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Original Article

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Spatialization of Tree Species Diversity in the State of Minas Gerais

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ABSTRACT

The state of Minas Gerais has a high ecological relevance mainly due to its forest species diversity. Understanding the spatialization of that diversity is of importance to develop environmental public policies. The hypothesis of this study is that the tree species diversity from different forest types, in the state of Minas Gerais, presents distribution with spatial dependence. Thus, the objective of this work was to prove that spatial dependence and to relate it between the forest types. Data from the project called "Forest Inventory of Minas Gerais" were used to calculate indices of Shannon, Simpson and Pielou. We used geostatistical and kriging tools to create spatial maps. As results, the mappings indicated that the state presents well-defined gradients of diversity and richness of forest species, increasing in North-South and from West-East directions. The spatial dependence and the spatialization of the tree species diversity show that the geostatistical modeling is a tool that supports the forest resource management. The maps of diversity can be used as indicators of potential areas for creating Conservation Units, establishing ecological corridors, besides supporting environmental policy development.

Keywords: public policies, diversity indices, geostatistics.

1. INTRODUCTION

In the first years of 21^{st} century the state of Minas Gerais has lost an expressive area of its native forest, reaching a deforestation of 370,974 hectares. The estimated remaining forest cover is around 19.5 million hectares (Carvalho et al., 2008), encompassing three main forest formations: Cerrado, located in the mid-West; Atlantic Forest, located in the East, and Caatinga, situated in the North of the state. Such formations represent an area respectively around 57%, 41% and 3.5% of the state (Oliveira-Filho & Scolforo, 2008). According to these authors, there are more than 2,400 recognized species in the state of Minas Gerais, demonstrating that, even after a massive deforestation, there are still many endemic species and considerable tree species richness.

The occurrence of different forest formations, added to environmental gradients resulting from its large territorial extension, makes the state of Minas Gerais an important laboratory of ecological surveys. However, describing and characterizing its forested areas and their distinct potentials are essential issues that should be comprehended before proposing some decision-making concerning to forest species conservation. In this sense, we could consider as relevant any research that subsidize the state government with information about its forest fragments, such as priority areas to allocate conservation unities, besides contributions for implementing public policies, among others. Research like these are even more important when it is considered that the forest degradation affects intra- and interspecific relationships in the regional ecosystems (Bierregaard & Dale, 1996).

The variation in the occurrence of forest species is an indicator that clarifies the interactions between environment and local vegetation, showing changes that occur by anthropic or natural actions. The characteristic of varying the number of species in communities is called diversity (Pielou, 1975). According to Gomide et al. (2006), the variation of species between communities can be represented and quantified through various ways, the most common being by means of diversity indices. Indices of Shannon, Simpson and Pielou are, respectively, mathematical formulations often used to quantify diversity, dominance and evenness of forest species (Gomide et al., 2006; Guedes & Krupek, 2016; Ariotti et al., 2016; Corsini et al., 2014).

The use of these indices, associated with the geostatistical methods and spatial interpolation, enables us to understand how forest species diversity are spatially distributed across large areas. In this type of study, the variable of interest, i.e., diversity, is sampled for generating semi variance models, allowing us to estimate it for all evaluated population (Amaral et al., 2013; Yamamoto & Landim, 2013).

The application of spatial techniques in tropical natural forest researches is recent (Amaral et al., 2010), since most of the surveys are related to forest plantations (Mello et al., 2005a, b; Mello et al., 2006; Kanegae et al., 2007; Mello et al., 2009). The development of researches aiming to understand spatial floristic indicators in tropical forests is necessary, since they may subsidize preservation and conservation actions in forest remnants in Cerrado, Atlantic Rainforest and Caatinga forest formations.

It is expected that the forest species diversity presents variations among the forest formations, once they are composed by highly variable species richness, and located in distinct environmental conditions. Some studies in Minas Gerais demonstrate that diversity may range from 2.236 (Deciduous Seasonal Forest areas) up to 4.523, (Semideciduous Seasonal Forest areas) (Corsini et al., 2014). Gomide et al. (2006) found indices ranging from 2.176 to 4.389 (Shannon), from 0.019 to 0.206 (Simpson), and 0.625 to 0.875 (evenness). The greatest species diversities tend to occur in the forest type Semideciduous Seasonal Forests, whereas the lowest ones occur in Tropical Deciduous Forests (Corsini et al., 2014; Gomide et al., 2006). In addition to the varied environmental conditions before mentioned, the level of anthropic intervention over the vegetation also contributes for reducing diversity and increasing its variation, which makes the environment susceptible to degradation (Gomide et al., 2006).

The hypothesis of this study is that the tree species diversity from forest types in the state of Minas Gerais presents distribution with spatial dependence. Thus, the objective was to prove such spatial dependence and relate it between the forest types.

2. MATERIAL AND METHODS

2.1. Study area and data collection

The forest fragments evaluated in this study are located in the state of Minas Gerais, Brazil (Figure 1). Phytosociological inventories were carried out as a step of the project called "Forestry Inventory of Minas Gerais", conducted between the years 2005 and 2008. The project had partnership with Federal University of Lavras and the state government of Minas Gerais. Tree communities were inventoried in five different forest types, being: Cerrado (62 communities), Semideciduous Seasonal Forest (75), Deciduous Seasonal Forest (15), Cerrado field (5), and Tropical Rainforest (8). According to Scolforo & Carvalho (2006), these forest types possess the following characteristics:

Cerrado and Cerrado field: They are vegetation which contain two strata; herbaceous-subshrub (or campestral), and tree-shrubs (or woody), in which the last one may be absent from the Campo Limpo forest type, or present with coverage ranging from 10% (in the Campo Sujo forest type) to 80% (in the Cerradão forest type). The woody stratum is composed by trees and tortuous shrubs, with thick bark and average height ranging from 1.5 (Campo Sujo) to 7 m (Cerrado field and Cerrado *sensu stricto*) but may reach up to 15 m (Cerradão). The campestral stratum presents density inversely proportional to the coverage of the woody stratum.

Seasonal Semideciduous Forest: It is a forest type with upper canopy with height from 4 m (in the case of altitude forests on shallow or litholic soils) to 25 m (in deeper soils), with emerging trees reaching 40 m height and dense understory. It has intermediary deciduousness (20-70%) of leaf mass of the canopy over the colder and drier season, besides less abundance of epiphytes and brackens when compared with rainforests. It presents variable density of vines and bamboos.

Deciduous Forest: It is a forest type with lower canopy with height from 6 m (on rock outcrops) to 15 m (in deeper soils), with emerging trees reaching 30 m height, and deciduousness (> 70%) of leaf mass of the canopy over the dry season. It has low occurrence of epiphytism and variable density of branches and terrestrial bromeliads, palm trees and lianas.

Tropical Rainforest: this forest type can be classified into dense or mixed. The dense formation possesses upper canopy from 4 m (in the case of altitude forests on shallow or litholic soils) to 25 m height (in deeper soils), with emerging trees reaching 40 m and a dense understory. It has an inexpressive deciduousness (< 20%) of leaf mass of the canopy over the colder and drier season, besides a high abundance of epiphytes and brackens. The density of vines and bamboos is

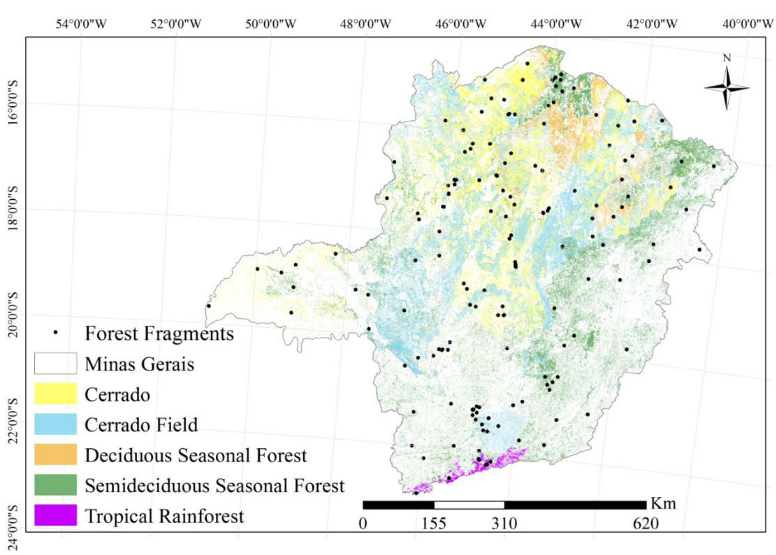

Figure 1. Location of studied forest fragments and land use with forest types of the state of Minas Gerais. Adapted from Forest Inventory of Minas Gerais.

variable. The mixed formation presents upper canopy from 15 m to 25 m height, where the most emerging trees is composed typically by araucarias. It has an inexpressive deciduousness (< 20%) of leaf mass of the canopy over the colder and drier season, and a high abundance of epiphytes and brackens.

A total of 4,307 plots with area varying from 225 to 1,000 m^2 were allocated in 165 forest fragments (tree communities). Considering all evaluated forest types, the total sampled area was of 134,159 m^2, in which an average of 98 forest species/forest fragment were identified.

More information concerning the soil and climatic conditions, forest fragment mappings, methodology for sampling and results of volume and phytosociological inventories can be seen in Scolforo et al. (2008a, b) and de Mello et al. (2008).

2.2. Diversity, dominance and equitability

For each sampled tree community, Shannon diversity index (H'), Simpson dominance index (S'), and Pielou equitability index (J') were calculated basing on information from phytosociological inventories, as described in Equations 1-3, respectively. The choosing of these indices is justified because they are indicators widely used in ecological studies, besides presenting robustness in the estimates of levels of diversity (Freitas & Magalhães, 2012; Scolforo et al., 2008a, b; Mello et al., 2008).

$$H' = -\sum_{i=1}^{S} \frac{n_i}{N} ln \frac{n_i}{N} \quad (1)$$

$$S' = \sum_{i=1}^{S} \frac{n_i (n_i - 1)}{N(N-1)} \quad (2)$$

$$J' = \frac{H'}{H_{max}} \quad (3)$$

Where $H_{max} = \ln(S)$; S = total number of sampled species; n_i = number of individuals sampled of the n^{th} species; N = total number of individuals sampled.

2.3. Spatial analysis

We took geographic midpoint in each tree community in order to use them on the spatial dependence analysis. The diversity indices above described were considered as variables of interest to fit the experimental semi-variograms, allowing us to detect the structure of spatial dependence. Gaussian (Equation 4) and Exponential (Equation 5) models (Journel & Huijbregts, 1978) were adjusted by using maximum likelihood method. The models present the following parameters: nugget effect (τ^2), sill ($\tau^2 + \sigma^2$) and range (φ) of the spatial dependence. The geostatistical analyzes were performed through the software R (R Development Core Team, 2011) and the GeoR package (Ribeiro & Diggle, 2001).

$$\gamma(h) = \tau^2 + \sigma^2 \left[1 - e^{-\left(\frac{h}{\varphi}\right)^2} \right] \text{ For } h > 0 \qquad \gamma(0) = 0 \quad (4)$$

$$\gamma(h) = \tau^2 + \sigma^2 \left[1 - e^{-\left(\frac{h}{\varphi}\right)} \right] \text{ For } h > 0 \qquad \gamma(h) = \tau^2 + \sigma^2 \text{ For } h \geq \varphi \quad (5)$$

Where: $\gamma(h)$ = semi-variance; τ^2 = nugget effect; σ^2 = contribution; h = distance in km between the samples; φ = range; e = exponential.

The model selection was based on the following statistical criteria: AIC value (Akaike, 1983), Reduced Mean Error (RME) (Equation 6) and Standard Deviation of the Reduced Error (SDRE) (Equation 7), calculated for each of the models after adjusting the parameters. Thus, the selected model should present the smallest AIC, the RME closest to zero, and the SDRE closest to one (Cambardella et al., 1994).

$$RME = \frac{1}{n} \sum_{i=1}^{n} \frac{(z_{xi} - \hat{z}_{xi})}{\sigma(\hat{z}_{xi})} \quad (6)$$

$$SDRE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \frac{|z_{xi} - \hat{z}_{xi}|}{\sigma(\hat{z}_{xi})}} \quad (7)$$

Where: n = number of observations; z_{xi} = observed value for the variable of interest in the point x_i; $\hat{z}_{xi}$ and $\sigma(\hat{z}_{xi})$ = respectively, predicted value for the variable of interest and its standard deviation, both in point x_i without considering the observation $\hat{z}_{xi}$.

After defining the best model, the evaluation of degree of spatial dependence (SD) of the variables of interest was performed basing on the percentage of structured variation (σ2) in relation to the sill (τ2 + σ2), as presented by Biondi et al. (1994). According to Zimback (2003), the SD assumes the following intervals: ≤ 25% (low spatial dependence), 25% < of ≤ 75% (moderate) and > 75% (strong). Once proven the spatial dependence, the indices of Shannon, Simpson and Pielou were estimated for non-sampled locations using ordinary kriging method (Z $*(t_0)$) (Equation 8). Finally, the species diversity and equitability were mapped forming a gradient throughout the state of Minas Gerais.

$$Z^*(t_0) = \sum_{i=1}^{n} \lambda_i Z(t_i) \tag{8}$$

Where: n = number of samples of Z(t) involved in the estimate of $Z^*(t_0)$, and λ_i = weights associated to each measured value $Z(t_i)$.

2.4. Probabilistic analysis

Due to its wide application, we selected the Shannon index to analyze the probability of occurrence of diversity values in a given interval. Eight diversity classes composed the frequency distribution, encompassing all the observed forest types. We adjusted two probabilistic density functions (pdf): Gaussian (Equation 9) and Weibull 3-P (Equation 10). The selection was based on the Kolmogorov-Smirnov test at 95% probability level, selecting the one with better adherence, such as Machado et al. (2010) and Binoti et al. (2011).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left(-\frac{1}{2}\right)\left[\left(\frac{x-\mu}{\sigma}\right)\right]^2} \tag{9}$$

Where: σ = standard deviation of the Shannon index; μ = average of the Shannon index; x = midpoint of a class of the Shannon index; e = exponential.

$$f(x) = \frac{b}{c}\left(\frac{(x-a)}{b}\right)^{c-1} e^{\left[-\left(\frac{x}{b}\right)^c\right]} \tag{10}$$

Where: x = midpoint of a class of the Shannon index; e = exponential; a = location parameter; b = scale parameter; c = shape parameter.

After adjusting and selecting the pdf, we analyzed the probability of occurrence of intervals for the tree species diversity in different forest types. Finally, the probability of the Shannon index, together with the spatialization diversity and evenness maps, allowed us to infer over the expected diversity of forest species in any tree community in the state of Minas Gerais. These results were also evaluated with soil and climatic conditions across the state of Minas Gerais.

3. RESULTS AND DISCUSSION

Table 1 presents descriptive statistics for the state and by forest types, for each one of the assessed indices, and number of tree species. In general, the mean tree diversity for the state of Minas Gerais, calculated by the Shannon index, was equal to 3.5062 nats/ind., with minimum and maximum values of 2.1490 and 4.7390 nats/ind., respectively. The Simpson index indicated a mean dominance of 0.0607, ranging from 0.0140 to 0.1990. The evenness calculated by the Pielou index ranged from 0.5830 to 0.9120, with average value of 0.7690. The average number of species for each type of forest type reflected a growing richness from Deciduous Seasonal Forest (67 species) to Campo Cerrado (69 species), Cerrado, (74 species), Seasonal Semideciduous Forest (123 species), and Tropical Rainforest (125 species). Gomide et al. (2006) found similar intervals for the indices of Shannon (2.17 to 4.138 nats/ind.), Simpson (0.019 to 0.206), evenness (0.625 to 0.875) and number of species (22 to 165) in 20 forest fragments in the forest types Semideciduous Seasonal Forest, Deciduous Seasonal Forest and Cerrado. These results also are similar to those obtained in other studies in vegetation of the state of Minas Gerais (Van Den Berg & Oliveira-Filho, 2000; França & Stehmann, 2004; Silva et al., 2004; Valente et al., 2011).

The largest values of tree species diversity by means of the Shannon index were observed in the forest fragments from Atlantic Rainforest, where there were also the largest number of tree species and with homogeneous tree distribution. Gomide et al. (2006) observed higher indices of diversity in forests from Semideciduous Seasonal Forest in the state of Minas Gerais. These authors emphasized that the greater diversities in this forest type is associated with higher moisture content and, consequently, less water restrictions. Among the main factors that may contribute to the high diversity, the environmental heterogeneity, certainly, has a great influence (Van Den Berg & Oliveira-Filho, 2000). The Deciduous Seasonal Forest was the forest type with lower diversity and richness. According to Gentry (1995), among the tropical forests, the Deciduous Seasonal Forest tends to have low diversity due to conditions of environment where it occurs, besides the lower levels of humidity.

Table 1. Descriptive statistics for floristic diversity indices and estimated richness of species in the arboreal communities located in the state of Minas Gerais.

Statistical Office	Simpson	Shannon	Pielou	Number of Species
General				
Minimum	0.0140	2.1490	0.5830	25
Average	0.0607	3.5062	0.7690	98
Maximum	0.1990	4.7390	0.9120	258
S	0.0346	0.5338	0.0553	54
CV (%)	56.9665	15.2256	7.1958	56
Cerrado				
Minimum	0.0200	2.3090	0.6260	33
Average	0.0660	3.3047	0.7599	74
Maximum	0.1610	4.2300	0.8660	193
Semideciduous Seasonal Forest				
Minimum	0.0140	2.1490	0.5830	25
Average	0.0553	3.7268	0.7803	123
Maximum	0.1990	4.7390	0.9120	258
Deciduous Seasonal Forest				
Minimum	0.0400	2.5440	0.6570	29
Average	0.0747	3.1691	0.7413	67
Maximum	0.1560	3.7070	0.8550	110
Cerrado field				
Minimum	0.0280	2.9170	0.7570	29
Average	0.0578	3.3836	0.7870	69
Maximum	0.0830	4.0180	0.8240	105
Tropical Rainforest				
Minimum	0.0230	2.7300	0.6590	53
Average	0.0464	3.7089	0.7748	125
Maximum	0.0980	4.3510	0.8350	256

Where: S and CV correspond to the standard deviation and the coefficient of variation for the variable diversity, respectively.

The variations among environments due to the presence of numerous vegetation types and plant formations, also contribute to changes in diversity among forest fragments. Factors related to soil water flow, fertility, brightness, topographical conditions, geographical location and climate increase this variation (Gomide et al., 2006). In addition, it is still cited the location of the fragments over rough terrain (Machado & Silva, 2010). In general, these conditions limit anthropic actions and deforestation, promoting forest conservation and preservation. In the state of Minas Gerais, for example, deforestation reduced in 152,635 ha the forest cover between the years 2003 and 2005 (Scolforo & Carvalho, 2006). According to Gomide et al. (2006), the degree of anthropic action that a forest fragment is subject contributes for reducing forest species diversity.

The Simpson index is strongly affected by high dominance species, reflecting the variety of species abundance (Magurran, 2013). Therefore, the higher the value of this index, the less will be the Shannon diversity index, as observed in the Deciduous Seasonal Forest. In Cerrado also occurs high dominance species in relation to Semideciduous Forest and Campo Cerrado forest types. Tropical Rainforest forest type, in turn, was the one with lowest dominance, therefore, the number of individuals belonging to each species had greatest evenness. It is assumed that the probability of selecting randomly two individuals, and they do not belong to the same species in Tropical Rainforest, is equal to 95.4%, whereas in the Seasonal Semideciduous Forest, the probability is 92.5%.

The Pielou index kept average values with low variation among the forest types, in which the observed average for the state was 0.7690, with coefficient of variation of 7.19%, such as found in other studies (Van Den Berg & Oliveira-Filho, 2000). The lower evenness in the Deciduous Seasonal Forest, and higher in the Campo Cerrado, in spite of the less species richness in relation to the other forest types, indicate a more equal distribution among the species.

The indices of Shannon (diversity), Simpson (dominance), Pielou (evenness), and number of species (richness) were analyzed by means of the experimental semivariogram. This analysis proved to be satisfactory, since the fittings had spatial dependence classified as moderate in all cases (Table 2). The Shannon index presented major spatial dependence (70.02%), whereas Pielou evenness presented the less one (41.30%). Except for the variable Pielou evenness, in which the best model was the Gaussian, for all other variables, the exponential model showed the best results according to the values of AIC, RME and SDRE. Amaral et al. (2013) found a strong spatial dependence for the Shannon index and number of species, however, the spherical and exponential models better fitted to the data.

The variogram analysis showed that the variables are spatially structured, i.e., it is possible to use the kriging spatial estimator to spatialize the variables throughout the state. The index of spatial dependence, proposed by Cambardella et al. (1994), showed that all variables present moderate dependence. The dependency distances ranged from 240 km (number of species) to 850 km (Pielou) (Table 2). The wide distribution of vegetation types, in particular the Semideciduous Seasonal Forest found throughout the state, contributes considerably to the large distance of spatial dependence. Furthermore, Minas Gerais has, on average, 900 km between its extreme points and its vegetation distributes in large domains.

The map of Shannon diversity index (Figure 2) shows the relationship between areas with greater diversity and the occurrence of communities belonging to the Semideciduous Seasonal Forest and Tropical Rainforest forest types, which present high species richness (Gomide et al., 2006; Van Den Berg &

Table 2. Fitting variables of semivariance models for each forest type and degree of spatial dependency (SD).

Variable	Model	τ^2	σ^2	φ	SD
Simpson	Exponential	0.0009	0.0013	600,000	59.09
Shannon	Exponential	0.1313	0.3066	500,000	70.02
Pielou	Gaussian	0.0002	0.0001	850,000	41.30
Number of Species	Exponential	1,435.4	1,679.4	240,802	53.92

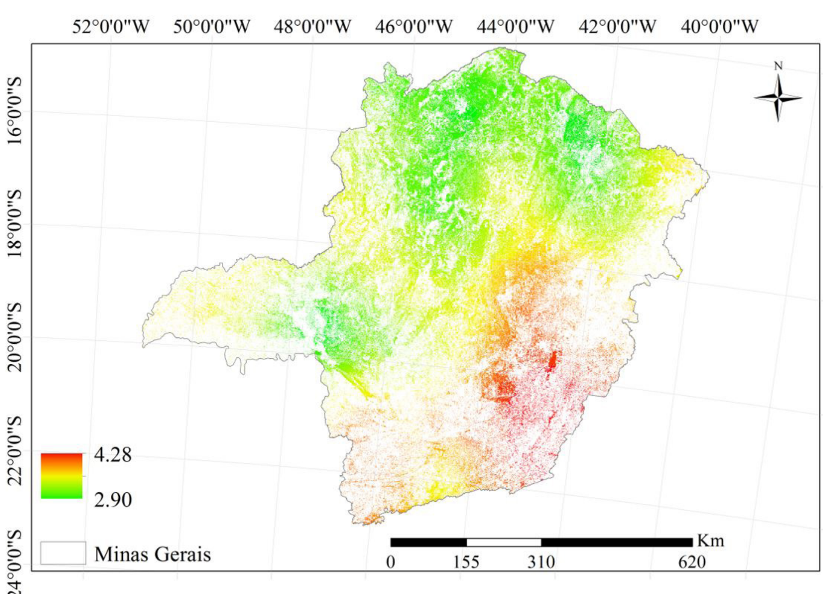

Figure 2. Map of distribution of the species diversity using Shannon's index calculated is arboreal communities located in the state of Minas Gerais.

Oliveira-Filho, 2000; Werneck et al., 2000; Souza et al., 2003; Guimarães et al., 2012; Moreira et al., 2013). We identified in the northern region a lesser diversity, which corresponds to the tree communities belonging to the phytogeographic regions Deciduous Seasonal Forest, Campo Cerrado, and Cerrado. These variations of diversity in the vegetation of the state of Minas Gerais favors the formation of a tree species richness gradient that increases in the north-south direction (Figure 3).

The spatialization of tree richness (Figure 3) is similar to that found for the Shannon index, which had the number of species increased from north to south, and from west to east of the state. These gradients are sensitivities to environmental differences, which added to peculiarities of each species, may limit its presence in the ecosystem. This occurs due to the variety of forest types, influenced by environmental factors such as climate and geographical location. Therefore, this contributes to the species richness distribution across the communities, resulting in considerable changes in the diversity in forest fragments. In addition, the development of trees is a direct consequence of ecological conditions and the use of available natural resources (Shimizu & Sebbenn, 2008).

Factors as climate, soil, rainfall, and temperature considerably influence on the similarity between environments (Van Den Berg & Oliveira-Filho, 2000), making them diversified. We observed that in larger diversity regions, there are larger rainfall levels, which cover the west and south of the state (Figure 4A). These both regions are occupied by Atlantic Rainforest, where there are the remnants of Deciduous Seasonal Forest and Tropical Rainforest. The average annual rainfall in these regions may exceed 1,000 mm. According to Carvalho et al. (2008), humid and superhumid climates are predominant in these regions (Figure 4B), which are under direct influence of high altitudes and rainfall levels came from Mantiqueira and Bocaina ridges.

The maps of dominance and evenness (Figures 5 and 6, respectively) corroborate with the map of tree diversity. The higher values of Simpson index observed for the north and west regions confirms a lower diversity associated with these regions. The homogeneous tree distributions into the species is represented by Pielou index, being greater in Semideciduous Seasonal Forest and Rainforest regions, where inclusive we did not observe less species in relation to the other regions. Gomide et al. (2006) studied Semideciduous Seasonal Forest remnants and noted low evenness when there is dominance of certain tree species, such as *Croton urucurana* Baillon, *Casearia sylvestris* Swartz, *Psidium guajava* L., *Nectandra nitidula* Nees, *Ruprechtia laxiflora*

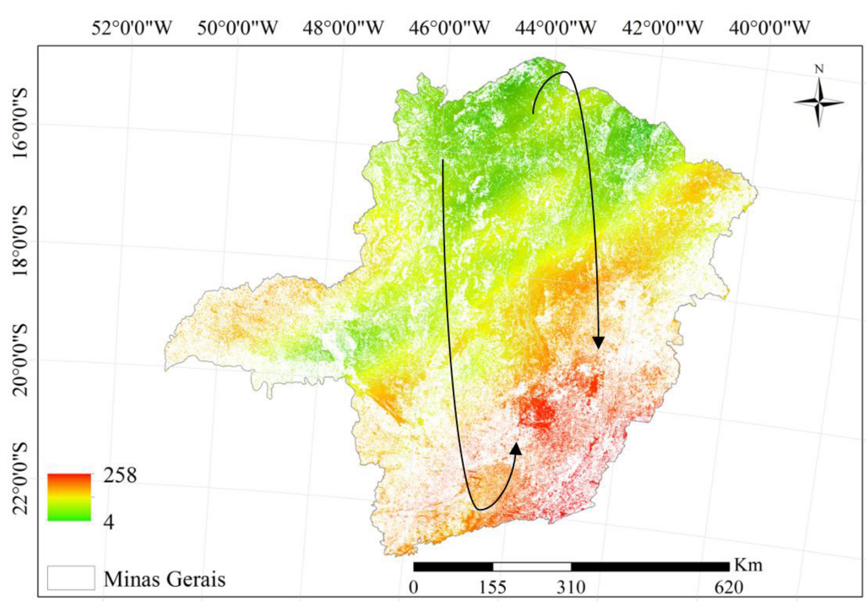

Figure 3. Map of the distribution of species richness by hectare, calculated is arboreal communities located in the state of Minas Gerais.

Meisner, and *Savia dictyocarpa* (Müll.Arg.) Müll.Arg. However, the fragments analyzed by these authors are located across the mid and north region of the state, where we observed medium and low evenness (Figure 6).

The smallest uniformity detected by Pielou evenness in the northern region may be due to characteristics that some species acquired to support adversities found in soils and climate from Cerrado. As examples, species like

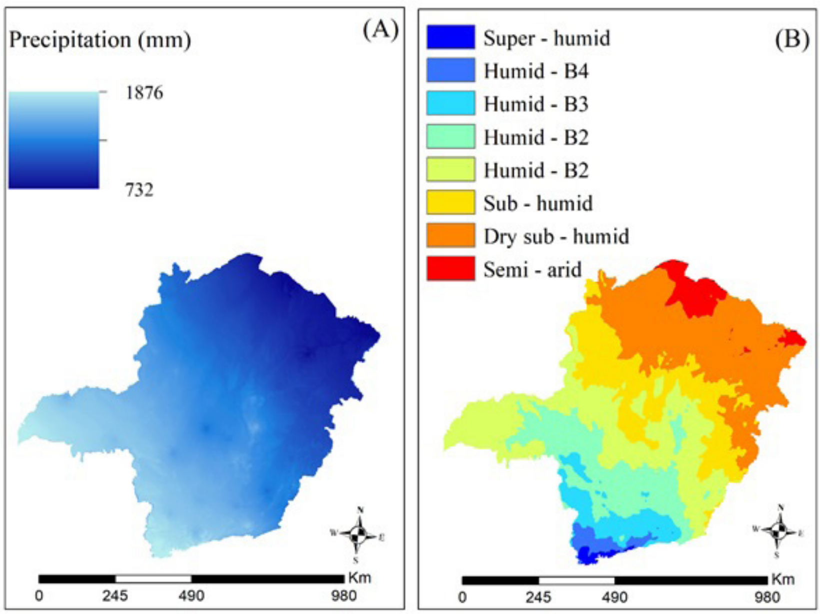

Figure 4. Map of total annual rainfall average (mm) (A) and climatic zoning that is basing on Thornthwaite moisture index (MI) (B) of the state of Minas Gerais.
Source: Carvalho et al. (2008).

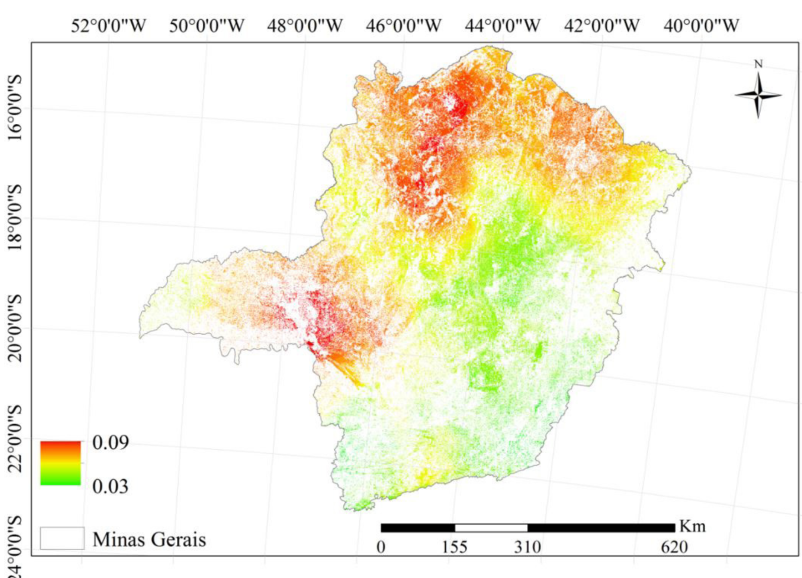

Figure 5. Map of species diversity distribution using Simpson's index calculated is tree communities located in the state of Minas Gerais.

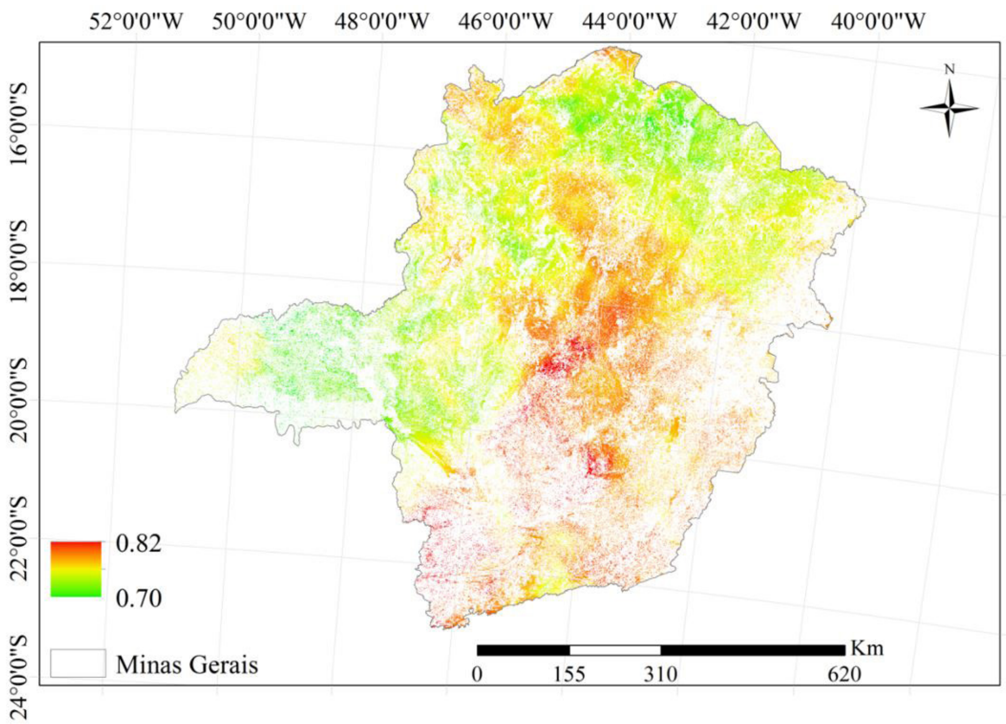

Figure 6. Map of distribution of the species diversity using Pielou's index calculated is arboreal communities located in the state of Minas Gerais.

Qualea parviflora Mart. and *Qualea grandiflora* Mart. are capable to absorb soil aluminum; and the cases of *Caryocar brasiliense* Cambess., *Byrsonima pachyphylla* JUSS., and *Dimorphandra mollis* Benth., that occur always in higher density communities (Scolforo et al., 2008a). Thus, the vegetation of the northern region has a trend in developing either depending on weather or soil conditions (IBGE, 2012).

Based on the probability density function (Table 3) fitted for Semideciduous Seasonal Forest fragments, there is a higher probability (34.8%) of finding forest fragments with diversity values between 3.75 and 4.25. In Atlantic Rainforest fragments, the more likely (33.36%) is the occurrence of diversity values between 3.25 and 3.75 nats/ind. In both forest types we observed the largest probability of obtaining diversity greater than 4.25 nats/ind., with distribution clearly asymmetric to the right. The Cerrado and Deciduous Seasonal Forest types had largest probabilities in presenting medium diversity, i.e. between 2.75 and 3.25 nats/ind., similar to a normal distribution (Figure 7). The Campo Cerrado distribution showed asymmetry to the left, confirming the lowest diversity indices, with 37.44% probability of occurrences of diversity between 2.25 and 2.75 nats/ind. Such findings corroborate with those obtained in forest fragments belonging to these forest types (Gomide et al., 2006; Van Den Berg & Oliveira-Filho, 2000; Souza et al., 2003; Scolforo et al., 2008a, b). According to Silva et al. (2004), anthropic intervention may reduce local species diversity so that local forests will tend to be in an initial stage of succession.

Such findings reflect the regional floristic characteristics of each forest formation in the state of Minas Gerais. This demonstrates the existence of a spatial structure of tree species diversity in north-south and east-west directions, which is influenced mainly by soil and climatic conditions, besides environmental and forest types variations. The findings also show the high richness and diversity in the state, subsidizing the establishment of public policies that ensure the maintenance and increasing of forest species diversity. In addition, the spatialization of these indicators supports measures of preservation, recuperation, and sustainable management of forest fragments.

Table 3. Probability of occurrence of diversity intervals by forest types in the state of Minas Gerais.

Forest type	< 2.25	2.25 ┤ 2.75	2.75 ┤ 3.25	3.25 ┤ 3.75	3.75 ┤ 4.25	>4.25
Cerrado	0.0092	0.1872	0.5518	0.2368	0.0148	0.0001
Deciduous Seasonal Forest	0.0107	0.2613	0.5972	0.1282	0.0026	0.0000
Semideciduous Seasonal Forest	0.0387	0.0817	0.1740	0.3298	0.3480	0.0277
Tropical Rainforest	0.0308	0.0785	0.1826	0.3336	0.3198	0.0548
Cerrado field	0.0000	0.3744	0.3015	0.1846	0.0957	0.0437

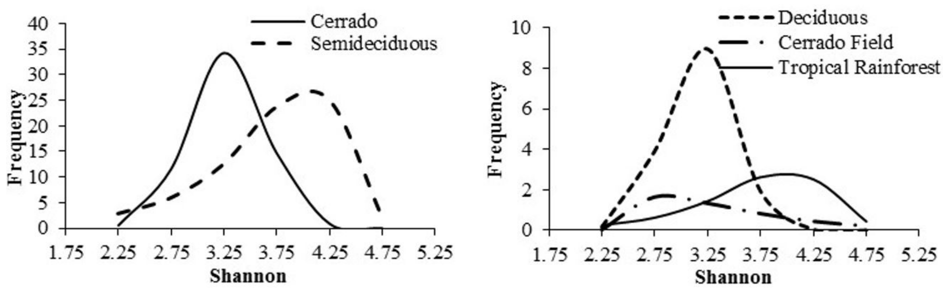

Figure 7. Frequency distribution of Shannon diversity index for forest types in the state of Minas Gerais.

4. CONCLUSION

The tree species diversity is a variable that has spatial dependence and can be geostatistically modeled and estimated in non-sampled forest fragments. The maps of tree species diversity can be used as indicators of potential areas for creation of Conservation Units, establishment of ecological corridors, besides supporting environmental policy developments.

The spatialization of tree species diversity in the state of Minas Gerais has a gradient which increases in north-south and west-east directions. Among the forest types, the greatest diversity is observed in Semideciduous Seasonal Forest, followed by the Atlantic Rainforest, Cerrado, Deciduous Seasonal Forest, and Campo Cerrado.

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