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Using geoestatistics for assessing biodiversity of forest reserve areas

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# USING GEOSTATISTICS FOR ASSESSING BIODIVERSITY OF FOREST RESERVE AREAS ([1])

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**ABSTRACT**

Protecting natural mosaics as forest reserves poses a challenge, because if they hold significant high levels of biodiversity, they may function as key seed sources for regenerating ecosystems and adjacent reforested areas. Currently, there is lack of information about the spatial organization of native species in core forest fragments remaining between reforested fields. Biodiversity as measured by species and number of individuals was assessed in two forest reserve zones located within reforestations of *Eucalyptus* sp and *Pinus* sp in Agudos, São Paulo, Brazil. The main objective was to compare the state of biodiversity within two natural areas with contrasting disturbance levels; a second objective was to investigate recognisable patterns of species and individuals spatial distribution. A grid-like set of plots was set up for data collection over each of the two study areas. Natural species were aggregated onto two groups using height classes, inferior level (< 0.5 m) and superior level (> 1.3 m) layers. Within each natural area the number of species and individuals of the height class > 1.3 m was counted on 50 square plots of 100 $m^2$ (10 x 10 m) whereas those of the height class < 0.5 m were counted on 250 subplots of 1 $m^2$ (1 x 1 m). Data analysis involved both statistical and geostatistical methods. Experimental semivariograms of number of species and individuals were modelled by a nugget component plus a spherical structure with autocorrelation ranging from approximately 20 to 60 m. Cross-semivariograms could also be computed and modelled in some cases. Nugget effects of both species and individual's count for inferior level were shown to be larger for small sized plots, whereas the spatially structured component increased as the plot size increased. Individual's count showed a higher continuity at close distances than species number in the superior level (> 1.3 m), and the reverse was true for the inferior level (< 0.5 m). Usefulness of kriging maps for comparing patterns of spatial variation between the two studied natural mosaics has been illustrated.

**Key words:** nugget effect, kriging, semiovariograms.

**RESUMO**

USO DE GEOESTATISTICA PARA AVALIAR A BIODIVERSIDADE DE RESERVAS NATURAIS

A proteção de fragmentos naturais dentro de áreas reflorestadas é importante por ser um banco de sementes e possuir espécies-chave de significância à biodiversidade, tornando-se um desafio para a pesquisa, pois colabora com a regeneração de ecossistemas e de áreas reflorestadas adjacentes. Atualmente, existe pouca informação sobre a organização espacial das espécies nativas nos fragmentos florestais remanescentes dentro de áreas reflorestadas. Assim, a biodiversidade foi avaliada por meio da ocorrência de espécie e do número de indivíduos em dois fragmentos de mata nativa situados dentro de reflorestamentos de *Eucalyptus sp.* e de *Pinus sp.* em Agudos, São Paulo, Brasil. O objetivo principal deste trabalho foi comparar a condição da biodiversidade dentro dos dois fragmentos naturais com níveis distintos de perturbação, e também investigar testes- padrão reconhecidos da distribuição espacial de espécies e indivíduos. Uma rede de parcelas de amostragem foi instalada para a coleta dos dados em cada uma das duas áreas de estudo. As espécies nativas foram reunidas em dois grupos de classes de altura sendo, um nível inferior (< 0,5 m) e um nível superior (> 1,3m). Dentro de cada uma das áreas de estudo, foi determinado o número de espécies e de indivíduos nas distintas classes de altura: plantas > 1,3 m em 50 parcelas de 100 $m^2$ (10 x 10 m), e < 0,5 m em 250 sub-parcelas de 1 $m^2$ (1 x 1 m). A análise dos dados foi realizada utilizando métodos estatísticos e geoestatísticos. Os semivariogramas experimentais para o número de espécies e indivíduos foram ajustados ao modelo esférico, considerando o efeito pepita com uma autocorrelação entre atributos variando entre 20 e 60 m. Em alguns casos, também se pôde construir e modelar semivariogramas cruzados. O efeito pepita para as parcelas de 1 $m^2$ tanto para espécies como para indivíduos na classe < 0,5 m é menor, demonstrando que esta componente espacialmente estruturada aumentou com o crescimento do tamanho da parcela. Na contagem individual observou-se maior continuidade para o nível superior (> 1,30 m), o contrário também pode ser observado para o nível inferior (<0,5m). O mapa de *krigagem* foi útil para comparar os testes-padrão de variabilidade espacial entre os fragmentos naturais estudados.

**Palavras-chave:** efeito pepita puro, *krigagem*, semivariograma.

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## 1. INTRODUCTION

Conserving plant biodiversity is receiving international attention. Worldwide, numerous species are becoming extinct, and even more plants that have not yet been identified, mainly in subtropical and tropical regions, are likely to be similarly threatened. The convention on biological diversity, signed in 1992 in Rio de Janeiro (Dias, 1996; Glowka, 1996), also advocates for sustainable management of natural, agricultural and forestry ecosystems.

Forest ecosystems hold the highest amount of biodiversity and so they play an important role as biodiversity banks. The rapidly increasing destruction of forest ecosystems is therefore a major threat to biodiversity conservation. Biodiversity in tropical and subtropical forests is known to be larger than in other types of forests (Kent and Coker, 1996). In the effort to conserve biodiversity, forest ecosystems have been treated as independent entities, which may then need a buffer zone around them just to keep off human disturbance. The biodiversity within these buffer zones is usually not considered to be of great importance. Forests, however, are a part of a landscape that can be recognized by the spatial repetitive cluster of interacting ecosystems, morphology and disturbance regimes. A heterogeneous landscape favors abundance in plant species and animals which require two or more landscape elements and it also enhances the species coexistence (Forman and Godron, 1986). In such a landscape species and species clusters differ greatly and so a wide range of patterns and measurements need to be used in order to describe them. Among these are species composition, species richness and species dominance.

The "cerrado" is the second largest biome of Brazil representing 22 % of the country, or approximately 2.070.000 km$^2$. It is a savanna in central Brazil, with a continuous layer of herbaceous species at the peak of the vegetation growth, scattered with shrubs and trees that sometimes form a continuous canopy. Thirty years ago, the cerrado area served primarily as rangeland, which today is still true in the less developed states covered with "cerrado". The state of São Paulo is located in Southeast Brazil and covers an area of approximately 250.000 km$^2$. Increasing agricultural soil use during colonization involved continuous land clearing, already significant during the 18$^{th}$ century, but more intensive during the 19$^{th}$ and 20$^{th}$ centuries. As a consequence, forest land in São Paulo state by the end of the 20$^{th}$ century was estimated at about 13 % (Kronka et al., 2003).

Considering the current need for biodiversity conservation, protecting natural mosaics as forest reserves poses a challenge. If they hold significant high levels of biodiversity, they may function as key seed sources that not only enrich the respective ecosystems but also adjacent reforested areas. Moreover, the outer part of any mosaic or patch has a significantly different environment from the interior and different species composition and abundance are found there. This is called the edge effect and it is often wider where the matrix, the continuous piece of terrain or binding, and the patch differ more in their vertical structure (Gamarra, 2008).

Thus, spatial distribution studies of species in forest fragments describes the biodiversity as a whole because the spatial structural analysis and display of the spatial variability using contour maps provides ways to understand the species interaction at the borders and also at the inner parts of the system. According to Stewart et al (2000) the spatial distribution of organisms is not random as they live in very heterogeneous environment both in space as well as in time.

There have been many reports on the efficiency of analytical techniques to quantitatively describe the spatial pattern of organisms, environmental factors and ecological processes (Perry et al., 2002; Fortin and Dale, 2005), with the objectives of adopting better management techniques for the species and their habitats (Escudero et al., 2003), minimizing the environmental impact of human activities (Stenger et al., 2002) and to recommend the appropriate statistical tests based on the spatial structure of the organisms (Legendre et al., 2004).

The main objective of this work was to assess the state of biodiversity within natural mosaics from the statistical as well as the spatial point of view. More specific objectives were: a) to compare two areas of natural vegetation characterized by a contrasting degree of disturbance and b) to investigate if there was a recognizable pattern of species and individuals distribution within the study areas.

## 2. MATERIAL AND METHODS

### Location of the study area and data description

Biodiversity was assessed in two forest reserve patches located within reforestation sites of *Eucalyptus* sp and *Pinus* sp in São Paulo, Brazil (Figure 1), located between 22°20'-22°29' S latitude and 48°51'-48°59' W longitude. Commercial species are mainly *Pinus caribaea hondurensis*, *Pinus caribaea caribaea*, *Pinus caribaea bahamensis*, *Pinus oocarpa* and *Eucalypitus grandis*. The two studied natural mosaics support high levels of species diversity with taxa that do not occur in the reforested woodland, even if they are more or less disturbed (Neves et al., 2006). These study patches will be referred to as areas A and B (Figure 1) and their size was 74.21 and 36.25 ha, respectively. Field inventories, aerial photographic analysis and historical documents indicate that the impact of human activities on area B is lower than in area A. Moreover, based on biodiversity comparisons with undisturbed "cerrado" regions located in São Paulo neighbour states, area B can be considered as a reference zone, being less disturbed (Neves et al., 2006).

The experimental design included square plots on both study areas, A and B. Though there are no practical rules the plot size was chosen to be large enough to cover the variation in species within a locality and it was also aimed to relate to the size of the vegetation being studied, i.e., larger quadrants for shrubs and trees and small ones for small plants (Kent and Coker, 1994).

A grid set of points was used for the data collection over each of the two study areas. Plots were set up along five parallel transects 100 m long x 10 m width with a distance of 10 m from each other (Figure 2). The natural species were aggregated onto two groups using height classes < 0.5 m and > 1.3m. Individuals > 1.3 m are considered as "arborescent", even if they are not adults. The height class < 0.5 m is constituted by samplings near herbaceous plants and gives indication of the forest regeneration potential.

The height class < 0.5 m will be referred to as "herbaceous" layer, whereas the height class > 1.3 m will be referred to as "arborescent" layer. Individual plants and species higher than 1.3 m were count on successive 100 m$^2$ plots along each one of the five transects. Individuals and species of the herbaceous layer were


**Figure 1.** Aerial view of the two study areas.

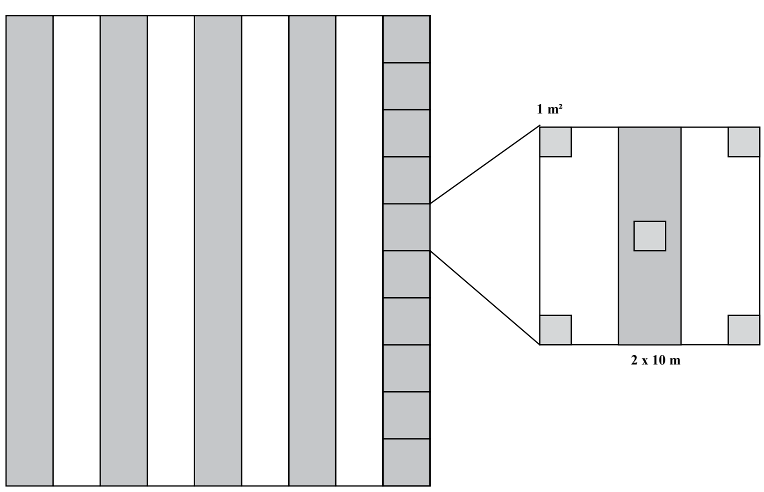


**Figure 2.** Experimental design used for inventory of species and individual number.

studied on 1 $m^2$ plots, and five of these plots were set up within each 100 $m^2$ plot. Number of species and individuals of the arborescent layer was surveyed on 50 square plots of 100 $m^2$, whereas those of the arborescent layer were surveyed on 250 subplots of 1 $m^2$. In both height classes all individuals and species in each plot have been surveyed.

Data analysis of diversity involved both statistical and geostatistical methods. Data sets were initially analyzed by descriptive statistics, and the mean, variance, standard deviation, coefficient of variation, maximum, minimum, skewness, and kurtosis were determined for number of species and number of individuals per vegetation class using the STAT software program, according to Vieira et al. (2002).

In order to verify the spatial structure of the studied variables a basic geostatistical analysis was performed using standard techniques. A detailed description of geostatistical methods had been provided by a number of authors, i. e., Matheron (1962-63), Journel and Huijbregts (1978), Vieira et al. (1983), Chilés and Delfiner (1999), etc. The used procedures included:

1) Calculation of sample variogram and fitting of models, using cross-validation for model validation. The criteria and procedures for fitting the semivariogram model were made according to Vieira et al. (1983); and

2) Estimation of values at the nodes of a fine mesh grid and prediction of the error variance by means of ordinary kriging.

Cross-semivariograms were analysed for the pairs of variables which showed significant correlation and cokriging maps were drawn.

Geostatistical analysis was performed using the software package described by Vieira (2000) and Vieira et al. (2002).

Spatial dependence can be expressed by the DD parameter (degree of spatial dependence), which is the proportion of structural variance ($C_1$) in relation to the threshold ($C_0 + C_1$). According to Zimback (2001), this can be used to classify the spatial dependence into weak if DD< 25 %; moderate for DD between 26 % and 75 %; and strong if DD> 75 %. When semivariance and cross-semivariance are dependent upon distance, i.e., when spatial autocorrelation between samples exists, values can be interpolated in the study field, without bias and with minimum variance, using the kriging and cokriging method.

Sampling size has been shown to critically affect results of ecological studies (Bellehumeur et al., 1997). Moreover, support of information is a fundamental issue in geostatistical studies. Herbaceous and arborescent vegetation classes were sampled at the 1 $m^2$ and 100 $m^2$ scale, respectively. In order to allow comparison statistical and geostatistical analysis of the herbaceous class were performed at both scales.

## 3. RESULTS AND DISCUSSION

### Descriptive statistics

Summary statistics for number of species and number of individuals of the herbaceous and the arborescent layers in the two studied areas are shown in Table 1. Because of the differences in sample sizes of the two vegetation classes, in Table 1 statistical parameters of the herbaceous class are listed at both scales. This change

**Table 1.** Summary statistics for number of species and number of individuals per vegetation class, per support size and per plot (STD = standard deviation, CV = coefficient of variation (%), Min= Minimum, Max=Maximum, Skew=Skewness and Kurt=Kurtosis)

| Class of plants < 0.5 m, herbaceous on 1 $m^2$ plots | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | Area | Plots | Mean | STD | C.V. | Min. | Max. | Skew | Kurt |
| Species | A | 250 | 3.15 | 1.679 | 53.32 | 0 | 9 | 0.67 | 0.729 |
| Individuals | A | 250 | 11.94 | 9.225 | 77.29 | 0 | 59 | 1.56 | 3.739 |
| Species | B | 250 | 4.62 | 1.739 | 37.64 | 0 | 10 | 0.44 | 0.460 |
| Individuals | B | 250 | 8.48 | 7.329 | 86.47 | 0 | 100 | 8.46 | 99.66 |
| Class of plants < 0.5 m, herbaceous on 100 $m^2$ plots | | | | | | | | | |
| Species | A | 50 | 15.74 | 4.65 | 29.52 | 7 | 27 | 0.027 | -0.630 |
| Individuals | A | 50 | 1194.0 | 518.9 | 43.47 | 380 | 2640 | 0.643 | -0.107 |
| Species | B | 50 | 23.10 | 4.34 | 18.78 | 13 | 32 | 0.057 | -0.593 |
| Individuals | B | 50 | 847.60 | 294.13 | 34.70 | 520 | 2400 | 3.196 | 15.37 |
| Class of plants >1.3m, arborescent layer on 100 $m^2$ plots | | | | | | | | | |
| Species | A | 50 | 18.00 | 3.77 | 20.97 | 11 | 25 | -0.29 | -0.830 |
| Individuals | A | 50 | 152.10 | 73.32 | 48.19 | 37 | 313. | 0.24 | -0.816 |
| Species | B | 50 | 16.56 | 2.757 | 16.65 | 10 | 21 | -0.33 | 0.025 |
| Individuals | B | 50 | 69.04 | 19.56 | 28.33 | 29 | 122 | 0.55 | 0.721 |

of sample size allows comparison of the two classes of vegetation assessed in this work (Bellehumeur et al., 1997). Note that values on 1 $m^2$ plots of the herbaceous vegetation are empirical counts, whereas those on 100 $m^2$ plots were obtained by estimation using the direct measurement on the smaller plot size.

As expected, the variance of species and individuals number of the herbaceous layer measured on 1 $m^2$ plots is larger than the respective figures on 100 $m^2$. Thus, it is empirically shown how increasing sample size decreases the coefficient of variation of the studied variables (Table 1). It is also worth mentioning that change of sample size linearly increases the number of individuals and, to a much lesser extent, increases the number of species. Mean individual number at the 100 $m^2$ scale results from multiplying the mean figure measured at the 1 $m^2$ scale by surface area. However, mean species number is not an additive variable so that a 100 $m^2$ fold increase in sampling unit leads to an increase in the mean value by a factor of about 5.

Variances or standard deviations and coefficients of variation of individual's counts were higher than those of species number in both height classes of vegetation for the sampling scales listed in Table 1.

On the measured 1 $m^2$ plots the lowest number of herbaceous species equals 0 and the highest are 9 and 10 for areas A and B, respectively. On the other hand, for the species values of this layer on 100 $m^2$ scales, the lowest figures are 7 and 13 and the highest are 27 and 32 for areas A and B, respectively. Skewness and kurtosis values of the herbaceous class, sampled on 1 $m^2$ plots, indicates that both species and individuals had a localized distribution, i.e., there are sites with high values but the vast majority has low values. This will cause differences between the mean, the median, and the mode. In contrast skewness and kurtosis values of the two studied vegetation layers assessed on 10 x 10 $m^2$ plots showed frequency distributions of all the studied variables close to normal, except for the number of individuals of the herbaceous plants in area B.

The mean number of arborescent species at the 100 $m^2$ scale for areas A and B was 18.00 and 16.56 and ranged between 11 and 25 and between 10 and 21, respectively. Mean values and range of oscillation of the number of species counted for the two studied vegetation classes exhibit also a similar order of magnitude. Notwithstanding, small differences in mean species number between plots and vegetation classes will need further discussion.

On the other hand, at the 100 $m^2$ plot scale, the number of individuals of the herbaceous class was much higher than that of the arborescent class in the two studied areas. In other words, the natural forest reserve areas have much more herbaceous individuals than trees. There is a funnel like arrangement of vegetation classes, which is viewed as a sign of continuity of an ecosystem.

Characterization of biodiversity status of the two studied areas can be first achieved by comparison of the number of species and the number of individuals (Table 1). In the arborescent vegetation class, both the recorded mean number of species and individuals at forest patch A (18.0 and 152.1, respectively) are greater than those recorded at forest patch B (16.56 and 69.04, respectively).

However, the mean total number of species in the herbaceous vegetation class followed an opposite trend, so that it was smaller in area A (15.74) than in area B (23.10). This has no bearing when the number of herbaceous individuals between area A (1194.0) and area B (847.6) are compared. For assessing human influence due to border effects on small natural forest patches, species abundance and composition of the herbaceous layer is a key issue, as the dominant tree-shrub layer is hardly affected by soil use around these patches unless forest clearing is carried out. The smaller species number in area A than in area B can be considered also an indication of the higher disturbance by extern impact of the former, although individuals count follows an opposite trend. This is consistent with Shannon index results (Neves et al., 2006) as well as the analysis of the vegetation condition and historical management data of the two studied patches, as quoted before.

### Geostatistical analysis

Mathematical models fitted to the experimental semivariograms, allow the nature of spatial variation to be displayed for any distances within the measured field. A summary of fitted models and their parameters is shown in Table 2. Variables studied were number of species and number of individuals of the two classes of vegetation herbaceous and arborescent considered here. Note also that in the herbaceous layer semivariogram analysis was performed for two different sample sizes.

The spatial dependence at small distances was assessed by the ratio of the spatial component ($C_1$) to the sill ($C_0 + C_1$), called DD index (Zimback, 2001), which represents the structural component proportion in the spatial variance, or conversely by the relative nugget effect (Cambardella et al., 1994). The pattern of spatial dependence was described by a model that presents both a structural and a random component in 9 out of 12 cases. The exceptions described by a pure nugget effect, without structural component, were the number of individuals of the herbaceous vegetation class at the 1 $m^2$ and 100 $m^2$ scales and the number of species of the arborescent vegetation class, both in the less disturbed

**Table 2.** Summary of semivariogram analysis of species number and individual's number. (Two vegetation classes per plot and two plots were assessed. Herbaceous layer was analyzed for two support sizes)

| Variable | Area | Model | $C_0$ | $C_1$ | DD (%) | a (m) | $r^2$ |
|---|---|---|---|---|---|---|---|
| | | | Class of plants < 0.5 m, herbaceous on 1 $m^2$ plots | | | | |
| Species | A | Spherical | 2.29 | 0.51 | 18.21 | 50.00 | 0.457 |
| Individuals | A | Spherical | 71.04 | 16.59 | 18.93 | 27.39 | 0.350 |
| Species | B | Spherical | 2.78 | 0.27 | 8.85 | 50.00 | 0.133 |
| Individuals | B | | | Pure nugget effect | | | |
| | | | Class of plants < 0.5 m, herbaceous on 100 $m^2$ plots | | | | |
| Species | A | Spherical | 0.01 | 21.13 | 99.91 | 32.10 | 0.993 |
| Individuals | A | Spherical | $120x10^3$ | $120x10^3$ | 50.00 | 40.00 | 0.918 |
| Species | B | Spherical | 6.38 | 14.08 | 68.81 | 60.00 | 0.960 |
| Individuals | B | | | Pure nugget effect | | | |
| | | | Class of plants >1.3m, arborescent layer on 100 $m^2$ plots | | | | |
| Species | A | Spherical | 5.40 | 8.90 | 62.23 | 21.1 | 0.988 |
| Individuals | A | Spherical | 356.60 | 5510.89 | 93.92 | 60.0 | 0.980 |
| Species | B | | | Pure nugget effect | | | |
| Individuals | B | Spherical | 0.00 | 424.62 | 100.00 | 60.00 | 0.963 |

patch B. Thus, the semivariogram analysis show that in most analyzed cases spherical models with a nugget effect provided good fit to the experimental semivariograms. Fitted spherical models showed various degrees of spatial dependence (DD) from weak to moderate or even high and range from about 20 to 60 m. Main results from spatial dependence analysis are next summarized:

1) In the herbaceous vegetation increasing of sample size from 1 $m^2$ to 100 $m^2$ shows a tendency to increase the relative importance of the structural component in the total spatial variance. Conversely, the nugget effect remains stable in 1 out of 4 study cases and decreased in 3 out of 4 cases (Table 2).

2) Taking into account the number of species for 10 x 10 $m^2$ plots the most disturbed natural forest patch (area A) appears to be more strongly spatially structured than the less undisturbed one (area B) for both the herbaceous and the arborescent layers (Figures 3 and 4).

3) In the arborescent layer the spatial dependence of the individual counts was rather strong, i. e. ratio of the structural component to the sill equals to 93.72 % and 100 % for the most and the least disturbed patches (areas A and B) respectively (Table 2). This means that at the 100 $m^2$ sampling scale number of individuals in the herbaceous layer tend to be randomly distributed, whereas the total number of individuals in the arborescent layer exhibits more spatial structure. The increase tendency in autocorrelation as a function of sample size was also observed by Bellehumeur et al. (1997) who analyzed tree density in a tropical rain forest from Malaysia.

On the other hand, Nangendo (2000) compared patterns of spatial dependence for number of individuals and number of species of three different vegetation classes (trees, sapling seedling) in grassland and burnt forest areas under tropical conditions in Uganda. Total counts of trees saplings and seedlings displayed spatial structure which was modelled by a random plus a structured component in the grassland area, whereas in the burnt forest area they were randomly distributed. The number of species showed to be spatially structured in 5 out of 6 cases studied. Ranges of spatial dependence found in our work are much smaller than those in the above mentioned work.

In order to investigate if coregionalisation could improve the description of spatial continuity and reduce the estimation errors of the kriging variance, cross-semivariograms between all pairs of variables which had significant correlations were constructed. Isotropic cokriging took species number as primary variable and individuals number as secondary variable. Sample size was 1 $m^2$ and 100 $m^2$ for herbaceous and arborescent vegetation height classes, respectively. Results are shown in Table 3. In the herbaceous class, a pure nugget effect was found, whereas in for the arborescent layer spherical cross-semivariogram model could be fitted. These results suggest that nugget value perhaps better describes variability occurring within the shortest sampling interval (Goovaerts 1999).

Kriging contour maps and kriging estimation variance maps of the studied variables were drawn. Figure 5 shows an example pattern of spatial variability for the individuals count in the arborescent layer at the less disturbed natural vegetation reserve zone (Area B). In this layer, micro-regions with large differences in individual's number, i.e. below 50 and above 70 individuals are apparent at the 100 $m^2$ plot scale. Thus kriging maps allow detecting spatial vegetation changes within forest reserve areas.

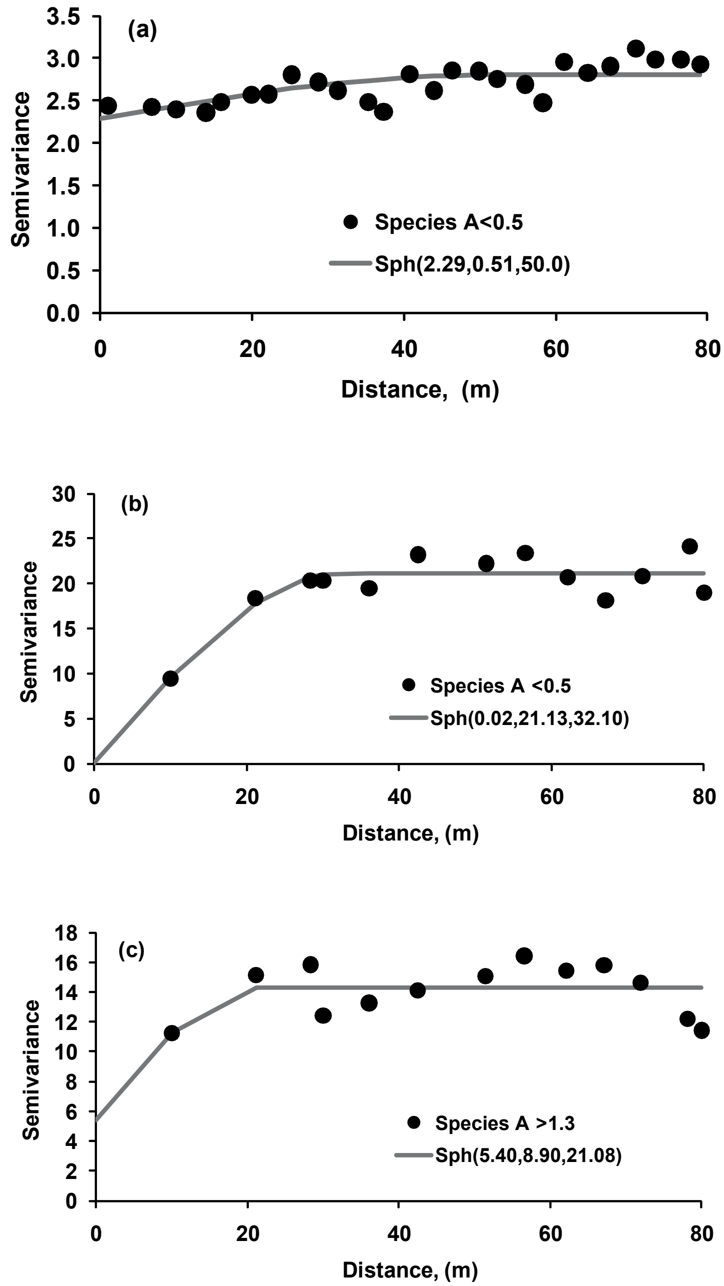


**Figure 3.** Experimental semivariograms and fitted models for species number in the most disturbed area (Area A) with natural vegetation. (a) Area A (1 m$^2$) species <0.5m; (b) Area A (100 m$^2$) species <0.5m; (c) Area A (100 m$^2$) species >1.3m.

The spatial variability pattern of arborescent and herbaceous individuals count in the two natural areas with "cerrado" vegetation was completely different, which is in accordance with distinct semivariogram models. On the other hand kriging maps allow analyzing the relation between patterns of spatial variability between individual's number and species number.

Kriged and cokriged maps were compared, in order to test the possible advantages in using coregionalization for estimation purposes (data not shown). Basically, both maps present the same results, with a little more detail on the cokriged map, owing to correlation between species and individual number. The limited improvement obtained by cokriging is expected because of the similitude of cross-

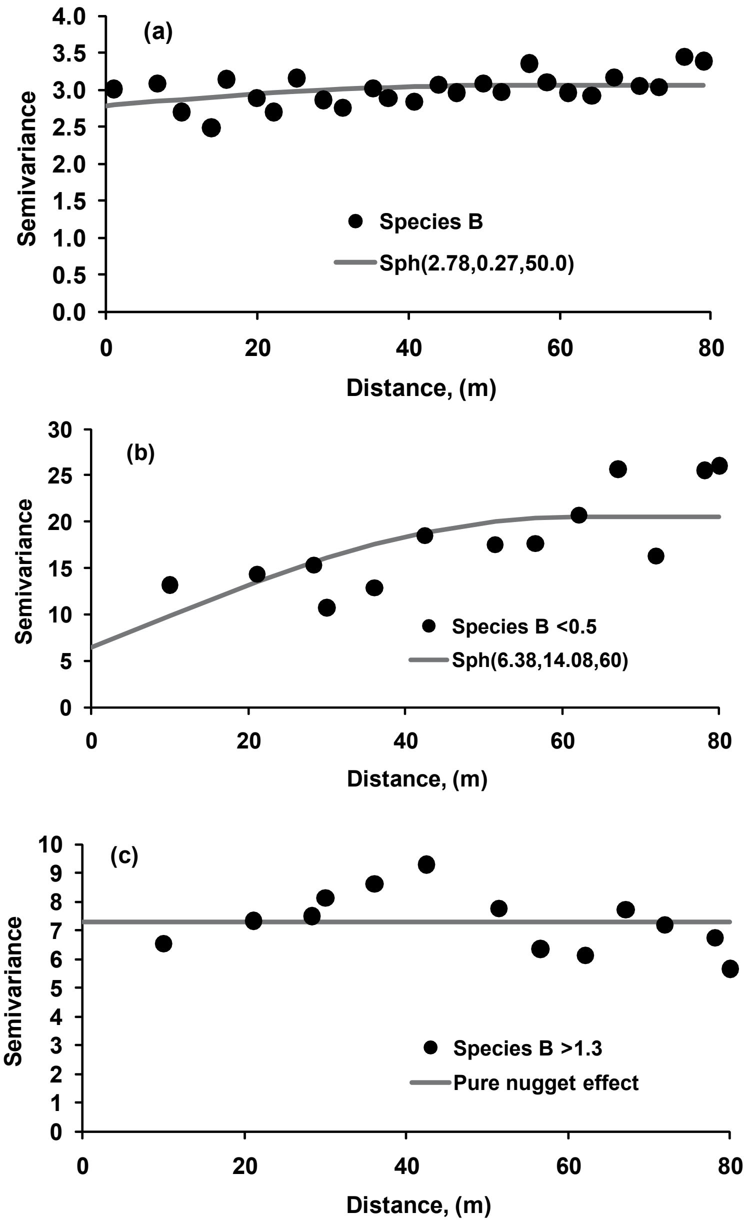


**Figure 4.** Experimental semivariograms and fitted models for species number in the less disturbed area (Area B) with natural vegetation. (a) Area B (1 $m^2$) species <0.5 m; (b) Area B (100 $m^2$) species <0.5 m; (c) Area B (100 $m^2$) species >1.3 m.

**Table 3.** Parameters for fitting the cross-semivariograms of individuals and species number in the two study areas considering two plant height groups in each area. (Indiv. = individuals)

| Variable | Area | Model | $C_0$ | $C_1$ | DD | a (m) | $r^2$ |
|---|---|---|---|---|---|---|---|
| Class of plants < 0.5 m, herbaceous | | | | | | | |
| Indiv. x species | A | Pure nugget effect | | | | | |
| Indiv. x species | B | Pure nugget effect | | | | | |
| Class of plants >1.3m, arborescent layer | | | | | | | |
| Indiv. x species | A | Spherical | 0,00 | -126,58 | 100 | 81,78 | 0,722 |
| Indiv. x species | B | Spherical | 5,14 | 13,66 | 72.6 | 40,00 | 0,130 |

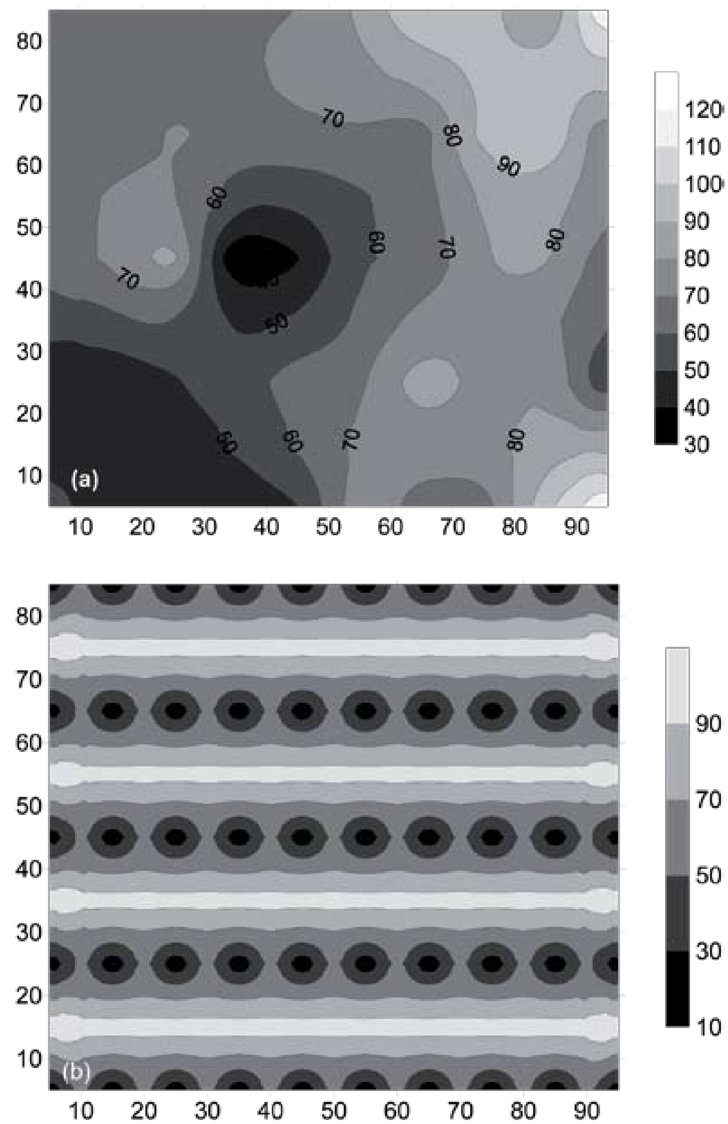


**Figure 5.** Kriging map for individuals number of the arborescent layer (> 1.3m) in the natural forest patch considered to be less undisturbed by human influences (Area B) and corresponding kriging estimation variance.(a) Number of individuals interpolated by kriging; (b) Estimation variances for number of individuals interpolated by kriging.

semivariograms and individual semivariograms, as previously discussed.

The results obtained with basic geostatistical tools seem promising. Further research is needed in order to assess the spatial dependence patterns of each of the species found during the survey. Moreover the spatial dependence of current biodiversity indices, as the Shannon index, should also be analyzed. On the other hand, other goestatistical technique such as indicator kriging may further help when taking into account spatial autocorrelation effects on native forest fragments management.

## 4. CONCLUSIONS

1. Sampling size affects the spatial dependence of both species number and individual's count.

2. Species number and individual's count show distinct patterns of spatial dependence when compared with the natural mosaics which means that studied sites have been somehow disturbed.

3. Cokriging can be used for mapping purposes instead of kriging but the small gain in precision is not worth it.

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