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THE USE OF GEOSTATISTICS TO MAP HERBIVORY BY NATIVE SPECIES IN AN URBAN FOREST RECOVERY AREA IN THE SOUTHEAST OF PARÁ

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ABSTRACT: Actions by herbivores can affect success in establishing seedlings. With precision forestry it is possible to map and identify the spatial relationships that occur. The objective of this study was to evaluate the spatial distribution of herbivore attacks, regrowth capacity and mortality. Characterization of the pattern of spatial variability of the variables was performed by geostatistical analysis, and spatial dependence was obtained through semivariogram adjustments. Sub-area 5 presented the highest occurrence of herbivory (55%), and the best fitted semivariogram model was the exponential, with strong spatial dependence (15.08%). Considering the 5 sub-areas, the species with the highest incidence of herbivory (79.49%) was the inga (*Inga edulis* Mart.), and the regrowth capacity of the plants was 1.44%. Herbivore attack did not affect the survival rate of the plants, and the mortality rate from various causes was 5.76%.

KEYWORDS: Spatial distribution, Semivariograms, Reforestation.

USO DA GEOESTATÍSTICA NO MAPEAMENTO DE HERBIVORIA EM ESPÉCIES NATIVAS EM ÁREA DE RECUPERAÇÃO FLORESTAL URBANA NO SUDESTE PARAENSE

RESUMO: A ação de herbívoros pode afetar o sucesso no estabelecimento de mudas, e através da silvicultura de precisão, torna-se possível mapear e identificar as relações espaciais ocorrentes. O objetivo do estudo foi avaliar a distribuição espacial dos ataques de herbívoros, capacidade de rebrota e mortalidade. A caracterização do padrão da variabilidade espacial das variáveis foi realizada por meio de análise geoestatística, e a dependência espacial obtida através de ajustes de

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semivariogramas. A subárea 5 apresentou maior ocorrência de herbivoria (55%), e o modelo de semivariograma que melhor se ajustou foi o exponencial, com dependência espacial forte (15,08%). Considerando as 5 subáreas, a espécie com maior incidência de herbivoria (79,49%) foi o ingá *(Inga edulis* Mart.), e a capacidade de rebrota das plantas foi de 1,44%. O ataque de herbívoros não afetou a taxa de sobrevivência das plantas, e a taxa de mortalidade por causas diversas foi de 5,76%.

PALAVRAS-CHAVE: Distribuição espacial, Semivariogramas, Reflorestamento.

USO DE GEOESTADÍSTICA PARA MAPEAR LA HERBIVORÍA DE ESPECIES NATIVAS EN UN ÁREA DE RECUPERACIÓN DE BOSQUES URBANOS EN EL SURESTE DE PARÁ

RESUMEN: La acción de los herbívoros puede afectar el éxito en el establecimiento de plántulas, a través de la silvicultura de precisión, es posible mapear y identificar las relaciones espaciales que ocurren. El objetivo del estudio fue evaluar la distribución espacial de los ataques de herbívoros, la capacidad de rebrote y la mortalidad. La caracterización del patrón de variabilidad espacial de las variables se realizó mediante análisis geoestadístico y la dependencia espacial se obtuvo mediante ajustes de semivariograma. La subárea 5 fue el área con mayor ocurrencia de herbivoría (55%), y el modelo de semivariograma que mejor se ajustó fue el exponencial, con fuerte dependencia espacial (15,08%). Considerando las 5 subáreas, la especie con mayor incidencia de herbivoría (79.49%) fue el ingá (*Inga edulis* Mart.), y la capacidad de regreso de las plantas fue de 1,44%. El ataque de los herbívoros no afectó la tasa de supervivencia de las plantas, y la tasa de mortalidad por diversas causas fue del 5,76%.

PALABRAS CLAVES: Distribución espacial, Semivariogramas, Repoblación forestal.

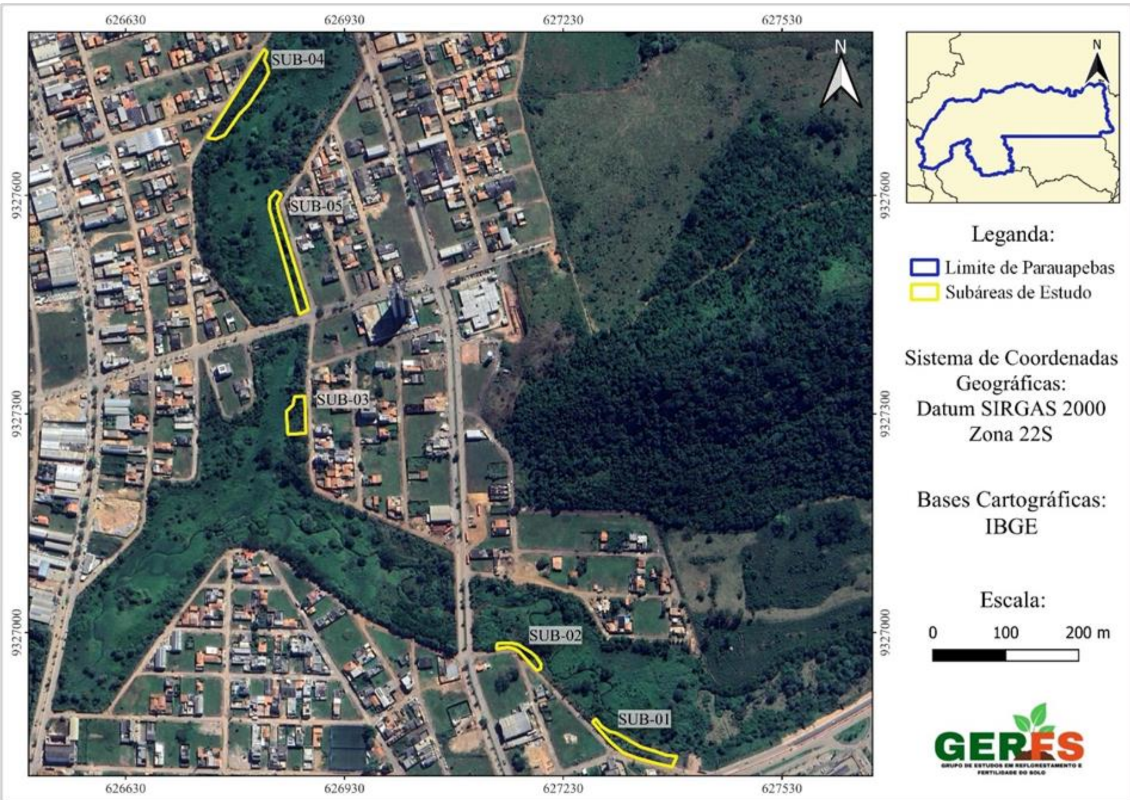
Success in restoring the vegetation of an area requires a choice of species adapted to the soil and climate conditions of the region, because their use reduces the risk of extinction of native species, besides helping to preserve the original characteristics of the environment (TAVARES, 2018; VIEIRA et al., 2018).

Some factors may affect the establishment of seedlings, including herbivory (GUREVITCH et al., 2009). Some plants may respond to herbivory and other disturbances in diverse ways, through defence mechanisms, and one such mechanism is related to the capacity that species have for re-establishing themselves and thus remain in the environment after disturbances (BARBOSA et al., 2014).

The action of herbivores can happen heterogeneously in the area, and through precision forestry it is possible to map and identify the spatial relationships occurring (SOARES, 2006; YAMAMOTO; LANDIM, 2013). Thus, the objective was to evaluate the spatial distribution by means of surface maps based on herbivore attack, regrowth capacity and mortality of native species seedlings planted in an urban forest recovery area.

The experiment was performed in an area that was undergoing a forest recovery process, located in the urban centre of the municipality of Parauapebas, southeast Pará, geographic coordinates 6°05'05.53 "S and 49°51'06.51 "W (Figure 1). According to the Köppen climate classification, the study area is included in the Am subclassification - rainy tropical with a brief dry season, with an average temperature of 26.1 °C and average annual rainfall of 1564 mm (CLIMATE, 2021).

Figure 1. Location map of the experimental area. Parauapebas, Pará.



Source: Authors (2022).

The area was divided into 5 sub-areas and 556 seedlings of native species were planted. The spacing adopted between plants and between rows was 3x2 m. The evaluation was performed 29 months after planting. The following parameters were evaluated: survival, herbivore attack, mortality from various causes, mortality due to herbivory and regrowth. Thus, the individuals in the stand were identified and received a code, according to the characteristic presented in the field, as shown in Table 1.

Table 1. Variables evaluated in the stand of native species in forest restoration area.

Code	PARAMETERS ASSESSED IN THE STAND	
	Representative colour	Description
1	Red	Seedling alive, without herbivory;
2	Purple	Seedling dead due to various causes;
3	Yellow	Seedling dead due to herbivory;
4	Orange	Seedling showed herbivory and remained alive;
5	Blue	Seedling has resprouted.

Source: Authors (2021).

The characterization of the pattern of spatial variability of the variables was performed through geostatistical analysis, and the spatial dependence obtained through semivariogram adjustments. The spatial dependence was obtained through semivariogram adjustment, as described by Vieira (2000) and presented in Equation 1:

$$y\ (h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h)\right]^2 \qquad (1)$$

In which:

$y(h)$ = Is the value of the semivariance for a distance h;

$N(h)$ = The number of experimental pairs of observations;

$Z(x_i)$ = Value of attribute Z at a position;

$Z(x_i + h)$= Value of attribute Z at a position, separated by a distance h.

The selection of the theoretical model was made by observing the lowest sum of the squared residuals (SQR), the highest coefficient of determination (R2) and the highest degree of spatial dependence (GDE). The semivariograms and kriging maps were determined using GS+ version 7 software (ROBERTSON, 2008).

The degree of spatial dependence (SDG) of the variables being studied was defined by the relationship (C/C0+C) and evaluated according to the classification by Cambardella et al. (1994), in which spatial dependence of SDG<25% is classified as strong, SDG between 25 and 75% is moderate, and SDG>75% is weak. The data were submitted to the method of interpolation by kriging and expressed in the form of surface maps by means of Surfer software version 11 (GOLDEN SOFTWARE, 2011).

The semivariograms showed a strong degree of spatial dependence in sub-areas 1, 2, 3 and 5, and moderate dependence in sub-area 4 (Table 2), according to the classification in Cambardella et al. (1994).

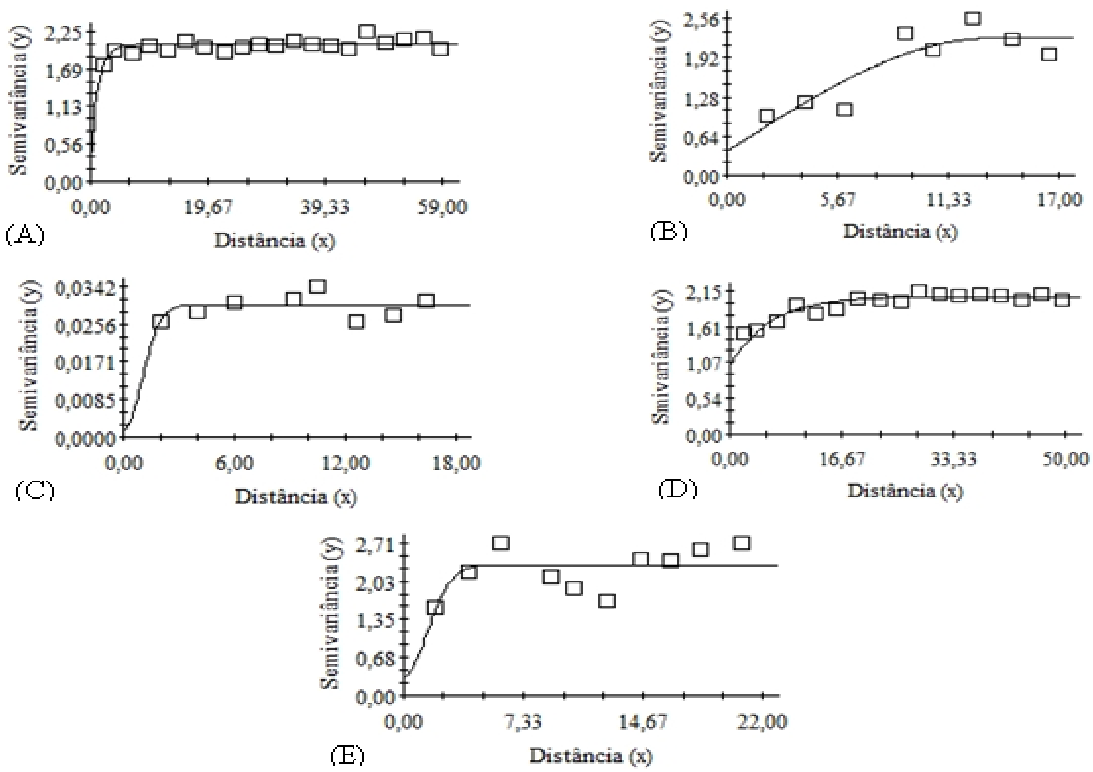
Table 2. Parameters of the theoretical model adjusted for the mapped variable.

Subareas	Model	C_0	$C + C_0$	SDG (%)	R^2
1	Exponential	0,26	2,05	12,65%	0,449
2	Spherical	0,40	2,24	17,67%	0,794
3	Gaussian	0,002	0,03	5,79%	0,204
4	Exponential	1,03	2,06	49,98%	0,866
5	Exponential	0,35	2,31	15,08%	0,332

Source: Authors (2021).

The semivariogram models that with the best fit were exponential, spherical and Gaussian, presenting ranges of 59, 17, 18, 50 and 22 meters (Figure 2), demonstrating that up to this distance the values present dependence among themselves (CIGAGNA et al., 2015).

Figure 2. Semivariograms: (A) sub-area 1 - exponential model; (B) sub-area 2 - spherical model; (C) sub-area 3 - Gaussian model; (D) sub-area 4 - exponential model; (E) sub-area 5 - exponential model.



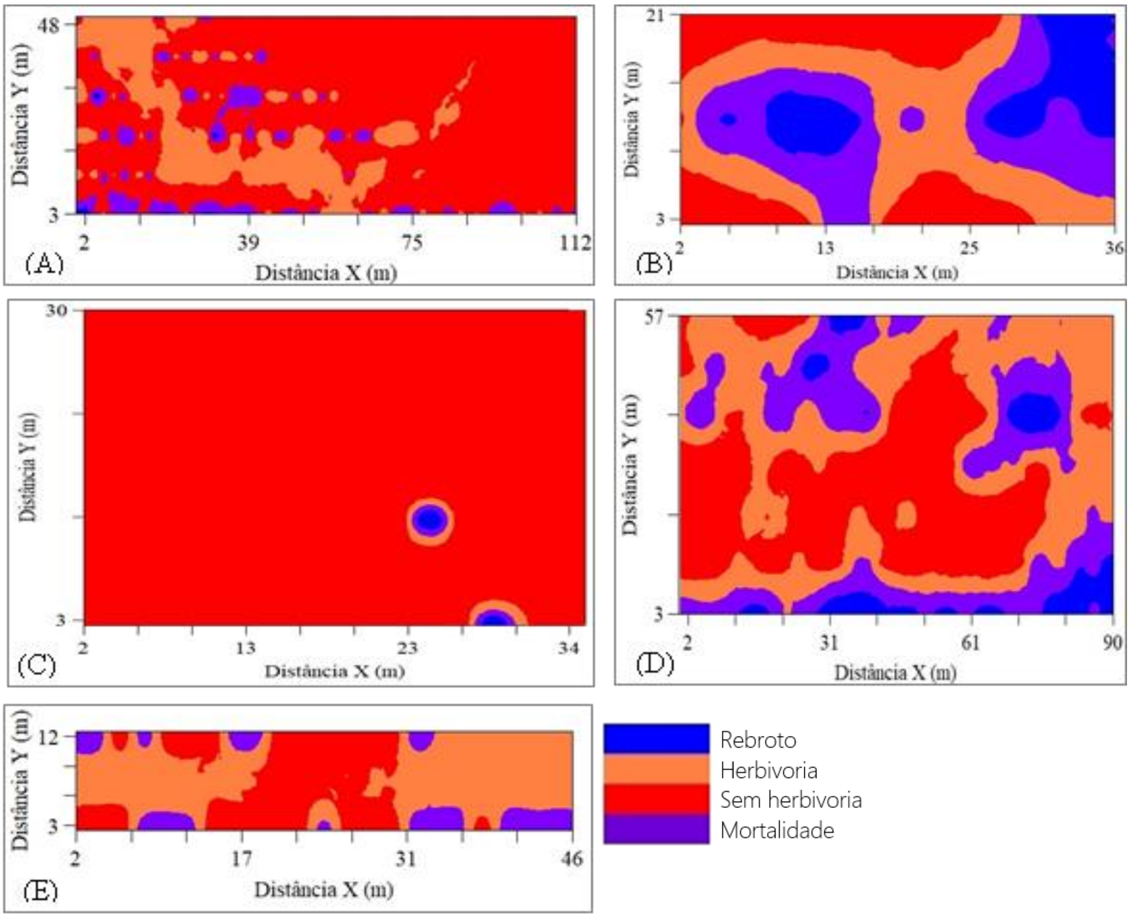
Source: Authors (2021).

Subarea 5 presented the highest occurrence of herbivory (55%), followed by subarea 4 (34.12%), subarea 1 (33.92%), subarea 2 (32.50%) and subarea 3 (2%). All plants with herbivory remained alive, and the mortality rate due to various causes was 5.76%, considering all sub-areas. According to Salomão et al. (2014), the expected mortality rate for reforestation areas is up to 20%, meaning that the value presented in this study (5.76%) is within the expected range.

The capacity of the plants to regrow was observed in a small quantity, with a percentage of 1.44% of the total plants. Regrowth was seen in the satisfactory development that those plants presented; even those that were attacked by herbivory, remained resistant. When regrowth did occur, it was due to other disturbances, like cutting or burning (MAURICIO, 2000; SILVA, 2022).

The kriging map of sub-area 1 (Figure 3-A) showed that herbivory was present with greater intensity in the initial portion of the lines, possibly due to the edge effect (ALENCAR et al., 2018). In sub-area 2, herbivory occurred in a more centralized manner (Figure 3-B), and the attack was concentrated on acaju-catinga (*Cedrela fissilis* Vell.) plants. In sub-area 4, herbivory was distributed throughout the entire area (Figure 3-D). This sub-area has the largest quantity of planted seedlings, including the golden trumpet tree (*Handroanthus albus* (Cham.) Mattos), which was attacked by Coleoptera from the Chrysomelidae family, which is the main herbivore of this species (RIBEIRO et al., 2006).

Figure 3. kriging maps for herbivore attack, mortality and regrowth. (A) subarea 1; (B) subarea 2; (C) subarea 3; (D) subarea 4; (E) subarea 5.



Source: Authors (2021).

Among the sub-areas studied, sub-area 3 (Figure 3-C) was the one that presented the lowest occurrence of herbivory (2%), justified by the greater quantity of Brazilian firetree (*Schizolobium parahyba* var. amazonicum (Huber x Ducke) Barneby) present in the area, because of the species studied, it presented the lowest percentage of herbivore attack (16.90%).

In sub-area 5, herbivory occurred in the region at the beginning and end of the rows (Figure 3-E), mostly composed of Brazilian peppertrees (*Schinus terebinthifolia* Raddi). Among the different pests that can attack the peppertree, leaf-cutting ants are considered the most important, probably due to the fruity odour that this tree exudes (GOMES et al., 2013).

Of the species mapped, inga (*Inga edulis* Mart.) showed the highest incidence of herbivory, possibly from attacks by leaf-cutting ants. These ants proliferate in degraded areas, especially areas at the preliminary stages of recovery, where pioneer species are more common because of their rapid growth (CARVALHO et al., 2012), e.g., Inga, which belongs to the ecological group of pioneers (SILVA et al., 2003). The pioneer species have larger and more vigorous leaves that attract this type of herbivore, unlike the late secondary species (COLEY, 1983).

The mapped area with the highest frequency of herbivory attacks was sub-area 5 (55%), and the species with the highest incidence of herbivory was inga (*Inga edulis* Mart.) (79.49%). The lowest incidence of herbivory was observed in Brazilian firetree (*Schizolobium parahyba* var. amazonicum (Huber x Ducke) Barneby) (16.90%). The mortality rate was 5.76% and the regrowth capacity of the plants was 1.44%.

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