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Lorey height for vertical stratification of an Alluvial Ombrophilous Forest

Altura de Lorey para estratificación vertical de bosques naturales

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SUMMARY

The method, which uses the arithmetic mean and standard deviation (M_1) of total heights (Ht), is often used in the stratification of uneven-aged forests and assumes that the Ht must follow a normal standard curve considering a standard deviation of the mean. In cases where this assumption is rejected, alternative methods are used, such as the fundamentals in multivariate analysis (M_2) and Lorey's mean height (M_3). The objective was to evaluate the method M1 considering its assumption and comparing it with methods M_2 and M_3. The data were collected in 308 contiguous plots of 100 m², installed in an Alluvial Ombrophylous Forest. The assumption of the method M_1 was analyzed adjusting a Normal Probabilistic Density Function, evaluated by the K-S test. The methods were evaluated using discriminant analyses, structural analyses and three-dimensional vertical profiles. It was verified that the assumption was not met. The discriminant analyses showed that the classification was 100 % correct in methods M_1 and M_3. The 13 most important species, in descending order, were the same in all three methods. However, from the 13th, the differences were more remarkable in the method M_1. Firstly, it is recommended to use the method M_3, as it is more practical and provides results that are equal to those obtained using the method M_2. However, if the objective is to obtain a higher level of detail, the option is the method M_2 since it allows obtaining up to five strata with 100 % correct classification.

Key words: total height, vertical strata, vertical structure, stratification methods.

RESUMEN

El método que usa la media aritmética y la desviación estándar de las alturas totales - Hts (M1) se usa a menudo en la estratificación de bosques con edades desiguales y supone que Hts debe seguir una curva estándar normal, considerando una desviación estándar de la media. En los casos en que se rechaza este supuesto, se utilizan métodos alternativos, como los fundamentos del análisis multivariado (M2) y la altura promedio de Lorey (M3). El objetivo de este estudio fue evaluar el método M1 considerando su suposición y comparándolo con los métodos M2 y M3. Los datos fueron recolectados en 308 parcelas contiguas de 100 m². Hts se obtuvieron en base a una varilla medida. La suposición del método M1 se analizó ajustando una función de densidad probabilística normal, evaluada mediante la prueba K-S. Los métodos se evaluaron mediante análisis discriminante, análisis estructural y perfiles verticales tridimensionales. Se encontró que la suposición no se cumplió. Los análisis discriminantes mostraron que la clasificación era 100 % correcta en los métodos M1 y M3. Las 13 especies más importantes, en orden decreciente, fueron las mismas en los tres métodos. Sin embargo, a partir del día 13, las diferencias fueron más notables en el método M1. Primero, se recomienda el uso del método M3, ya que es más práctico y proporciona los mismos resultados que los obtenidos por el método M2. Sin embargo, si el objetivo es obtener un mayor nivel de detalle, la opción es el método M2, ya que permite obtener hasta cinco estratos con una clasificación 100 % correcta.

Palabras clave: altura total, estratos verticales, estructura vertical, métodos de estratificación.

INTRODUCTION

Structural studies are important indicators of the sustainability of forest activities (Souza *et al*. 2003) since they generate information about the dominance that certain species exert over others. This, in terms of competition for light, contributes to identifying the ecological behavior and habits of these species in the different height strata, thus allowing understanding the strategies of regeneration, growth and survival (Curto *et al*. 2013). This information is essential, among other things, for the definition of conservation policies, for degraded area recovery programs

(Brito *et al*. 2007) and, above all, for the definition of silvicultural treatments and the assessment of impacts from logging activities (Calegário *et al*. 1994), thus encouraging more reliable forestry planning.

Although there is awareness of the importance of vertical structures for decision making, most studies that address the phytosociological characterization of forests in the Amazon only use tables of importance value that characterize horizontal structures and exclude vertical ones (Curto *et al*. 2013). The main reasons for its exclusion are the difficulty in analyzing them (Curto *et al*. 2013) and, mainly, the determination of the lower and upper limits of the strata, which are most often controversial and imperceptible (Durigan *et al*. 2000), with young trees of the upper stratum growing in the lower and mean strata. It is also worth noting that these limits are the basis for calculating the absolute and relative sociological positions and the extended importance values of the species, which characterize the vertical structures (Freitas y Magalhães 2012).

Several methods are used to define the boundaries of strata in unequal forests (Curto *et al*. 2013). The one described by Souza (1990) is one of the most used in the Amazon. This method is based on the use of the arithmetic mean and standard deviation of total heights (Ht), so that the forest is divided into three strata: lower, mean and upper. The lower stratum comprises all trees with Ht lower than the mean of the Ht minus one unit of the standard deviation of the Ht, whereas the upper stratum includes the trees with height higher than the average of the Ht plus a unit standard deviation of the Ht. The mean stratum, in this case, comprises all trees between the lower and upper strata (Souza 1990).

These strata are conceptually and mathematically similar to the three area proportions under a standard normal curve, considering a standard deviation of the mean. Therefore, the percentage of values between plus and minus one standard deviation of the mean will be 68.2 %, while below and above a standard deviation of the mean will be 15.9 %, which will correspond to the middle, lower and upper strata of Souza (1990), respectively. Accordingly, if the Ht data obtained in forest inventories do not follow a standard normal curve, theoretically, Souza's method (1990) will be estimating the boundaries of the strata incorrectly and, consequently, the vertical structures of the forests will affect the decisions to be taken in the management or conservation activities.

The solution to this type of problem is the adoption of alternative methods, such as that described by Souza *et al*. (2003), which determines the strata by means of cluster and discriminant analyses. The objective of the cluster analysis is the identification of homogeneous and distinct groups called strata, which are formed by classes of Ht with previously determined amplitude; while the discriminant confirms the distinction and classification of the groups obtained in the cluster analysis (Souza *et al*. 2003, Souza y Souza 2004). The method of Souza *et al*. (2003) has shown characteristics that may be better than others of vertical stratification of unequal forests, although few studies in the Amazon use it due to the "popularity and practicality" of Souza's method (1990), which in most cases is applied without evaluating whether Ht data follow a standard normal curve.

Another acceptable solution is the reconciliation of Ht of trees with one or more measurement variables more accurate than height, for example, the diameter measured at 1.30 m from the soil (DBH), since the estimates of Ht are routinely obtained through visual estimates, which makes it more difficult to correctly identify the boundaries of strata. In addition, even if the Ht were obtained by means of equipment (*e.g.* hypsometers), these presuppose that the visualization is performed from the same point, from the base to the top of the tree, which is impracticable among Amazonian physiognomies (Durigan *et al*. 2000, Curto *et al*. 2013). Therefore, it also decreases the precision of the measurements and the definition of the strata. The height of Lorey (HL) would be an adequate option for this situation, since the arithmetic mean of Ht is weighted by the sum of the sectional areas, obtained from the DBH minimizing the influence of tall and thin trees as well as of low and thick trees in the calculation of mean height (Lorey 1878).

The hypotheses that guided this study were: H_0 = Ht data that follow normal curves can be stratified according to Souza (1990); H_1 = Ht data that do not follow normal curves can not be stratified according to Souza (1990); and HL and the method of Souza *et al*. (2003) demonstrate a more coherent stratification when the H_0 hypothesis is rejected. Thus, the objective of this study is to evaluate the use of the Souza's method (1990) to obtain the boundaries of the vertical strata of a flooded forest in the Amazon, as well as to evaluate the use of Lorey height (Lorey 1878) and the method of Souza *et al*. (2003) as alternatives to cases where the Souza's method (1990) does not apply.

METHODS

Study area. The study was carried out on the Ilha da Paz Amazônica, in the areas of Tapajós National Forest. It is a section of periodically flooded forest with 3.08 ha, belonging to the community Jamaraquá, located at the geographic coordinates 2°49'07.24'' S and 53°02'13.52'' W, on the right bank of Tapajós River. The climate of the region, according to the classification of Köppen, is Ami, that is, humid tropical with annual thermal variation of less than 5 ºC, average annual temperature of 25.5 °C, average relative humidity of 88 % and average annual rainfall of 1,820 mm (Alvares *et al*. 2013). The forest typology is classified as Alluvial Ombrophylous Forest, with a period of flooding from December to June, while the ebbing period occurs between July and November (Santos *et al*. 2017).

Data collection. Data collection was performed by dividing the area into 308 contiguous sample units of 10 x 10 m

(100 m²), covering the largest possible floodable area. In each sample unit, all trees with diameters of 1.30 m of soil height (DBH) equal to or higher than 10 cm were measured, identified and referenced in Cartesian coordinates (X, Y). Tree individuals that met the inclusion criteria and presented bifurcations below 1.30 m were evaluated as a single individual. In these cases, after registration of the diameters of each branch, the quadratic diameter formula (1) was used to determine the general diameter of the individual.

$$d = \sqrt{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2} \quad [1]$$

where: d = quadratic diameter (cm) and d_i = diameter of each branch.

Tree diameters were taken with the aid of a tape measure and the Ht were estimated visually, based on a metric rod. The bifurcated trees had only a measured height, which was that of the stem that presented higher Ht. Preliminary identification of the botanical material was done in the field at the species level and was later conferred, supplemented and corrected by specialists from the taxonomy and herbaria laboratory of the Federal University of the West of Pará. Classification of species followed the proposed system by Angiosperm Phylogeny Group III (Angiosperm Phylogeny Group 2009).

Data analyses. The total Ht were stratified by three methods. The first method (M_1), proposed by Souza (1990), is based on the use of arithmetic mean and standard deviation of Ht. The limits of the lower, mean and upper strata obtained by this method were obtained by expressions (2), (3) and (4) respectively (Souza 1990).

$$\text{Lower stratum: } Ht < (HT_m - 1s) \quad [2]$$

$$\text{Middle stratum: } (HT_m - 1s) \leq Ht \leq (Ht_m + 1s) \quad [3]$$

$$\text{Upper stratum: } Ht > (Ht_m + 1s) \quad [4]$$

where: Ht = total height of the trees sampled; Ht_m = arithmetic mean of the total Ht of the trees sampled; and s = standard deviation of the total Ht of the trees sampled.

The M_1 method evaluated if the Ht data followed a standard normal curve by adjusting a Normal Probability Density Function (PDF). If it does, it can be stated that the M_1 method correctly classified the trees in the three strata of Ht, since it describes the same proportion of values below a normal curve with more or less one standard deviation of the mean. If not, the method was inefficient and alternative methods are recommended. The PDF parameters were estimated by the maximum likelihood method, and the quality of the fit was evaluated using the Kolmogorov-Smirnov adhesion test, at 95 % probability.

The second method (M_2) is based on the use of the cluster analysis (Souza *et al*. 2003). In this method, trees were initially organized in ascending order of Ht, to later be grouped into classes with a width of 1.0 m. Afterwards, an X data matrix of Ht was elaborated, where each variable x_{ij} represented the height of the i-th tree classified in the j-th height class (Souza *et al*. 2003). The matrix X was the input for the cluster analysis. The clustering criteria used to obtain the groups composed of classes of Ht, called Ht strata, were the euclidean distance (5, 6) and the Ward method (Souza *et al*. 2003). The Ht strata were determined by plotting a cut line on the dendrogram resulting from the cluster analysis. The line was drawn so as to form three Ht strata, therefore comparisons between methods would be possible since the other methods necessarily describe three strata.

$$d_{ij} = \sqrt{\sum_{h=1}^{p} \left(x_{hi} - x_{hj}\right)}, \; h = 1, 2, 3, \cdots, P \quad [5]$$

$$d_{ij}^2 = \left(x_i - x_j\right)^2 \quad [6]$$

where: d_{ij} = estimated Euclidean distance between classes i and j; x_{hi}= diameter of the ith class in the ith class of diameter; x_{hj} = diameter of the ith class in the jth class of diameter; and d_{ij}^2 = distance between the means of groups I and J.

The third method (M_3) is an adaptation of the M_1 method, so that the arithmetic mean of the total Ht is replaced by the mean height of Lorey (H_L) (Lorey 1878), obtained by means of the expression (7). Therefore, lower, mean and upper strata were obtained according to expressions (8), (9) and (10), respectively.

$$H_L = \frac{\sum_{i=0}^{n} Ht_i \cdot g_i}{\sum_{i=0}^{n} g_i}, \text{ where } g_i = \frac{\pi \cdot DBH^2}{40{,}000} \quad [7]$$

$$\text{Lower stratum: } Ht < (H_L - 1s) \quad [8]$$

$$\text{Middle stratum: } (H_L - 1s) \leq Ht \leq (H_L + 1s) \quad [9]$$

$$\text{Upper stratum: } Ht < (H_L + 1s) \quad [10]$$

where: H_L = mean Lorey height of the trees sampled (m); g_i = sectional area of the ith tree (m²); DBH = diameter at 1.30 m from the soil of the i-th tree (cm); and Ht and s = defined above.

The three methods were evaluated through Fisher's discriminant analysis, which aimed at evaluating the number of correct classification of methods M_1, M_2 and M_3, and comparative analyses of vertical structures, which were obtained according to Freitas and Magalhães (2012), and by means of vertical profiles. In relation to vertical structures, only the parameters absolute sociological position (PSA)

and expanded importance value (VIA) were compared, since the others, frequency (FA), density (DA) and absolute dominance (DoA), are the same in all the methods. The parameters FA, DA and DoA make up the horizontal structure and were analyzed for complementing the vertical analysis within the phytosociological study of the forest. It was also evaluated, for each species and for the community, if the number of trees in the strata was different among M_1, M_2 and M_3. The test applied, in this case, was the chi-square for contingency tables, at 95 % probability (Zar 1996).

Throughout the results and discussions, the words lower, mean and upper will be followed by the subscripts $_{M1}$, $_{M2}$ and $_{M3}$, which respectively signify methods M_1, M_2 and M_3. Therefore, the words $mean_{M1}$, $mean_{M2}$ and $mean_{M3}$ imply that the mean strata were obtained using M_1, M_2 and M_3, respectively. The data were processed in software R version 3.3.2 (R Core Team 2018), using the scatterplot3d package (Ligges and Mächler 2003), for the construction of vertical profiles, and vegan (Oksanen *et al*. 2018), for cluster and discriminant analyses. Adjustment of Normal PDF and chi-square test were performed using the software Easy Fit and Microsoft Excel 2016, respectively.

RESULTS

The values of the arithmetic mean and the standard deviation of Ht were 10.1 and 4.05 m, respectively. The M_1 showed that the $lower_{M1}$ stratum was constituted by trees of 4.0 to 5.9 m height and added up to 16.0 % of trees. Regarding $mean_{M1}$, it covered all trees with height of 6.0 to 13.9 m, accounting for 71.3 % of the inventoried trees (table 1). The $upper_{M1}$, in turn, included trees with height of 14.0 to 25.1 m, adding up to 12.7 % of the trees. It was also observed that although the strata of the M_1 method should represent the three area proportions under a standard normal curve, plus or minus one standard deviation of the mean, there is a surplus of 0.15 and 3.03 % of trees in the $lower_{M1}$ and $mean_{M1}$, respectively, and a deficit of 3.08 % in the $upper_{M1}$. The results of the discriminant analysis showed significant differences (F = 28.387), with Wilk's Lambda values close to zero and probabilities of 0.095, 0.381 and 0.524 for the $lower_{M1}$, $mean_{M1}$ and $upper_{M1}$ strata respectively. The confusion matrix showed that 95.2 % of the Ht classes were correctly identified in the vertical strata of the M_1 method (table 1).

The histogram with the distribution of Ht showed that the area has a high abundance of trees in the initial classes, with a reduction in the larger classes (figure 1A). However, from a statistical point of view, this behavior was not described by a Normal Probability Density Function, since the Ht distribution deviated significantly from a normal distribution, as verified by the Kolmogorov-Smirnov test, which showed that the value in D_{calc} (0.170) was greater than D_{tab} (0.042), to 95% probability. In addition, trends of under and overestimation of the number of trees in different height clases were observed.

The M_2 method considering the dendrogram with a cut line at a euclidean distance equal to 100, registered three homogeneous and distinct groups called strata $lower_{M2}$, $mean_{M2}$ and $upper_{M2}$ (figure 1B). The $lower_{M2}$ covered the first eight height classes, with a range of 4.0 to 10.9 m, while the $mean_{M2}$ included classes 9 to 16, ranging from

Table 1. Amplitude of the strata and matrix of confusion of the methods M_1, M_2, and M_3. N = number of trees per Ht stratum; *P* = priori probabilities.

Amplitud de los estratos y matriz de confusión de los métodos M_1, M_2 y M_3. N = número de árboles por estrato Ht; *P* = probabilidad a priori.

Method	Stratum	Amplitude (m)	N	*P*	Classification			Sum	Hit (%)
					$Lower_{M1}$	$Average_{M1}$	$Upper_{M1}$		
M_1	$Lower_{M1}$	4.0 - 5.9	163	0.095	1	0	0	1	100
	$Average_{M1}$	6.0 - 13.9	729	0.381	1	8	0	9	88.9
	$Upper_{M1}$	14.0 - 25.1	130	0.524	0	0	11	11	100
Sum		-	1022		2	8	11	21	95.2
M_2	$Lower_{M2}$	4.0 - 10.9	703	0.333	7	0	0	7	100
	$Average_{M2}$	11.0 - 19.9	274	0.429	0	9	0	9	100
	$Upper_{M2}$	20.0 - 25.1	45	0.238	0	0	5	5	100
Sum		-	1022		7	9	5	21	100
M_3	$Lower_{M3}$	4.0 - 9.9	555	0.286	6	0	0	6	100
	$Average_{M3}$	10.0 - 17.9	393	0.381	0	8	0	8	100
	$Upper_{M3}$	18.0 - 25.1	74	0.333	0	0	7	7	100
Sum		-	1022	-	6	8	7	21	100

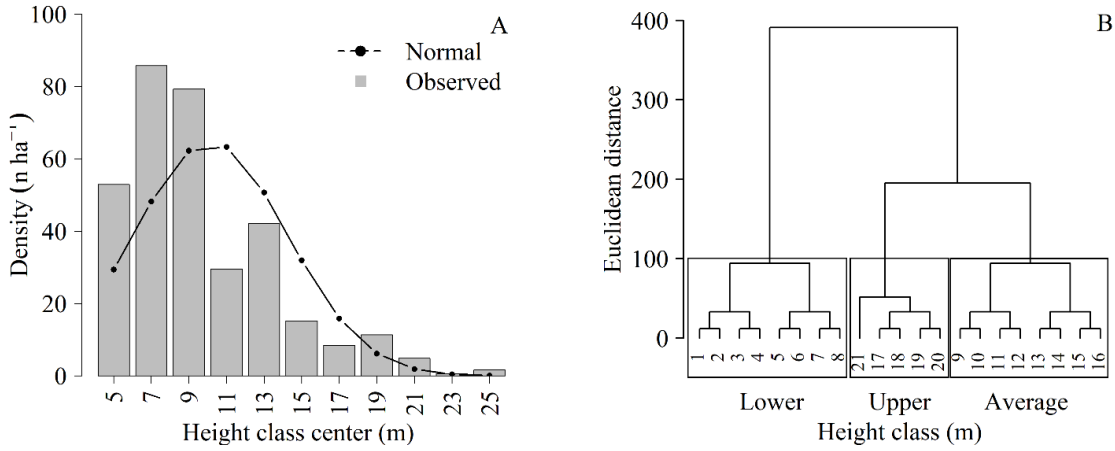

Figure 1. Distribution curve of the tree density obtained by the Normal PDF of the M1 method (A) and dendrogram of the cluster analysis of the M_2 method (B).

Curva de distribución de la densidad arbórea obtenida por el FDP normal del método M1 (A) y dendrograma del análisis de conglomerados del método M_2 (B).

11.0 to 19.9 m. The upper$_{M2}$, in turn, encompassed classes 17 through 21, resulting in an amplitude of 20.0 to 25.1 m. The lower$_{M2}$, mean$_{M2}$ and upper$_{M2}$ strata, 68.8 %, 26.8 % and 4.4 % of the trees. The discriminant analysis showed significant differences (F = 64.723), with Wilk's Lambda values close to zero and probabilities of 0.333, 0.429 and 0,238 for lower$_{M2}$, mean$_{M2}$ and upper$_{M2}$ strata, respectively. The confusion matrix showed that 100 % of the Ht classes were correctly classified in the strata of the method M_2 (table 1).

The M_3 method demonstrated that the mean height of Lorey (H_L) and the standard deviation of Ht were 14.0 and 4.05 m, respectively. Therefore, the lower$_{M3}$ stratum was composed of trees with 4.0 to 9.9 m in height and added up to 54.3 % of the trees, while the mean$_{M3}$ covered all tree individuals with a height of 10.0 to 17.9 m, making up 38.5 % of the trees sampled. The upper$_{M3}$, in turn, included trees with a height of 18.0 to 25.1 m, accounting for 7.2 % of tree individuals. The discriminant analysis showed significant differences (F = 62.542), with Wilk's Lambda values close to zero and probabilities of 0.286, 0.381 and 0.333 for lower$_{M3}$, mean$_{M3}$ and upper$_{M3}$ strata, respectively. The classification procedure showed that 100.0 % of the Ht classes were correctly identified in the Ht strata (table 1). The vertical profiles clearly showed a greater similarity between the strata of Ht obtained by the methods M_2 and M_3, with differences between the lower and upper limits of up to 2.0 m, while in the method M_1 these differences ranged from 4.0 to 6.0 m (figure 2).

The vertical structures, regardless of the stratification method, showed the same frequencies (FA), densities (DA) and absolute dominances (DoA) for all species, changing only their density in strata, absolute sociological position (PSA) and importance value (VIA) (table 2). The ten species of higher densities (DA ≥ 7.79 trees ha^{-1}) in the community, in descending order, were *Campsiandra laurifolia*, *Glycoxylon pedicellatum*, *Hevea brasiliensis*, *Tetragastris altissima*, *Mabea caudata*, *Vantanea parviflora*, *Swartzia* sp., *Inga capitata*, *Inga auristellae* and *Couepia hoffmaniana*, which together account for 70.8 % of all the DA. The ten most dominant species (DoA ≥ 0.389 m^2 ha^{-1}), in descending order, were *Hevea brasiliensis*, *Campsiandra laurifolia*, *Glycoxylon pedicellatum*, *Inga capitata*, *Tetragastris altissima*, *Vataireopsis speciosa*, *Vantanea parviflora*, *Inga auristellae*, *Nectandra* sp. and *Sideroxylon obtusifolium*, which together account for 68.5 % of all DoA.

The ten species of higher density (DA ≥ 4.22 trees ha^{-1}) in lower$_{M2}$ stratum, in descending order, were *Campsiandra laurifolia*, *Mabea caudata*, *Glycoxylon pedicellatum*, *Vantanea parviflora*, *Tetragastris altissima*, *Swartzia* sp., *Couepia hoffmaniana*, *Pera glabrata*, *Guarea guidonia* and *Inga capitata*. The same species were the densest (DA ≥ 2.92 trees ha^{-1}) in lower$_{M3}$ stratum, but not in exactly the same order. The first five, in this case, in descending order, were *Campsiandra laurifolia*, *Mabea caudata*, *Vantanea parviflora*, *Glycoxylon pedicellatum* and *Tetragastris altissima*. The lower$_{M1}$ stratum. in turn, exhibited as more dense (DA ≥ 0.97 trees ha^{-1}), in descending order, the species *Campsiandra laurifolia*, *Glycoxylon pedicellatum*, *Tetragastris altissima*, *Hevea brasiliensis*, *Vantanea parviflora*, *Mabea caudata*, *Swartzia* sp., *Inga capitata*, *Inga auristellae* and *Couepia hoffmaniana*.

The ten species of higher density (DA ≥ 1.95 trees ha^{-1}) in the mean$_{M2}$ stratum, in descending order, were *Hevea brasiliensis*, *Glycoxylon pedicellatum*, *Tetragastris altissima*, *Campsiandra laurifolia*, *Coccoloba latifolia*, *Inga auristellae*, *Inga capitata*, *Vantanea parviflora*, *Myrciaria floribunda* and *Brosimum guianense*. The same species were the ten most dense (DA ≥ 3.89 trees ha^{-1}) in the mean$_{M3}$ strata, but not exactly in the same sequence.

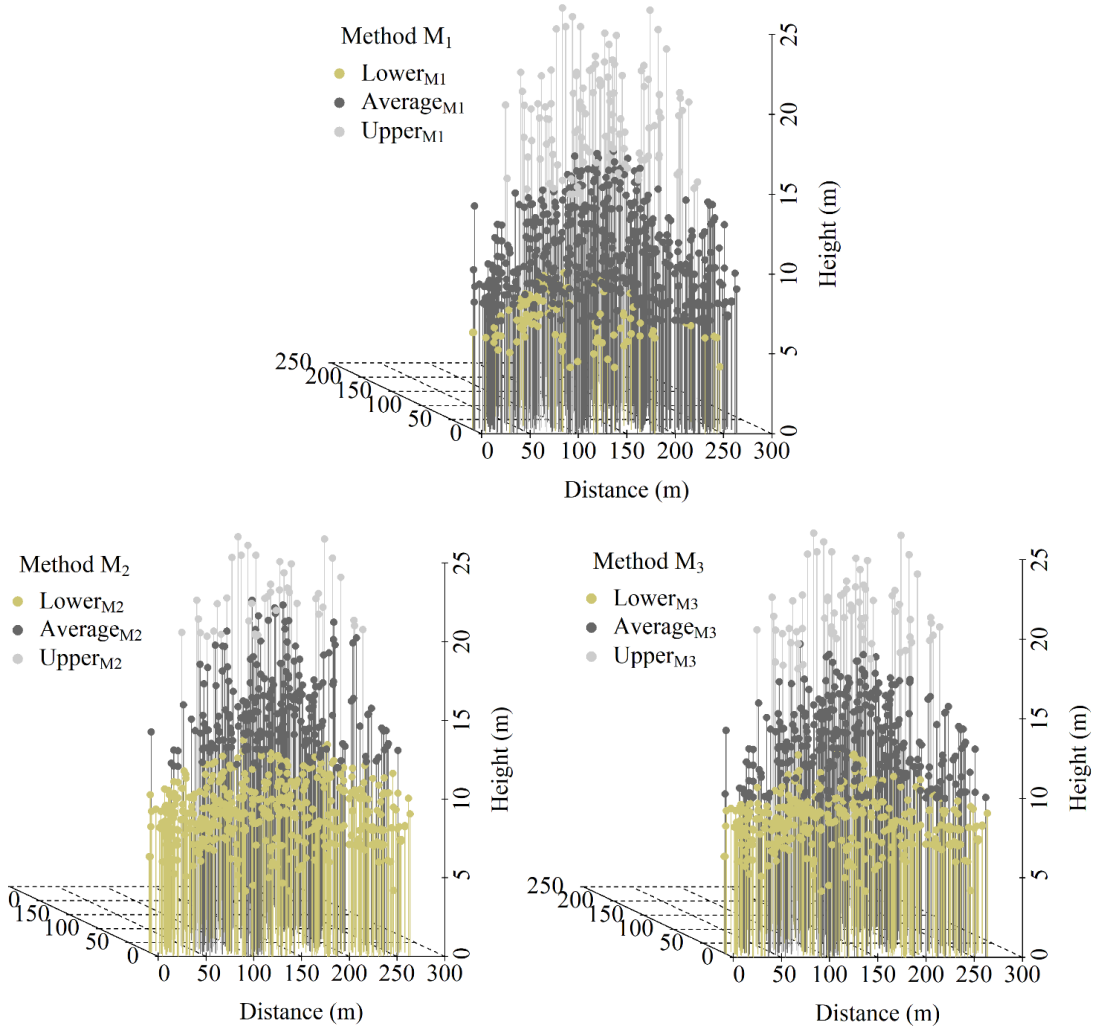

Figure 2. Illustration of the strata of Ht obtained by the methods M1, M2 and M3.

Ilustración de los estratos de Ht obtenidos por los métodos M1, M2 y M3.

Campsiandra laurifolia was the first in the DA ranking, followed by the species *Glycoxylon pedicellatum*, *Tetragastris altissima*, *Hevea brasiliensis* and *Inga auristellae*. The mean$_{M1}$ stratum, in turn, presented as more dense (DA ≥ 5.84 trees ha^{-1}), in descending order, the species *Campsiandra laurifolia*, *Glycoxylon pedicellatum*, *Tetragastris altissima*, *Hevea brasiliensis*, *Vantanea parviflora*, *Mabea caudata*, *Swartzia* sp., *Inga capitata*, *Inga auristellae* and *Couepia hoffmaniana* (table 2).

The ten species of higher density (DA ≥ 0.325 trees ha^{-1}) in the upper$_{M2}$ stratum, in descending order, were *Hevea brasiliensis*, *Vataireopsis speciosa*, *Nectandra* sp., *Tapirira guianensis*, *Dialium guianense*, *Glycoxylon pedicellatum*, *Sideroxylon obtusifolium*, *Vantanea parviflora*, *Dipteryx polyphylla* and *Licania kunthiana*. The same species were among the densest (DA ≥ 3.89 trees ha^{-1}) in the upper$_{M3}$ strata, except the tenth, which was replaced by the species Crudia pubescens. The first five, in this case, in descending order, were *Hevea brasiliensis*, *Dialium guianense*, *Glycoxylon pedicellatum*, *Vataireopsis speciosa* and *Tapirira guianensis*. The upper stratum M_1, on the other hand, presented density (DA ≥ 0.65 trees ha^{-1}), in descending order, the species *Hevea brasiliensis*, *Coccoloba latifolia*, *Glycoxylon pedicellatum*, *Inga auristellae*, *Nectandra* sp., *Tapirira guianensis*, *Dialium guianense*, *Sideroxylon obtusifolium*, *Vataireopsis speciosa* and *Vantanea parviflora*.

The species of higher PSAs in the structure, calculated by the M_2 method, in descending order, were *Campsiandra laurifolia*, *Glycoxylon pedicellatum*, *Mabea caudata*, *Tetragastris altissima*, *Vantanea parviflora*, *Hevea brasiliensis*, *Swartzia* sp., *Couepia hoffmaniana*, *Pera glabrata* and *Inga capitata*. The first seven species of this method, in descending order, were also the same in the structure of the method M_3, followed by *Inga capitata*, *Couepia hoffmaniana* and *Inga auristellae*. The highest PSAs in the structure of the method M_1, in descending order, were *Camp-*

Table 2. Vertical structures of the 20 populations with the highest VIA, obtained through the M_1, M_2 and M_3 methods. EI = lower stratum; MS = average stratum; MS = upper stratum; PSA = absolute sociological position; and VIA = expanded importance value. The values in parentheses indicate the importance position of the species in the forest structure of the area.

Estructuras verticales de las 20 poblaciones con mayor VIA, obtenidas por los métodos M_1, M_2 y M_3. IE = estrato inferior; MS = estrato medio; MS = estrato superior; PSA = posición sociológica absoluta; VIA = valor de magnitud. Los valores entre paréntesis indican la importancia de la especie en la estructura forestal del área.

Scientific names	Method M_1					Method M_2					Method 3				
	EI_{M1}	EM_{M1}	ES_{M1}	PSA	VIA	EI_{M2}	EM_{M2}	ES_{M2}	PSA	VIA	EI_{M3}	EM_{M3}	ES_{M3}	PSA	VIA
Campsiandra laurifolia Benth.	22.4	69.48	0.65	53.22	19.475(1)	86.36	5.84	0.33	60.99	20.592(1)	71.10	20.78	0.65	4.,65	20.036(1)
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	-	11.36	12.01	9.63	10.881(2)	3.90	14.29	5.20	6.74	10.490(2)	2.27	11.36	9.74	6.31	10.623(2)
Glycoxylon pedicellatum Ducke	1.95	20.78	2.92	15.50	7.193(3)	13.96	11.04	0.65	12.59	6.805(3)	9.74	14.29	1.62	10.90	6.904(3)
Tetragastris altissima (Aubl.) Swart	1.30	18.83	0.33	13.68	6.985(4)	12.99	7.47	-	10.94	6.618(4)	8.44	12.01	-	9.20	6.660(4)
Vantanea parviflora Lam.	5.20	11.36	1.30	9.0	5.241(5)	12.99	4.22	0.65	10.09	5.386(5)	12.34	4.55	0.97	8.52	5.428(5)
Mabea caudata Pax *et* K.Hoffm.	7.14	10.71	-	8.78	4.342(6)	17.53	0.33	-	12.15	4.813(6)	16.56	1.30	-	9.49	4.736(6)
Inga capitata Desv.	-	9.09	0.65	6.57	3.704(7)	4.22	5.2	0.33	4.31	3.398(7)	3.57	5.84	0.33	4.21	3.513(7)
Swartzia sp.	0.97	9.42	0.33	6.91	3.285(8)	8.44	1.95	0.33	6.34	3.212(8)	5.52	4.87	0.33	4.89	3.162(8)
Inga auristellae Harms	0.33	6.49	2.27	4.97	2.874(9)	3.25	5.84	-	3.80	2.717(9)	0.97	7.79	0.33	3.55	2.790(9)
Myrciaria floribunda (H.West ex Willd.) O.Berg	0.65	5.84	0.97	4.40	2.408(10)	4.22	3.25	-	3.77	2.326(10)	2.92	4.55	-	3.34	2.367(10)
Nectandra sp.	0.65	2.60	1.95	2.20	2.199(11)	2.60	1.62	0.97	2.27	2.209(11)	1.95	2.27	0.97	2.00	2.234(11)
Vataireopsis speciosa Ducke	-	2.27	1.30	1.79	2.082(12)	1.30	0.97	1.3	1.21	2.004(12)	0.65	1.62	1.30	1.07	2.017(12)
Couepia hoffmaniana Kl.	1.30	6.49	-	4.84	1.877(13)	7.14	0.65	-	5.09	1.915(13)	6.17	1.62	-	3.97	1.883(13)
Coccoloba latifolia Lam.	-	4.22	3.25	3.42	1.731(14)	1.62	5.84	-	2.68	1.632(16)	1.62	5.84	-	3.13	1.788(14)
Pera glabrata (Schott) Poepp. ex Baill.	0.65	5.84	-	4.27	1.659(15)	6.49	-	-	4.47	1.689(14)	6.49	-	-	3.53	1.667(15)
Guarea guidonia (L.) Sleumer	2.27	2.60	-	2.22	1.477(18)	4.87	-	-	3.35	1.635(15)	4.55	0.33	-	2.59	1.610(16)
Brosimum guianense (Aubl.) Huber	0.33	3.90	0.65	2.91	1.658(16)	2.60	2.27	-	2.40	1.589(17)	0.97	3.90	-	2.03	1.600(17)
Crudia pubescens Spruce ex Benth.	0.33	2.92	0.97	2.26	1.575(17)	2.92	0.97	0.33	2.29	1.581(18)	1.62	1.95	0.65	1.68	1.548(18)
Licania kunthiana Hook.f.	-	2.27	0.97	1.75	1.360(19)	1.30	1.62	0.33	1.34	1.306(19)	0.97	1.95	0.33	1.30	1.340(19)
Sideroxylon obtusifolium (Roem. *et* Schult.) T.D.Penn.	-	0.65	1.62	0.67	1.097(20)		1.62	0.65	0.46	1.070(20)		1.30	0.97	0.57	1.102(20)
Subtotal	45.46	207.14	32.14	159.1	83.1	198.7	75	11.04	157.27	83	158.44	108.12	18.18	128.93	83
Others	7.47	29.55	10.07	23.55	16.9	29.55	13.96	3.57	24.22	17	21.75	19.49	5.85	19.73	17
Total	52.92	236.69	42.21	182.64	100	228.25	88.96	14.61	181.5	100	180.19	127.6	24.03	148.66	100

siandra laurifolia, *Glycoxylon pedicellatum*, *Tetragastris altissima*, *Mabea caudata*, *Hevea brasiliensis*, *Vantanea parviflora*, *Mabea caudata*, *Swartzia* sp., *Inga capitata*, *Inga auristellae* and *Couepia hoffmaniana*.

The 13 species with the highest VIA values, in descending order, were: *Campsiandra laurifolia*, *Hevea brasiliensis*, *Glycoxylon pedicellatum*, *Tetragastris altissima*, *Vantanea parviflora*, *Mabea caudata*, *Inga capitata*, *Swartzia* sp., *Inga auristellae*, *Myrciaria floribunda*, *Nectandra* sp., *Vataireopsis speciosa* and *Couepia hoffmaniana*, which together added 72.5, 73.4 and 72.5 % of the entire VIA of the vertical structures obtained by methods of M_1 and M_3, respectively, maintained the same positions recorded in the method M_2, while the others changed, on average, two positions to more or less (table 2).

The chi-square test for contingency tables showed that the number of community trees in the lower, mean and upper strata is dependent on the selected stratification method, since the values of the χ^2 calculated were higher than the χ^2 95 % probability (table 3). The same test also showed that for 46 species no differences were recorded between the number of trees in the three strata of Ht obtained by methods M_1, M_2 and M_3. The other species, showed in table 3, presented significant differences in at least one of the Ht strata. The species *Campsiandra laurifolia*, for example, showed differences in the number of trees for the lower and mean strata obtained by the three methods, indicating that the number of trees was dependent on the stratification method, whereas among the upper stratum no dependence was recorded. The same occurred for the species *Glycoxylon pedicellatum*, *Tetragastris altissima*, *Vantanea parviflora* and *Swartzia* sp., all located among the nine most important species of the Ilha da Paz Amazônica.

DISCUSSION

The vertical strata were better estimated in methods M_2 and M_3. The certainty of their higher efficiencies was corroborated by the discriminant analysis, which demonstrated that 100 % of the Ht classes were correctly classified in the lower, mean and upper strata, while in the method M_1 the percentage was 95.2 %. The same finding was observed by Curto *et al*. (2013) that, comparing different methods in a Semideciduous Seasonal Forest in the municipality of Guaçuí, Espírito Santo, concluded that the method M_2 was one of the most efficient, while the method M_1 did not allow a detailed analysis on the behavior of the species in the mean stratum, due to the strong tendencies of concentrating more trees in the said stratum, thus hindering interpretations.

The high number of trees *Campsiandra laurifolia* and *Mabea caudata* in the $lower_{M3}$ stratum also corroborates the efficiency of methods M_2 and M_3, because they are medium-sized species that are between 7 and 12 m high (Silva *et al*. 1988, Dezzeo *et al*. 2003, Silva 2013) and rarely reach Ht higher than 15 m, thus being within the limits calculated for the $lower_{M2}$ (4.0 – 10.9 m) and $mean_{M3}$ (4.0 - 9.9 m) strata. In a contact area of the Jaci-Paraná and Madeira Rivers in the state of Rondônia, Reis (2010) observed that trees of *Campsiandra laurifolia* and *Mabea caudata* had, on average, 12.0 and 11.0 m, respectively. It is also important to remember that these species are characteristic of the sub-forest (Vieira *et al*. 2017). This corroborates the observations made, which recorded the presence of only a few shrubs and vines below the canopy of these species. The higher degree of similarity between M_2 and M_3 is also corroborated from the vertical profiles and distribution trends of the number of trees in the strata. The method M_1, for example, grouped the community and species trees in the mean stratum, while in methods M_2 and M_3 the grouping occurred in the lower stratum, followed by the mean and upper strata, respectively.

The same species, considering the method M_1, were characteristic of the $mean_{M1}$ stratum; however, this behavior seems illogical, based on the results and observations mentioned above. Therefore, considering the boundaries of the $lower_{M1}$ (4 - 5.9 m) stratum, the mean Ht of the species *Campsiandra laurifolia* (8.0 ± 3.4 m) and *Mabea caudata* (7.0 ± 2.2 m) and the Ht obtained in other surveys (Dezzeo *et al*. 2003, Reis 2010, Rodrigues *et al*. 2012), one can deduce that the upper limit of the $lower_{M1}$ stratum was not correctly estimated, as observed through the discriminant analysis, which revealed that one of the height classes was wrongly allocated in the $mean_{M1}$ stratum, resulting in a hit rate of 88.9 %. The probable reason for this situation was the significant deviation of Ht from a standard normal distribution. It is also important to remember that, for the evaluated methods, the hit rate should not necessarily be 100 %, due to difficulties in obtaining the total tree Ht in natural forests of the Amazon, which, consequently, adds errors to the calculation of the limits of the Ht strata. Curto *et al*. (2013) and Silva *et al*. (2019) show that the height estimate performed visually by an inexperienced and experienced person, respectively, tends to underestimate the height of the trees. It is not affirmed that the method M_1 is the same as the others, because this depends on other analyses; nonetheless, that 88.9 % fit for the stratum $mean_{M1}$ and 95.2 % for the method M_1 may not be a bad result.

The method M_1 assumes that Ht should follow a standard normal distribution, considering a standard deviation of mean, however the effects of rejection of this assumption did not influence the order of ecological importance of the main species, since, independently of the applied method, the first thirteen species, in descending order, were the same, and these represented more than 70 % of the VIAs. The changes recorded from the 13th species were not large, around two positions for more or less, because the VIA is more influenced by the horizontal parameters, *i.e.*, frequency, density and absolute dominance, which, consequently, end up attributing lower weight to the vertical parameters, that is, absolute sociological posi-

Table 3. Contingency table with observed and expected values (in brackets) of trees for the community and species in the Ht strata obtained by the M_1, M_2 and M_3 methods, Ilha da Paz Amazônica, Pará state, Brazil. * = $P < 0.05$; ns = not significant, 95 % probability.

Tabla de contingencia con valores observados y esperados (entre paréntesis) de árboles para la comunidad y las especies en los estratos Ht obtenidos por los métodos M_1, M_2 y M_3, Ilha da Paz Amazônica, estado de Pará, Brasil. * = $P < 0,05$; ns = no significativo, 95 % de probabilidad.

Species	Lower stratum				Average stratum				Upper stratum			
	M_1	M_2	M_3	χ^2_{calc}	M_1	M_2	M_3	χ^2_{calc}	M_1	M_2	M_3	χ^2_{calc}
Community	163 (474)	703 (474)	555 (474)	327.45*	729 (465)	274 (465)	393 (465)	238.18*	130 (83)	45 (83)	74 (83)	43.86*
Campsiandra laurifolia Benth.	69 (185)	266 (185)	219 (185)	113.4*	214 (99)	18 (99)	64 (99)	210.62*	2 (2)	1 (2)	2 (2)	0.05^{ns}
Mabea caudata Pax *et* K.Hoffm.	22 (42)	54 (42)	51 (42)	13.81*	33 (13)	1 (13)	4 (13)	46.16*	- (0)	- (0)	- (0)	-
Glycoxylon pedicellatum Ducke	6 (26)	43 (26)	30 (26)	25.24*	64 (47)	34 (47)	44 (47)	9.17*	9 (5)	2 (5)	5 (5)	3.39^{ns}
Tetragastris altissima (Aubl.) Swart	4 (23)	40 (23)	26 (23)	26.60*	58 (39)	23 (39)	37 (39)	14.85*	1 (0)	- (0)	- (0)	0.25^{ns}
Vantanea parviflora Lam.	16 (31)	40 (31)	38 (31)	10.36*	35 (21)	13 (21)	14 (21)	13.58*	4 (3)	2 (3)	3 (3)	0.25^{ns}
Swartzia sp.	3 (15)	26 (15)	17 (15)	15.96*	29 (17)	6 (17)	15 (17)	14.69*	1 (1)	1 (1)	1 (1)	0.75^{ns}
Couepia hoffmaniana Kl.	4 (15)	22 (15)	19 (15)	10.98*	20 (9)	2 (9)	5 (9)	18.31*	- (0)	- (0)	- (0)	-
Pera glabrata (Schott) Poepp. ex Baill.	2 (14)	20 (14)	20 (14)	13.77*	18 (6)	- (6)	- (6)	32.13*	- (0)	- (0)	- (0)	-
Guarea guidonia (L.) Sleumer	7 (12)	15 (12)	14 (12)	2.40^{ns}	8 (3)	- (3)	1 (3)	9.58*	- (0)	- (0)	- (0)	-
Inga capitata Desv.	- (8)	13 (8)	11 (8)	10.34*	28 (21)	16 (21)	18 (21)	3.33^{ns}	2 (1)	1 (1)	1 (1)	0.06^{ns}
Myrciaria floribunda (H.West ex Willd.) O.Berg	2 (8)	13 (8)	9 (8)	6.34*	18 (14)	10 (14)	14 (14)	1.77^{ns}	3 (1)	- (1)	- (1)	2.75*
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	- (6)	12 (6)	7 (6)	9.59*	35 (38)	44 (38)	35 (38)	1.13^{ns}	37 (28)	16 (28)	30 (28)	7.45*
Inga auristellae Harms	1 (5)	10 (5)	3 (5)	7.45*	20 (21)	18 (21)	24 (21)	0.62^{ns}	7 (3)	- (3)	1 (3)	7.78*
Crudia pubescens Spruce ex Benth.	1 (5)	9 (5)	5 (5)	4.95*	9 (6)	3 (6)	6 (6)	2.13^{ns}	3 (2)	1 (2)	2 (2)	0.38^{ns}
Duroia fusifera Spruce ex K.Schum	3 (7)	9 (7)	8 (7)	2.11^{ns}	6 (2)	- (2)	1 (2)	6.04*	- (0)	- (0)	- (0)	-
Roupala brasiliensis Klotzsch	3 (7)	9 (7)	8 (7)	2.11^{ns}	6 (2)	- (2)	1 (2)	6.04*	- (0)	- (0)	- (0)	-
Brosimum guianense (Aubl.) Huber	1 (4)	8 (4)	3 (4)	4.69*	12 (10)	7 (10)	12 (10)	1.04^{ns}	2 (1)	- (1)	- (1)	1.13^{ns}
Coccoloba latifolia Lam.	- (3)	5 (3)	5 (3)	3.23^{ns}	13 (16)	18 (16)	18 (16)	0.66^{ns}	10 (3)	- (3)	- (3)	16.23*
Lonchocarpus spruceanus Spruce ex Benth.	- (2)	5 (2)	1 (2)	4.38*	6 (4)	1 (4)	5 (4)	2.19^{ns}	- (0)	- (0)	- (0)	-
Sloanea dentata L.	2 (4)	5 (4)	5 (4)	0.69^{ns}	3 (1)	- (1)	- (1)	2.75*	- (0)	- (0)	- (0)	-
Qualea cassiquiarensis Spruce ex Warm.	- (1)	3 (1)	- (1)	2.75*	3 (3)	1 (3)	4 (3)	0.78^{ns}	1 (0)	- (0)	- (0)	0.25^{ns}

tion (PSA). Such justification helps to understand why the VIA of species among methods M_1, M_2 and M_3 were very similar, although the chi-square test for contingency tables pointed out significant differences between the number of trees in the strata obtained by the three methods for all the most ecologically important species in Ilha da Paz Amazônica. It is also probable that in very heterogeneous forests, that is, in those where there is no dominion of a group of species, the differences in the structures are more significant, changing even the species of superior ecological importance due to the balance among the parameters that constitute the VIA, mainly PSA.

The vertical strata obtained by methods M_2 and M_3 were more similar in all criteria and better than the method M_1, which indicates that the use of Lorey height (HL) is a viable alternative for cases in which the Ht data do not follow a standard normal curve. The method M_1, although it did not meet its basic assumption, showed that its vertical structure was very similar to those obtained by the others, since in practice they are used to describe the species with the highest frequency, density and dominance and with the best sociological positions (Freitas y Magalhães 2012). This, among the methods, did not present much difference, resulting in the same conclusions that can be obtained from the vertical structures of methods M_2 and M_3. For example, if there was a need to select species for recovery of floodplain areas in Tapajós River Basin, the recommended species according to methods M_1, M_2 and M_3 would be *Campsiandra laurifolia*, *Mabea caudata* and *Tetragastris altissima*, as they are dominant, ecologically important and characteristics of wetlands (Ferreira y Prance 1998).

Another conclusion obtained from the three structures, showing their similarities, is that the selection of the species *Hevea brasiliensis* should be cautious, since places with excessive humidity are the least indicated for their planting, since they provide ideal conditions for the incidence of diseases that limit the growth and survival of smaller trees (Vieira *et al*. 2017). The structures of methods M_2 and M_3 demonstrate that *Hevea brasiliensis* is not abundant in $lower_{M2}$ stratum. Regarding $lower_{M1}$ stratum, the method M_1 it is totally absent, showing that some process generated a high mortality rate of smaller trees of this species. Evaluating forest phytosociology in this same area of study, Vieira *et al*. (2017) stated that the low abundance of *Hevea brasiliensis* in the lower stratum is a result of the high flood levels of Tapajós River observed since 2003, while the high abundance in the mean and upper strata occurred due to the low levels recorded between 1970 and 2003, period during which the higher areas would have provided edaphic conditions for the establishment of this species.

Therefore, it is recommended that the method M_3 be used first, since it is more practical and provides the same results as those obtained from the method M_2, which requires a higher level of statistical knowledge. On the other hand, if the objective is more detailed strata, the best option is the method M_2 because it allows obtaining more than three strata. In this study, for example, up to five strata with a 100 % correct classification can be obtained, according to Fisher's discriminant analysis. The method M_1 can be used in vertical structural analyses, nonetheless it is recommended to evaluate its basic assumption, so that a more coherent stratification is achieved. The results of this study also raise questions to be worked on in the future, on the real importance of evaluating the vertical structure of forests, since the horizontal parameters exert a superior influence on the VIA. In this case, would it be better to evaluate only the horizontal structure or propose an expression where all VIA parameters have equal importance?

CONCLUSIONS

The methods that consider the cluster analysis and the mean Lorey height were better than the arithmetic mean and standard deviation of the Ht, allowing a more coherent stratification and discussion about the behavior of the species in the community. The arithmetic mean and standard deviation of the Ht can be used in vertical structural analyses of forests, however, it is recommended to evaluate their basic assumption. The use of Lorey's mean height is operationally feasible for stratification of unequal forests, and can be used in the structural analyses of forests.

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