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PERFORMANCE ASSESSMENT OF METHODOLOGIES FOR VERTICAL STRATIFICATION IN NATIVE FORESTS

AVALIAÇÃO DO DESEMPENHO DE METODOLOGIAS PARA ESTRATIFICAÇÃO VERTICAL EM FLORESTAS NATIVAS

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ABSTRACT

Vertical stratification – as well as other environmental phytosociological parameters for uneven-aged stands in forest structures – is one of the factors that regulates the amount of energy present in a forest, although it is often disregarded. The objective of this study is to evaluate the performance of some commonly used methodologies to characterize the vertical stratification of a forest fragment. Researchers from UESB – State University of Southwest Bahia collected data in a Seasonal Forest fragment located in the city of Vitória da Conquista, Bahia, Brazil. The standard method used in the study was the Sociological Position Method. Results were compared to six other methods: IUFRO; Vega; Longhi; Calegário; Souza and Leite; and Hasenauer. The performance of each method was assessed according to the "c" coefficient. Results of the standard method showed 954 individuals (656 dominant; 232 codominant; and 66 dominated). The "c" coefficient was found to be efficient to interpret the performance of these methods. The IUFRO Method showed the best performance when compared to the Sociological Position Methods.
Keywords: phytosociology; uneven-aged stands; sociological position.

RESUMO

A estratificação vertical, bem como vários parâmetros ecológicos de suma importância para a estrutura fitossociológica em florestas inequiâneas, reflete a quantidade de energia existente na floresta. O presente trabalho teve como objetivo avaliar o desempenho das metodologias usuais de caracterização da estratificação vertical em florestas. O levantamento de dados foi realizado em um fragmento de Floresta Estacional, no município de Vitória da Conquista, no *campus* da Universidade Estadual do Sudoeste da Bahia. A Posição Sociológica foi considerada como método padrão neste estudo. Os resultados obtidos foram comparados com outros seis diferentes métodos: IUFRO, Vega, Longhi, Calegário, Souza e Leite e Hasenauer. O desempenho dos métodos foi avaliado segundo o coeficiente "c". Foram classificados pelo método padrão 954 indivíduos obtendo os seguintes resultados: 656 dominantes, 232 codominantes e 66 dominados. O coeficiente "c" mostrou-se eficiente na interpretação do desempenho dos métodos. O método da IUFRO apresentou o melhor desempenho em comparação ao Método da Posição Sociológica.
Palavras-chave: fitossociologia; florestas inequiâneas; posição sociológica.

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INTRODUCTION

According to Vale et al. (2009), studies in natural forests focus on horizontal phytosociological structures, ignoring vertical stratifications in many cases. Freitas and Magalhães (2012) state that vertical structures define different synuseae arrangements, since the strata have been determined by the species that have uniform ecological requirements.

Vertical stratification, along with stem density, reflects energy balance as well as richness, diversity, and the biomass production of a particular forest, thereby working as an indicator of environmental sustainability (SOUZA et al., 2003). Therefore, the presence of a species in different layers of height is evidence of environmental sustainability (SOUZA; SOUZA, 2004).

Canopy formation is a feature of tropical forests due to the presence of high trees and an understory formed by shade-tolerant and lower-height species (GOURLET-FLEURY et al., 2005). Therefore, creating a vertical grouping of individuals according to height (strata) is recommended.

In phytosociology studies, each stratum requires the calculation of its phytosociological value, enabling the evaluation of the sociological position of each species. This information permits a better understanding of the situation of the species, since it complements the vision presented by its horizontal structure.

Subdivisions of natural forests in different strata are very complex because of the great variability in observed heights. There are several methodologies for the vertical stratification of natural forests, some of which are easy to use while others are more complex. The decision of which method to use will depend on the complexity of the forest formation and the choice of the researcher.

Marangon et al. (2008) distributed the trees in 10 height classes (strata) of three meters each. Guedes-Bruni et al. (2006) used height classes of two meters to stratify individuals. Negrelle (2006), Liebsch, Goldenberg and Marques (2007) and Leyser et al. (2009) did a vertical structure division using only four strata. However, it is more common to divide a forest into three or fewer strata (SOUZA et al., 2003; GUILHERME; MORELLATO; ASSIS, 2004; SOUZA et al., 2007; HERRERA et al., 2009; VALE et al., 2009).

The Sociological Position Method aims at classifying individuals by viewing the trees in the field and then grouping the trees into one of the pre-established strata (emerging, dominant, co-dominant or dominated), thus translating the reality of the field (ORELLANA; KOEHLER, 2008).

According to Martins (2012), there is not one best procedure to determine the number of vertical strata, and often the division is done arbitrarily. This analysis results from the wide variety of methods for vertical stratification. In addition, some of these methods frequently cannot fully express the reality observed in a natural forest.

In this context, this study purports to:

- propose a methodology to compare several vertical stratification methods;
- evaluate the most common methods for vertical stratification; and
- determine which method presents results closer to field reality.

MATERIALS AND METHODS

A group of researchers from UESB – State University of Southwest Bahia collected data in a Seasonal Forest fragment (Figure 1) located in the city of Vitória da Conquista, UESB *campus*, Bahia, Brazil. This fragment is described as typical vegetation in southwestern Bahia (forest ecotones between Atlantic Forest and Caatinga biomes), and is commonly known as "*mata-de-cipó*". Usually, species of the family Fabaceae are predominant in this forest formation, where most individuals are relatively tall, predominantly thorny, and involved by woody lianas with evergreen foliage, which gives the false impression of a wet environment in times of insufficient natural resources such as water (VELOSO; RANGEL FILHO; LIMA, 1991).

According to Koppen's climate classification, the regional climate is Cwb (tropical climate at an elevation), showing, in the warmest month, an average temperature below 22 °C, 700 mm of precipitation, average relative humidity between 70 and 85%, and 923 meters of altitude (SILVEIRA, 2011). The predominant soil found in this area is Dystrophic Yellow Alic Latossol.

FIGURE 1: General view of Seasonal Forest fragment located in the *campus* of the State University of Southwest Bahia, in the city of Vitória da Conquista, Bahia state, Brazil.
FIGURA 1: Vista geral do fragmento de Floresta Estacional localizado no *campus* da Universidade Estadual do Sudoeste da Bahia, na cidade de Vitória da Conquista (Estado da Bahia - Brasil).

Sixty contiguous plots (10 x 10 m) provided data for this study. All individuals with circumference at breast height (1.30 m from the ground) ≥ 15 cm were included. The tree height was measured using a laser rangefinder (940 nm wavelength and accuracy of ±1 m).

The standard method used in this study was the Sociological Position Method (ORELLANA; KOEHLER, 2008) because it expresses the real condition of individuals in the forest environment, since it also observes the vertical structure position. In this way, it is possible to verify the situation of individuals in relation to shade. For the evaluation of the Sociological Position Method, a classification considering three height classes was determined: 1 - dominant; 2 - codominant and; 3 - dominated.

Results obtained using this methodology were compared to six other methods. A description of each one of these methods is presented below:

a) IUFRO's Method (LAMPRECHT, 1990)

It is based on forest dominant height (H_{dom}). The dominant height is obtained by determining the average height of 80 trees with the largest circumference at breast height (CBH). Using these values, the study proceeds to vertical stratification according to the following rules:

- Inferior stratum ($H_j < H_{dom}/3$)
- Middle stratum ($H_{dom}/3 \leq H_j < 2H_{dom}/3$)
- Superior stratum ($H_j \geq 2H_{dom}/3$)

Where: H_j = height of j-th tree to be classified in the stratum.

b) Vega's Method (VEGA, 1966)

This method depends on the range (variation) of tree heights ($h_{max} - h_{min} = A$). This value is then used to split the range into three parts:

- Inferior stratum ($h_j < h_{min} + A/3$);
- Middle stratum ($h_{min} + A/3 \leq h_j \leq h_{min} + 2A/3$);
- Superior stratum ($h_j \geq h_{min} + 2A/3$).

Where: h_{min} = minimum height sampled; h_{max} = maximum height sampled.

c) Longhi's Method (1980 apud LONGHI et al., 1999)

First, it is necessary to arrange tree heights in ascending order. Next, percentages of height frequency and the accumulation of these percentages are determined. After that, it is possible to generate a curve that links the cumulative frequency and the total height. Finally, the three strata are established observing the criterion where each stratum should cover 1/3 of the total sampled heights. Therefore, heights equivalent to 33.3% of the cumulative frequency is the limit between the inferior and the middle strata, and height equivalent to 66.7% is the limit between the middle and the superior strata.

d) Souza and Leite's Method (SOUZA; LEITE, 1993)

Initially, it is important to calculate the arithmetic mean of heights (Hm) measured in the field, and in sequence, the mean standard deviation (σ). Thus, individuals are classified into different strata according to the following criteria:

- Inferior stratum = (H_j < (Hm - 1σ)
- Middle stratum = (Hm - 1σ) ≤ H_j ≤ (Hm + 1σ)
- Superior stratum = H_j > (Hm + 1σ)

e) Calegário's Method (CALEGÁRIO; SCOLFORO; SOUZA, 1994)

This method also requires an arrangement of tree heights in ascending order. The chi-square test (χ^2) is applied at a significance level of 95%, verifying the existence of homogeneous height groups, according to Equation 1:

$$\chi_j^2 = S_j^2/\overline{H}_j) \,.\, (j - 1) \; (j = 2, 3..., k, ..., n) \qquad \text{(Equation 1)}$$

Where: χ_j^2 = chi-square value calculated to j-th group of trees; S^2_j = variance of tree heights in the j-th group; $\overline{H}_j$ = arithmetic mean of the heights in the j-th group.

When the "calculated" value is greater than the "tabled" value, it means that the sample data is statistically homogeneous. Therefore, the group is identified as the first stratum of height or inferior stratum. The inferior limit corresponds to the minimum sampled height while the superior limit refers to the value of the j-th height measured. The same methodology is repeated for the identification of the other strata.

An adjustment is needed to conduct the analysis of this method, because it only distinguishes two strata while the standard method identifies three different strata. To solve this problem, a first regression is made to calculate the total number of individuals in the middle and inferior strata (Calegário 1). In the second case (Calegário 2), this total number of individuals is determined considering the individuals in the middle stratum and the superior stratum. In the third case (Calegário 3), the individuals of the middle stratum are distributed between the inferior and superior strata.

f) Hasenauer's Method (HASENAUER, 2006)

The first step for this method is to observe the total amplitude of the height of the tree population (H_{max} - H_{min} = A). Then, strata of three heights are determined according to the following ratio:

0-50% for the inferior stratum;

50-80% for the middle stratum; and

80-100% for the superior stratum.

In order to compare all the methods described previously, a linear regression was performed using the results obtained during stratification. The results from the standard method were plotted on coordinate "x" (absciss axis) and those results obtained using all methodologies presented in this study were plotted on coordinate "y"(ordinate). By using the information from regressions and their respective determination coefficients "R^2", it was possible to obtain the Pearson correlation coefficient "r" for all methodologies, through the square root of the previous coefficient (determination coefficient). Pearson correlation ("r" coefficient) measures the direction and the degree of linear relationship for the quantitative values obtained in the stratification methods (MOORE, 2007).

For the purpose of measuring the performance of all methodologies proposed in this paper, the study compared the vertical stratification results obtained from all described methods with the results from the Sociological Position Method (standard method). A commonly used methodology for this comparison was proposed by Allen et al. (1986), which was based on (i) the Estimated Standard Error (ESE) (Equation 2) and (ii) on agreement or adjustment index (Equation 3), which provides an approximation of the number of individuals per stratum, estimated by the methods evaluated in relation to the standard method (WILLMOTT; CKLESON; DAVIS, 1985):

$$\text{ESE} = \frac{\left(\Sigma\left(y-\hat{y}\right)^2\right)^{1/2}}{n-1} \qquad \text{(Equation 2)}$$

Where: ESE = number of individuals per stratum; y = number of individuals per stratum estimated by the standard method; $\hat{y}$ = number of individuals per stratum estimated by the proposed method; n = strata numbers

$$d = 1 \quad \frac{\sum_{i=1}^{n} (\text{Ni} - Oi)^2}{\sum_{i=1}^{n} \left[\left(\left|\text{Ni} - \overline{O}\right|\right) + \left(\left|\text{Ni} - \overline{O}\right|\right)\right]^2} \qquad \text{(Equation 3)}$$

Where: d = agreement or adjustment index; Ni = number of individuals in the stratum calculated by the available method; Oi = number of individuals in the stratum calculated by the standard method; $\acute{O}$ = average number of individuals by stratum, obtained by the division of the total number of individuals by the number of strata; n = number of strata.

The “d” values varied from zero (situation considered as non-concordance) to one (when there is total concordance).

With the “r” and “d” coefficients, it was possible to calculate the “c” coefficient proposed by Camargo and Sentelhas (1997) by multiplying the previous two coefficients (d x |r|), resulting in the following classification (Table 1):

TABLE 1: Interpretation criteria of “c” coefficient proposed by Camargo and Sentelhas (1997).
TABELA 1: Critérios de interpretação do coeficiente “c” proposto por Camargo e Sentelhas (1997).

“c” value	Performance
> 0.85	Excellent
0.76 a 0.85	Great
0.66 a 0.75	Good
0.61 a 0.65	Regular
0.51 a 0.60	Tolerable
0.41 a 0.50	Poor
≤ 0.40	Terrible

RESULTS AND DISCUSSION

In this study, 954 individuals were classified according to the Sociological Position Method: 66 trees in the inferior stratum (dominated), 232 in the middle stratum (codominant), and 656 in the superior stratum (dominant), as shown in Table 2.

TABLE 2: Number of individuals (n) and the respective percentages (%) in the inferior (1), middle (2), and superior strata (3), using all methodologies described previously.

TABELA 2: Número de indivíduos (n) e respectivas porcentagens (%) nos estratos inferior (1), médio (2) e superior (3), utilizando todos os métodos descritos anteriormente.

Strata	Soc. Pos.		IUFRO		Vega		Longhi		Souza and Leite		Calegário		Hasenauer	
	n	%	n	%	n	%	n	%	N	%	n	%	n	%
1	66	6.9	4	0.4	45	5	182	19.1	180	18.9	836	87.6	537	56.3
2	232	24.0	310	32.5	791	83	560	58.7	656	68.8	-	-	403	42.2
3	656	68.8	640	67.1	118	12	212	22.2	118	12.4	118	12.4	14	1.5
Total	954	100	954	100	954	100	954	100	954	100	954	100	954	100

IUFRO's Method showed a value of 10.58 m as dominant height. This method's results were the closest to the standard method in relation to individual percentages (Table 2). Curto et al. (2013) also tested this method on a Semideciduous Seasonal Forest fragment and, unlike this study, classified 50.1% of the trees in the inferior stratum, 42.7% in the middle, and only 7.2% in the superior stratum.

When Vega's Method was applied, 5% of the individuals were classified in the inferior stratum and 12% in the superior stratum, whereas the vast majority (83% of individuals) were present in the middle stratum (see Table 2).

Longhi's Method showed 182 individuals in the inferior stratum ($H < 6.8$ m), 560 in the middle ($6.8 \text{ m} \geq H \geq 9.9$ m), and 212 in the superior stratum ($H > 9.9$ m), as can be seen in Table 2 and Figure 2.

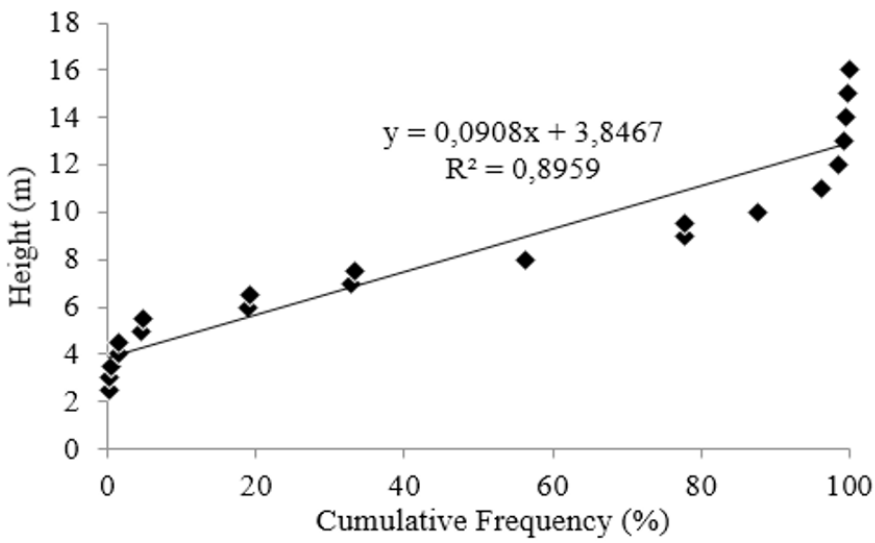

FIGURE 2: Distribution of the heights of the individuals sampled by cumulative frequency and its equation and determination coefficient (R^2) in a fragment of Seasonal Forest located at UESB, Vitória da Conquista *campus*.

FIGURA 2: Distribuição da altura dos indivíduos amostrados através da frequência acumulada e da respectiva função e coeficiente de determinação (R^2), em um fragmento de Floresta Estacional localizado no *campus* da UESB, *campus* Vitória da Conquista.

Souza and Leite's Method showed a great concentration of individuals (68.8%) in the middle stratum (see Table 2). This is due to the use of central tendency measuring (average with standard deviation), a result that is expected for this method. Paula et al. (2004) and Curto et al. (2013) found most individuals in the middle stratum – 81.3% and 75.3% respectively – confirming those results.

In Calegário's Method, the chi-square test allowed the distinction of two groups. The first group included individuals from 2.1 to 10 meters high, and the second one trees from 10.1 to 16 meters, where 87.6% of these individuals (836 individuals) belonged to the first stratum (inferior), and 12.4% (118 individuals) in the second (or superior) stratum (Table 2). Calegário, Scolforo e Souza (1994) tested this methodology in different vegetation categories such as Rainforest, Dry Forest and *Angico* Forest, and concluded that all of these cases showed a greater concentration of individuals in the inferior stratum.

Finally, Hasenauer's Method classified most individuals in the inferior stratum (56.3%), while the superior stratum had only 1.5% of the individuals (Table 2), the furthest results when compared to the standard method.

These last two methods tend to concentrate most individuals in the inferior stratum. In the case of Hasenauer's Method, this is due to the split in half of the total amplitude for that stratum, while in the second case (Calegário's Method), the result is due to the size of the tree group needed to distinguish each stratum.

The correlation coefficient "r" indicated a high relation between the IUFRO and the standard method, which had 0.97 as "r" value. All the other correlations were negative (Table 3), demonstrating that as the values of the Sociological Position Method increase, values of the other methods decrease. The methods with the worst performance according to the "r" coefficient were Hasenauer and Calegário's Methods, the latter showing the maximum negative correlation, indicated by the score of the "x" axis in total opposition to the "y" axis. Longhi, Vega, and Souza and Leite Methods showed "r" values close to "zero", which indicates no linear correlation between those methods and the standard method.

TABLE 3: Determination coefficient "R^2", Pearson's correlation coefficient "r", Estimated Standard Error (ESE), agreement index "d", Camargo and Sentelhas' (1997) "c" coefficient, and performance according to the "c" index.

TABELA 3: Coeficiente de determinação "R^2", coeficiente de correlação de Pearson "r", Estimativa do Erro Padrão (ESE), índice de concordância "d", coeficiente ''c'' de Camargo e Sentelhas (1997) e desempenho segundo o índice "c".

Methods	R^2	r	ESE	d	c	Perform.
Sociological Position x IUFRO	0.95	0.97	71.36	0.99	0.96	Excellent
Sociological Position x Veja	0.02	-0.16	548.80	0.31	0.05	Terrible
Sociological Position x Longhi	0.03	-0.17	398.86	0.30	0.05	Terrible
Sociological Position x Souza and Leite	0.12	-0.35	491.03	0.22	0.08	Terrible
Sociological Position x Calegário 1	1.00	-1.00	538.00	0.00	0.00	Terrible
Sociological Position x Calegário 2	1.00	-1.00	770.00	0.00	0.00	Terrible
Sociological Position x Calegário 3	1.00	-1.00	654.00	0.00	0.00	Terrible
Sociological Position x Hasenauer	0.99	-0.99	575.87	0.00	0.00	Terrible

The IUFRO's Method proved, once again, to have a better performance than the other methods, obtaining an ESE value of only 71.36% and "d" value very close to 1 (Table 3). These results indicate a great correlation between this method and the standard method. Thus, according to the "c" index, IUFRO's method may be considered as showing great final performance. Therefore, the efficiency of the IUFRO Method in uneven-aged forest stands is evident, because of its better performance in all evaluation methodologies.

The methods shown by Hasenauer and Calegário presented null "d" and "c" values (Table 3). Furthermore, they have the highest ESE values, indicating a complete lack of agreement between them and the standard method.

Longhi, Vega, and Souza and Leite Methods had high ESE's values and very low "d" values (0.30, 0.31, and 0.22, respectively) as indicated in Table 3. Their values resulted in very low "c" coefficients, leading to a poor performance of these methods. They showed a poor performance because they concentrated more on the individuals in the middle strata. Paula et al. (2004), Herrera et al. (2009) and Curto et al. (2013) obtained very similar results, despite the different physiognomies in which the studies were conducted. This concentration occurred because these methods use arithmetic mean as a concept, which does not represent natural structures.

CONCLUSIONS

The IUFRO Method shows the best performance when compared to the Sociological Position Method.

The "c" coefficient, proposed by Camargo and Sentelhas (1997), proved to be efficient in interpreting the performance of the methods.

Methods that use the arithmetic mean as a concept do not present results that express the natural vertical structure.

Most statistical methods, despite suppressing the interference of the observer, cannot truly express the reality found in a natural forest.

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