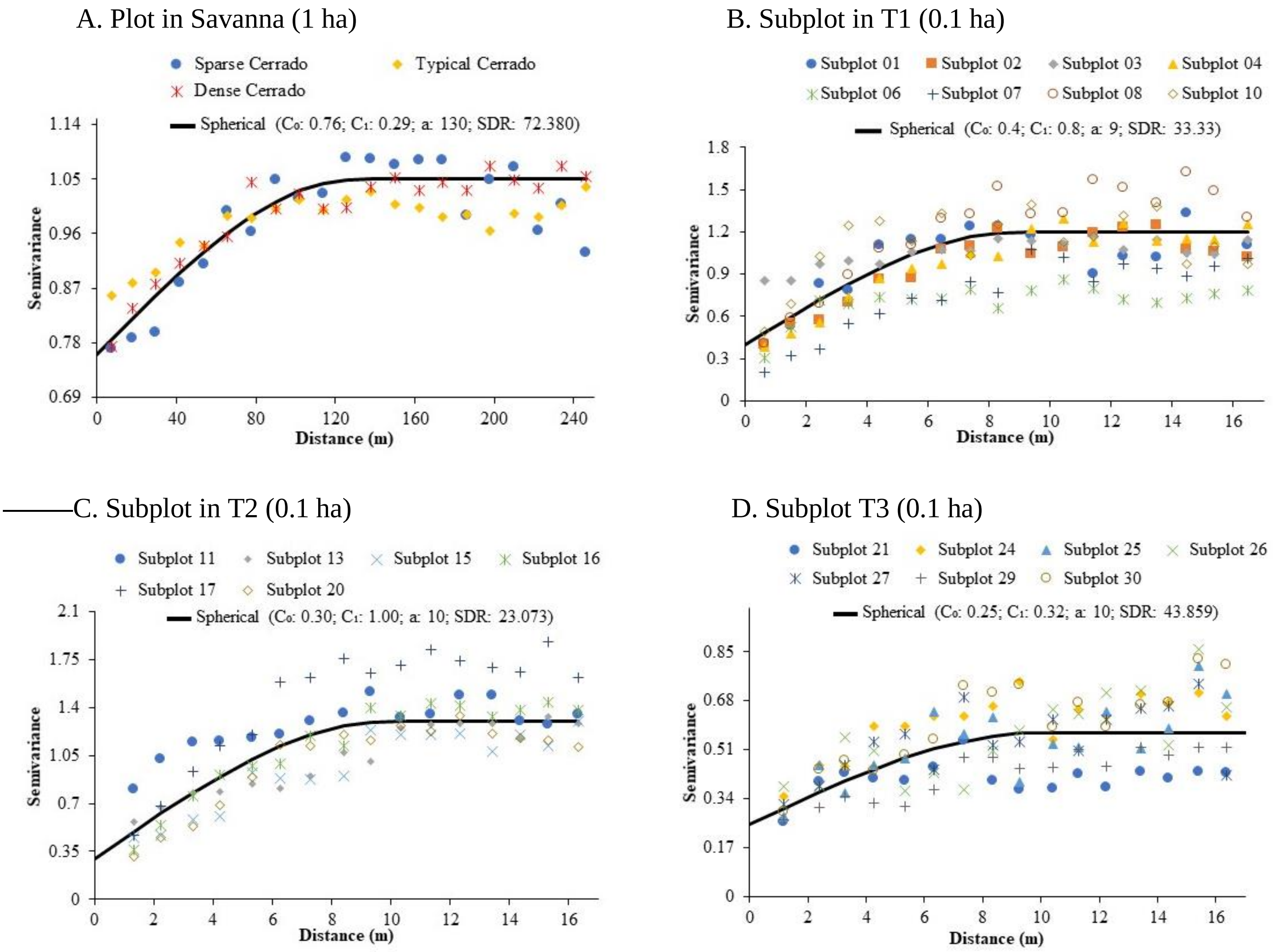

Figure 3. Scaled semivariograms corresponding to plots and subplots in the Parque Estadual do Mirador, Maranhão.C_0 - Nugget effect; C_1 - Structural variance; a (m) - Range; SDR (%) - Spatial dependence ratio

For the scaled semivariograms of subplots, there was high spatial dependence in T2 (Figure 3C), and median spatial dependence in T1 and T3 (Figures 3B and D). According to Vieira (2000) and Silva et al. (2018), the scaled semivariograms allows grouping different values of semi variance, considering the same distance. Thus, it is possible to infer that the DBH trend in the physiognomies is more homogeneous, corroborating the individual SDR values (Table 2). The use of geostatistics tools made it possible to describe the spatial variability of vegetation, indicating the occurrence of variations in DBH, corroborating with Ribeiro and Walter (2008). The class intervals of diameters described communities with balanced recruitment and mortality rate, reflecting the balance in plant community (Santos et al., 2017).

The use of geostatistics tools made it possible to show that DBH in physiognomies and subplots have different scales of spatial variability, according to Vieira (2000), with a lower spatial continuity value in T2, a portion with greater homogeneity. The geostatistical analysis described the community structure in the present study, constituting a tool promising for evaluating the spatial trend of plant strata.

Conclusions

The structure and spatial variability of vegetation in savanna area was properly evaluated by geostatistic tools. The tested hypothesis was confirmed, once Savanna's physiognomies have different scales of spatial variability, conditioned by the pattern of plant distribution present in the plots, demonstrating median spatial dependence in sparse and dense Cerrado, with plant formations with greater differentiation in DBH. The largest number of subplots without detection of spatial variability in typical Cerrado was caused by the spacing used between arboreal individuals. The vegetation structure in the Parque Estadual do

Mirador showed a self-regenerating pattern, with a concentration of DBH values in the smallest classinterval (0.1-0.4 m), indicating the occurrence of a balanced replacement of adult individuals.

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References

Cambardella, C. A.; Mooman, T. B.; Novak, J. M.; Parkin, T. B.; Karlen, D. L.; Turco, R. F.; Konopa, A. E. 1994. Field scale variability of soil properties in central Iowa soil. Soil Science Society of America Journal, v.58, p.1501-1511. DOI:10.2136/sssaj1994.03615995005800050033x

Freire, G. S.; Ferreira, R. A.; Oliveira, E. V. S.; Oliveira, M. I. U. 2022. Caracterização Florística de Áreas de Nascentes na Sub-Bacia Hidrográfica do Rio Piauitinga, Sergipe, Brasil. Revista Brasileira de Geografia Física 15, 123-139.

Gholami, S. H.; Ahmadiyan, Z.; Sayad, E. 2021. Spatial analysis of tree regeneration in a preserved area in Zagros forests, Iran. Environmental Resources Research, 9, 31-42. DOI: 10.22069/ijerr.2021.5526

IBGE - Instituto Brasileiro de Geografia e Estatística. Manual técnico da vegetação brasileira. 2.ed. Rio de Janeiro, Diretoria de Geociências. Coordenação de Recursos Naturais e Estudos Ambientais. 2012, 271p.

Lima, P. M.; Arruda, D. M.; Fonseca, R. S.; Silva, D. D. 2020. Structure and Diversity Of The arboreal component in Cerrado *Sensu Stricto* in northern Minas Gerais. Floresta, 51, 61-069. DOI: 10.5380/rf.v51i1.67302

Mews, H. A.; Marimon, B. S.; Maracahipes, L.; Franczak, D. D.; Marimon-Junior, B. H. 2011. Dinâmica da comunidade lenhosa de um Cerrado Típico na região Nordeste do Estado de Mato Grosso, Brasil. Biota Neotropica, v.11, p.73-82. DOI: 10.1590/S1676-06032011000100007

Morais, F. F. De; Monteiro, R.; Ikeda-Castrilon, S. K. 2019. Estrutura da comunidade arbórea de uma área de cerrado, sudoeste do estado de Mato Grosso, fronteira Brasil–Bolívia. Revista Equador, v.8, p.332-349. DOI: 10.26694/equador.v8i3.9485

Morais, L. A., Araújo, M. F. V., Conceição, G. M., 2021. Levantamento florístico das angiospermas do Parque Estadual Cânion do rio Poti, Buriti dos Montes – PI. Revista Brasileira de Geografia Física 14, 04, 1987-2014.

Neves, D. A.; Lemos, F.; González, A. P.; Vieira, S. R.; Siqueira, G. M. 2010. Using geoestatistics for assessing biodiversity of forest reserve areas. Bragantia, v.69, p.131-140. DOI: 10.1590/S0006-87052010000500014

Oliveira Filho, A. T.; Ratter, J. A. Vegetation physiognomies and woody flora of the cerrado biome. In: Oliveira, P. S.; Marquis, R. J. (Ed.). The Cerrados of Brazil. New York: Columbia University Press, 2002. p.91-120.

Parente, L.; Nogueira, S.; Baumann, L.; Almeida, C.; Maurano, L.; Affonso, A. G.; Ferreira, L. 2021. Quality assessment of the PRODES Cerrado deforestation data. Remote Sensing Applications: Society and Environment, v.21, p.100444. DOI: 10.1016/j.rsase.2020.100444

Peixoto, E. De S.; Alves, M. Da S.; Fina, B. G. 2020. Fitossociologia de um fragmento de cerrado na Fazenda Bosque Belo, município de Aquidauana-MS. Braz. Journal Animal Environment Research, v.3, p.4210-4227. DOI: 10.34188/bjaerv3n4-126

Pessoa, M. J. G.; Maracahipes-Santos, L.; Santos, J. O. Dos; Oliveira, B. De; Silva, I. V. Da; Abadia, A. C.; Lenza, E. 2021. Composição florística, diversidade e efeitos edáficos em duas comunidades de savanas rochosas na Amazônia e Cerrado, Brasil. Ciência Florestal, v.31, p.1383-1406. DOI: 10.5902/1980509841937

Ribeiro, J. F.; Walter, B. M. T. As principais Fitofisionomias do Bioma Cerrado. In: Sano, S. M.; Almeida, S. P. De; Ribeiro, J. F. (Ed.). Cerrado: ecologia e flora. Planaltina: Embrapa, CPAC, 2008. p.151-199.

Rios, M. N. Da S.; Sousa-Silva, J. C.; Malaquias, J. V. 2018. Mudanças pós-fogo na florística e estrutura da vegetação arbóreo-arbustiva de um cerrado sentido restrito em Planaltina, DF. Ciência Florestal, v.28, p.469-482. DOI: 10.5902/1980509832028

Sano, E. E.; Rosa, R.; Brito, J. L. S.; Ferreira, L. G. 2010. Land cover mapping of the tropical savanna region in Brazil. Environmental Monitoring and Assessment, v.166, p.113-124. DOI: 10.1007/s10661-009-0988-4

Santos, M. J. F. Dos; Andrade, V. C. L. De; Freitas, B. C.; Ferreira, R. Q. De S.; Bandeira, S. B.; Souza, P. B. 2017. Fitossociologia e estrutura diamétrica de um fragmento de Cerrado Sensu Stricto, Sul do Tocantins. Scientia Agraria Paranaensis, v.16, p.328-334. DOI: 10.18188/1983-1471/sap.v16n3p328-334

Santos Neto, C. A. L.; Ferreira, L. V.; Costa Neto, S. V.; Jardim, M. A. G. 2023. Florística e estrutura da comunidade arbórea na floresta de terra firme da FLONA de Caxiuanã, Pará, Brasil. Revista Brasileira de Geografia Física 16, 1-35.

Silva, E. G.; Guilherme, F. A. G.; Carneiro, S. E. E.; Pinheiro, M. H. O.; Ferreira, W. C. 2019. Heterogeneidade ambiental e estrutura da vegetação arbustivo-arbórea em três áreas de Cerrado sentido restrito no Sudoeste goiano. Ciência Florestal, 29, p.924-940. DOI: 10.5902/1980509823788

Silva, L. S; Martins, A. R.; Garcia, T. A. S.; Teixeira, R. S.; Salomão, N. V. 2022. Fragmentos de Caatinga são florística e estruturalmente similares? Revista Brasileira de Geografia Física, 15, 3202-3211.

Silva, R. A.; Siqueira, G. M.; Costa, M. K. L.; Guedes Filho, O.; Silva, E. F. de F. 2018. Spatial Variability of Soil Fauna Under Different Land Use and Managements. Revista Brasileira de Ciência do Solo, v.42, p.e0170121. DOI: 10.1590/18069657rbcs20170121

Silva, R. A.; Siqueira, G. M. 2020. Multifractal analysis of soil fauna diversity indexes. Bragantia, 79, 1-14. DOI: 10.1590/1678-4499.20190179

Siqueira, G. M.; Silva, R. A. 2022. Relationship scales of soil arthropods and vegetation structure of Cerrado phytophysiognomies. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.479-487. DOI: 10.1590/1807-1929/agriambi.v26n7p479-487

Soares Filho, B.; Macedo, R. R.; Costa, C. A.; Coe, W.; Rodrigues, M.; Alencar, A. Cracking Brazil's forest code. Science, v.344, p.363–364, 2014. DOI: 10.1126/science.1246663

Strassburg, B. B.; Brooks, T.; Feltran-Barbieri, R.; Iribarrem, A.; Crouzeilles, R.; Loyola, R.; Latawiec, A. E.; Oliveira Filho, B. F.; Scaramuzza, C. De M.; Scarano, F. R.; Soares Filho, B.; Balmford, A. 2017. Moment of truth for the Cerrado hotspot. Nature Ecology and Evolution, v.1, p.0099. DOI: 10.1038/s41559-017-0099

Vieira, S. R. Geoestatística em estudos de variabilidade espacial do solo. In: Novais, R. F.; Alvarez V. V. H.; Schaefer, G. R. (ed.). Tópicos em ciência do solo I. Viçosa: Sociedade Brasileira de Ciência do Solo, 2000. 54p.

Warrick, A. W.; Nielsen, D. R. Spatial variability of soil physical properties in the field. In: Hillel, D. (Ed.). Applications of soil physics. New York: Academic Press, 1980, p.319-344.