RELATION OF THE STRUCTURE AND DIVERSITY OF VEGETATION WITH LANDSCAPE METRIC IN THE VANGUARDIA FOREST RESERVE, VILLAVICENCIO, COLOMBIA

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Resumo

Relação da estrutura e diversidade da vegetação com as métricas da paisagem na Reserva Florestal Protetora Vanguardia, Villavicencio, Colômbia. Algumas atividades antrópicas causaram diminuição da cobertura da Reserva Vanguardia e mudanças na diversidade e estrutura da vegetação. O objetivo do estudo foi comparar a diversidade e estrutura da vegetação, relacionando variáveis de habitat com métricas da paisagem. A vegetação foi amostrada em cinco setores; em cada setor foram estabelecidas 3 parcelas de 50 x 2 m, exceto em Ocarros onde foram avaliadas 4 parcelas. Em cada parcela, todas as árvores e arbustos com diâmetro na altura do peito DAP ≥ 1,0 cm foram censurados. Uma ANOVA foi realizada para comparar a estrutura e diversidade entre as parcelas. Um dendrograma de similaridade florística foi desenvolvido usando o índice de Bray-Curtis. As correlações de Pearson foram calculadas entre as variáveis do habitat e as métricas de paisagem usando o PAST. Nenhuma diferença significativa na diversidade e abundância foi encontrada entre as parcelas comparadas. As médias e cobertura do DAP mostraram diferenças estatísticas entre algumas parcelas. A riqueza de árvores, arbustos e abundância total foi positivamente correlacionada com a distância até as rodovias. A diversidade foi negativamente correlacionada com a distância até o fragmento de floresta maduro. As diferenças de cobertura e DAP sugerem que a reserva está enfrentando diferentes graus de perturbação, causando variação nos atributos ecológicos. As correlações positivas entre algumas variáveis de vegetação e métricas da paisagem indicam que as estradas influenciam a estrutura e diversidade da vegetação.

Palavras-chave: correlação, diversidade, floresta de sopé, paisagem, perturbação.

Abstract

Some human activities have caused a decrease in coverage in the Vanguardia Reserve and changes in the diversity and structure of the vegetation. The objective of the study was to compare the diversity and structure of vegetation, relating habitat variables with landscape metrics. Vegetation was sampled in five sectors; in each sector 3 plots of 50 x 2 m were established, except in Ocarros where 4 plots were evaluated. In each plot, all trees and shrubs with diameter at breast high DBH ≥ 1.0 cm were censored. An ANOVA was performed to compare the structure and diversity between plots. A floristic similarity dendrogram was developed using the Bray-Curtis index. Pearson correlations were calculated between habitat variables and landscape metrics using PAST. No significant differences in diversity and abundance were found between the compared plots. DBH averages and coverage showed statistical differences between some plots. The richness of trees, shrubs and total abundance was positively correlated with the distance to the roadways. The diversity was negatively correlated with the distance to the mature forest fragment. The differences in coverage and DAP suggest that the reserve is facing different degrees of disturbance, causing variation in ecological attributes. The positive correlations between some vegetation variables and landscape metrics indicate that the roads influence the structure and diversity of the vegetation.

Keywords: correlation, disturbance, diversity, foothill forest, landscape metric.

INTRODUCTION

The Vanguardia Forest Reserve (PFR) is one of the protected areas located in the foothills of the plains neighboring the city of Villavicencio, Meta, whose objective is focused on the protection of the high basins for water supply and the conservation of representative samples of the ecosystems corresponding to a portion of the so-called "Villavicencio Refuge" (CORMACARENA, 2007). However, a part of the reserve's ecosystems has been and continues to be degraded, generating changes in the vegetation cover that affect the structure and diversity of the plant community. Urban expansion represents the greatest threat today, which in turn generates other threats such as the extraction of firewood and timber, overgrazing, infrastructure construction, and the development of poorly planned but still incipient tourism (CORMACARENA, 2007).

The foothills forests neighboring Villavicencio fulfill multiple functions mainly associated with water regulation and the maintenance of a natural infrastructure for the development of activities related to ecotourism (CORMACARENA, 2007). However, no study has linked the diversity and structure of vegetation with landscape

metrics at the local scale. The study sites constitute the critical habitat of some species in a high-risk-of-extinction category such as *Dichapetalum spruceanum* Baill., *Gustavia hexapetala* (Aubl.) Sm., and *Licania subarachnophylla* Cuatrec. (CORMACARENA, 2007). These areas are also used by some endemic species of fauna, among which stand out *Colostethus ranoides* (Boulenger, 1918), *Callicebus ornatus* (Gray, 1866), *Aotus brumbacki* (Hershkovitz, 1983), and *Myrmecophaga tridactyla* (Linnaeus, 1758) (CORMACARENA, 2007). The foothill areas where the PFR Vanguardia is located, in addition to being part of a tropical flora refuge during the Pleistocene, have also constituted an exchange area between the Andean and Amazon flora, which has contributed to overall high levels of biodiversity at these sites (HERNANDEZ-CAMACHO *et al.*, 1992).

The study of changes in the state of plant cover is a landscape-scale approach that is increasingly used in protected areas to make reports in the first instance on the current state of present ecosystems, which can serve as basis for studies of landscape functionality (CARREIRAS *et al.*, 2014; VADJUNEC *et al.*, 2018). However, few studies have attempted to relate landscape metrics with vegetation characteristics, which can also be used to assess the influence of disturbances on vegetation (YEBOAH; CHEN, 2016; MORENO-JIMENEZ *et al* 2017). In this study, variables of the forested vegetation of the reserve are related to the metrics of the landscape, in order to evaluate the current state of the vegetation that serves as a reference framework for the establishment of ecological conservation and restoration processes in degraded areas of the reservation. This study sets the following research questions: How do the attributes of forest vegetation vary in fragmented sites with different degrees of advance in ecological succession? What is its relationship with some landscape metrics that allows inferring the impact of socioeconomic variables on vegetation? In this sense, and according to information on anthropogenic pressures in the study area, it is hypothesized that there are differences in the diversity and structure of vegetation between sites, and some correlations between landscape metrics and characteristics of the wooded vegetation. According to the above, the main research objectives of the study were the following: (i) to compare the diversity and structure of the vegetation in areas of fragmented forest of the Vanguardia PFR; (ii) to relate landscape metrics with variables of the forest vegetation of the reserve.

MATERIALS AND METHODS

Study area and sampling sectors

The Vanguardia PFR is located on the eastern slope of the eastern mountain range in the municipality of Villavicencio, Meta, Colombia; it covers an area of 750 ha including the area proposed for expansion, reaching heights between 380 - 830 m in the foothill area of the plains (CORMACARENA, 2007). Vanguardia is a national protected area that is furrowed by the Troncal al Llano road that connects Villavicencio with the departments of Arauca and Casanare and naturally limited by the Guatiquía river in the northwestern portion (CORMACARENA, 2007) (Figure 1).
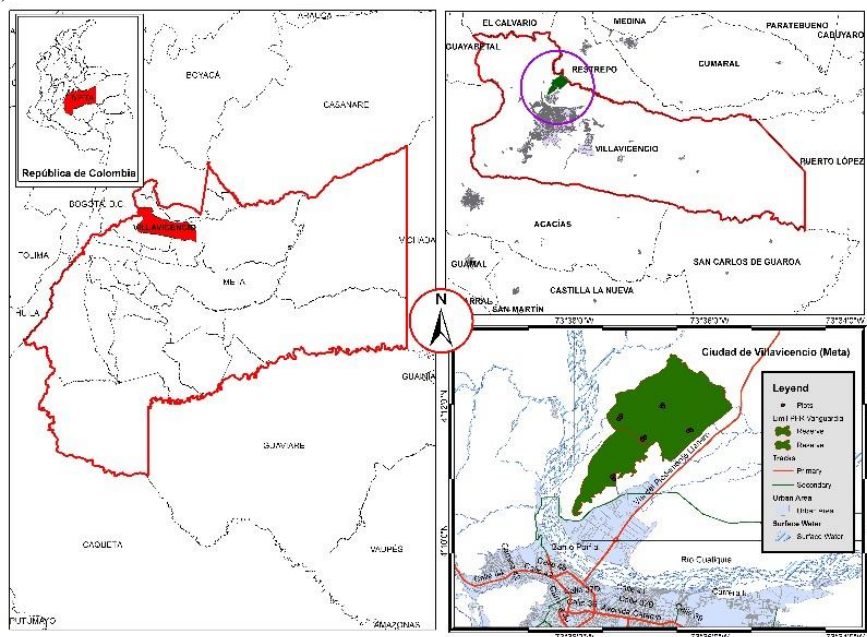

Figura 1. Localização geográfica da área de estudo e das 16 parcelas amostrais na Reserva Florestal Protetora Vanguardia.

Figure 1. Geographical location of the study area and the 16 sampling plots in the Vanguardia Protected Forest Reserve.

The PFR Vanguardia constitutes an island amidst transformed and fragmented ecosystems, with some portions of original primary forests in the foothills of the eastern mountain range. Around 440 species of plants, 51 species of amphibians, 41 species of reptiles, 27 of mammals and 161 of birds have been registered in the reserve (CORMACARENA, 2007).

Vegetation sampling

Vegetation samplings were carried out in five (5) sectors within the Vanguardia Reserve between 483 and 683 m altitude: Casa Verde (n = 3 sampling plots, P1, P2 and P3); Ocarros (n = 4 sampling plots, P4, P5, P6 and P7); Pozo Azul (n = 3 sampling plots, P8, P9 and P10); Orange House (n = 3 sampling plots, P11, P12 and P13); Hacienda Baviera (n = 3 sampling plots, P14, P15 and P16). The criteria used for the selection of the sectors were the presence of fragmented areas and ease of access.

In total, 16 plots of 50 x 2 m each were established, with a minimum distance of 50 m between each one, for a total sample size of 0.16 ha; this size is consistent with the method proposed by Gentry (1982) for inventory of woody plants in 0.1 ha. In each plot, all trees and shrubs with a diameter at breast height DBH ≥ 1.0 cm at 1.0 m above ground level were surveyed; also palms, lianas and ferns plants were recorded in this study, except herbs. DBH, individual height and coverage data were collected; the latter was calculated as the area of the ellipse according to the following formula:

$$Ellipse\ area = 3,1415 \times rDm \times rDn$$

where: rDm = radius of the largest diameter of the cup (major), rDn = radius of the smallest diameter of the cup.

Species identification was carried out by dendrologist Francisco Castro, and The Plant List was used to confirm the correct name of the species. No plant collections were made.

Structure and diversity

Two measurements of diversity were quantified in this study: The Fisher alpha diversity index and the Shannon index with the help of the PAST vers. 3.2 program. To assess whether the sampling effort was sufficient, a species accumulation curve was constructed taking into account the 16 sampling plots; for this, Estimate S 9.1.0 was used. The curve was adjusted with the non-parametric estimators Chao 1 and Chao 2. The floristic similarity between the sampling plots was established by means of a Cluster Analysis. For this, the Bray-Curtis index was used with the UPGMA grouping method, and the square root of the abundances of the species. To determine the vegetation structure, the percentages of abundance, cover and the number of species were calculated for the compilation or total of the sampling plots, and discriminated for three strata, namely: shrub (1- 4 m), tree (4 - 8 m) and arboreal (≥ 8 m).

Landscape metrics

From each sampling plot, the proximity to the fragments of mature forest (Dfb) and infrastructures associated with human activities were identified and determined: Distance to the nearest house (Dv); Distance to the nearest pasture edge (Dp); Distance to the nearest paved main road (Dvp); Distance to nearest unpaved secondary road (Dvs); Distance to the closest trail (Ds) (BURTON; SAMUELSON, 2008). To determine the distances to the closest neighbor of each plot, the average coordinates of each of these were calculated from the coordinates of the starting point and the ending point, using the QGIS software vers. 3.20.0 RC, locating the centroid of the plot on the map coverage and land use. By means of photo interpretation of satellite image (Cnes-Airbus Maxar Technologies - 2019) the properties identified as grassland or paddocks were digitalized; additionally, houses or buildings and non-road were geo-referenced.

In order to define the main routes, the mapping base (routes) established by the SIGOT - Geographical Information System for Planning and Territorial Planning was used; in this cartography, the Villavicencio - Restrepo highway was identified as the primary route and the old Villavicencio - Bogotá highway and the unpaved roads that cross the reserve were identified as secondary routes. From this information and using the QGIS software, the vector analysis tool "closest neighbor" was found, defining the minimum distance between the midpoint (centroid) of each plot and each of these variables (fragment of mature forest, via main, secondary roads, paddock, housing and non-passable road).

RESULTS

Floristic composition

In this study, 1342 individuals distributed in 61 families, 159 genera and 231 species among arboreal, shrub, palm, liana and fern plants were registered. Ten families concentrate 53% of the total species: Leguminosae (28), Rubiaceae (21), Melastomataceae (12), Lauraceae (11), Arecaceae (10), Euphorbiaceae (9), Myrtaceae (9), Burseraceae (8), Bignoniaceae (7), and Annonaceae (6), highlighting the diversity represented by the first two families containing 28 and 21 species respectively; a total of 26 families registered a single species each. The most diversified genera were *Miconia* (8), *Inga* (6), *Myrcia* (5), *Ocotea* (5) and *Pouteria* (5). Table 1 shows the composition, diversity and equity of the plant community in 16 sampling units.

Table 1. Composition, diversity and equity of the plant community in 16 sampling plots, Vanguardia Protected Forest Reserve.

Tabela 1. Composição, diversidade e patrimônio da comunidade vegetal em 16 parcelas amostrais, Reserva Florestal Protetora Vanguardia.

Plot No.	Individuals	Family	Genera	Species	Fisher Alpha Diversity	Shannon	Equity
1	89	29	45	58	72.2	3.8	0.94
2	65	22	30	40	44.2	3.4	0.93
3	68	20	27	34	27	3	0.87
4	83	28	41	44	37.9	3.5	0.94
5	85	24	37	40	29.4	3.2	0.88
6	72	26	35	36	28.6	3.2	0.91
7	79	18	24	25	12.6	2.4	0.77
8	72	15	24	25	13.5	2.7	0.84
9	98	21	29	34	18.4	2.9	0.84
10	70	14	22	22	11	2.6	0.85
11	56	22	25	29	24.2	3.1	0.94
12	93	29	41	50	44	3.6	0.94
13	90	18	34	35	21	3.1	0.87
14	115	27	49	51	35	3.5	0.9
15	81	29	37	41	33.1	3.3	0.89
16	126	27	41	43	23	3.1	0.83
Total	1342						

The species accumulation curve generated with the inventory carried out in the study area is illustrated in Figure 2. This inventory exceeded the expected value of wealth by 75% according to the Chao 1 and Chao 2 estimators. It was evidenced that the inventory was relatively complete since the Chao 1 and Chao 2 estimators calculated 20 and 30% more species than those observed, respectively. Likewise, the curves of "singletons" and "doubletons" tend to an asymptote, which shows a reliable inventory (Figure 2). Both the percentage of "singletons" and "doubletons" were low in the sample (6.8% and 9.1% respectively).
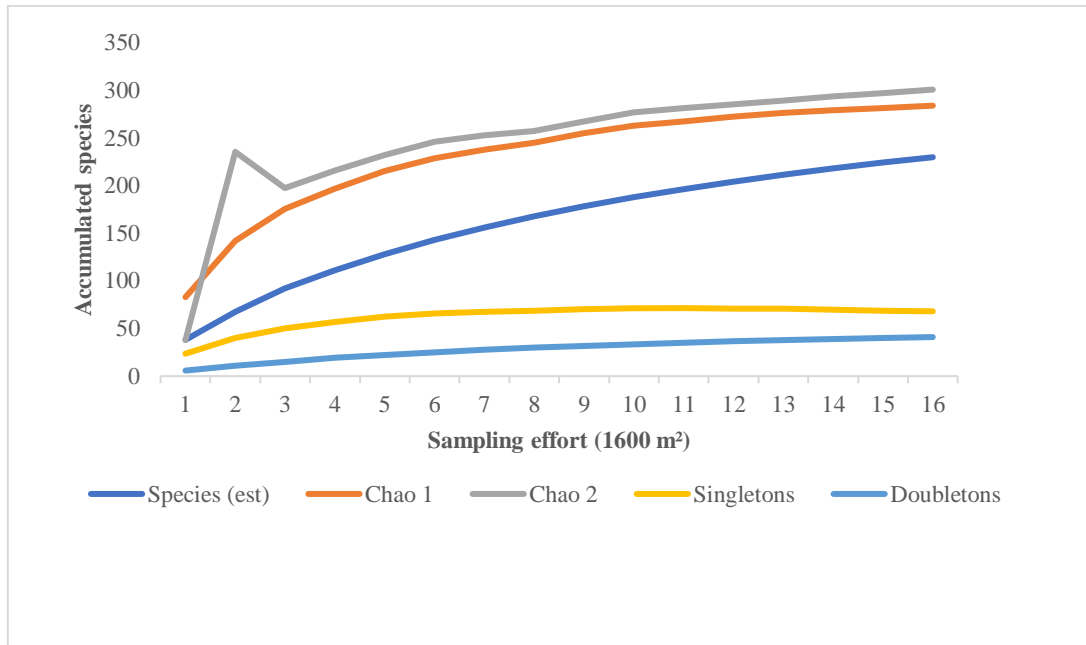
Figure 2. Species accumulation curve generated from the sampling units established in the Vanguardia Protected Forest Reserve, based on non-parametric estimators of wealth (Chao 1 and Chao 2). (The "singletons" and "doubletons" curves of the sampling are also illustrated).

Figura 2. Curva de acumulação de espécies gerada a partir das unidades amostrais estabelecidas na Reserva Florestal Protegida Vanguardia, com base em estimadores não paramétricos de riqueza (Chao 1 e Chao 2). (As curvas "singletton" e "doubleton" da amostragem também são ilustradas).

According to the dendrogram in Figure 4, the floristic similarity between the sampling plots varied between 0.07 and 0.53. The change of species or percentage of dissimilarity between sampling plots was 82.4%. Most of the groups differentiated in Figure 3 according to the degree of similarity, correspond to spatially close sampling units. The lowest floristic similarity was recorded between plot 13 and the rest of the plots (0.07), while the greatest similarity was recorded between plots 5 and 6 (0.53). Among the plant species that occurred exclusively in plot 13 and in low population abundances, are the following: *Alchornea discolor* Hook.f., *Cassia moschata* Benth., *Jacaranda obtusifolia* Bonpl., *Miconia dolichorryncha* Naudin, *Oenocarpus minor* Mart., *Protium glabrescens* Swart, *Vismia macrophylla* Kunth and *Vochysia ferruginea* Mart.
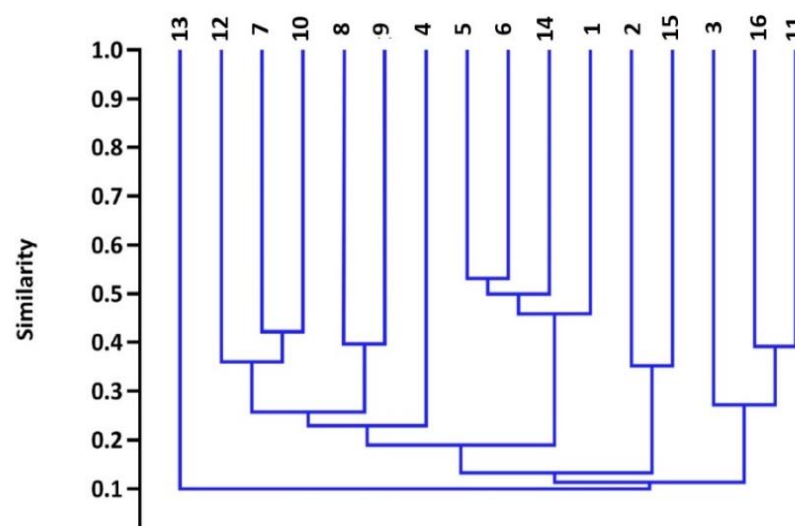

Figure 3. Floristic similarity dendrogram of 16 sampling plots based on the Bray-Curtis index, Vanguardia Protected Forest Reserve.

Structure and life forms

In general, the canopy of the primary and secondary forests of the study area has heights of approximately 20 to 30 m. The arboreal stratum is made up of the following dominant species in the 16 study plots: *Anaxagorea dolichocarpa* Sprague & Sandwith (46 individuals), *Casearia javitensis* Kunth (43 individuals), *Mabea piriri* Aubl. (61 individuals), *Pseudolmedia laevis* (Ruiz & Pav.) J.F.Macbr. (51 individuals), *Virola sebifera* Aubl. (57 individuals) and by two species of palms *Wettinia praemorsa* (Willd.) Wess.Boer (71 individuals) and *Euterpe precatoria* Mart. (52 individuals). The most representative stratum is the arboreal with coverage of 78%, abundance of 35% and with the largest number of species (37). The shrub layer (a) and tree (ar) present similar values of abundance and cover (a: 33%, 34% and ar: 5% and 17%), as well as the number of species (31 and 33 respectively).

Regarding the habits found in the forests of the Vanguardia PFR, the predominant one was the trees with 73% species and 80% of cover; shrubs, palms and lianas were represented by less than 10% of species and cover.

Ecological attributes

The ANOVA results indicate that there are no statistically significant differences between the samples studied for total abundance (Tukey; $p \geq 0.05$). Plots 14 and 16 presented the highest abundance values (115 and 126 individuals respectively), while the lowest value was registered in plot 11 (56 individuals respectively). On the other hand, plot 1 registered the highest value of wealth and diversity according to the diversity indices α of Fisher, Shannon and Equity; in contrast, the lowest values of these indices were registered in plots 7 and 10 respectively (Table 1).

With respect to the average data of DAP and Coverage, the ANOVA indicates statistically significant differences between the sampled plots ($p \leq 0.05$). Plot 7 presented the highest DAP value, being statistically different from that of the other plots, with the exception of plot 3 (Tukey; $p \leq 0.05$, Figure 4A). In turn, plot 3 presented the highest coverage value, which was statistically different from plots 1, 4, 8, 9, 10, 15 and 16 (Tukey; $p \leq 0.05$, Figure 4B). In contrast, the average height values showed a different pattern, with no statistical differences between the plots (Tukey; $p \geq 0.05$, Figure 4C).
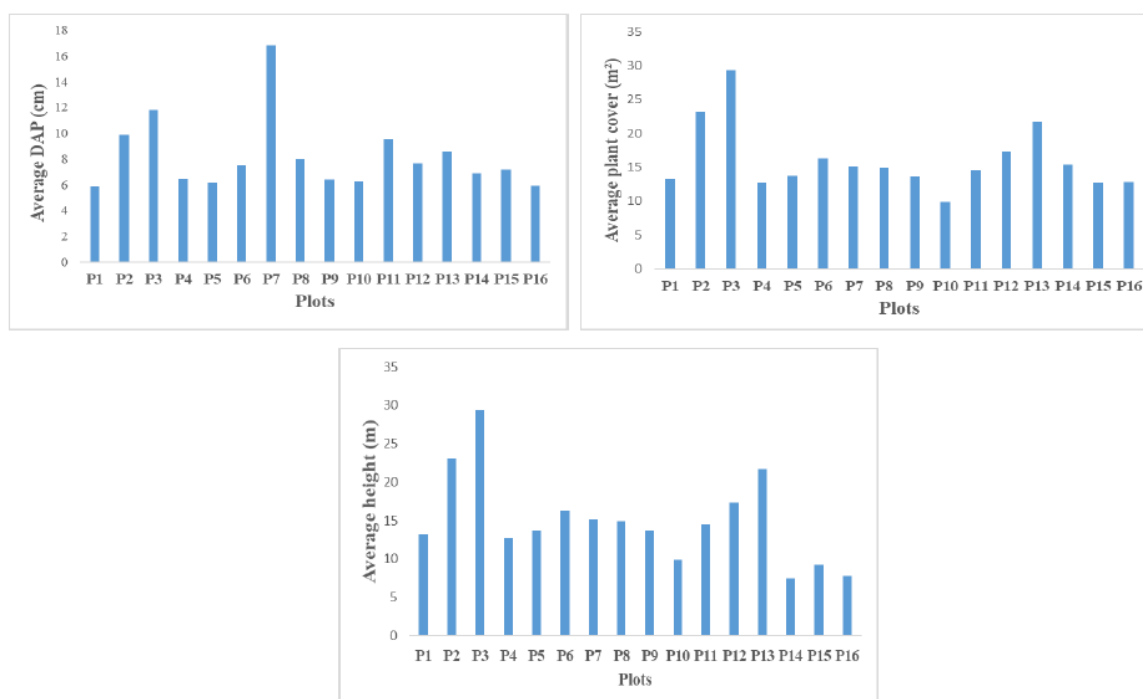

Figure 4. Average values of ecological attributes in 16 sampling plots, Vanguardia RFP, Villavicencio, Colombia. A. diameter at breast height; B. plant cover; C. height of individuals.
Figura 4. Valores médios de atributos ecológicos em 16 parcelas de amostragem, Vanguardia RFP, Villavicencio, Colômbia. A. diâmetro à altura do peito; B. cobertura vegetal; C. altura dos indivíduos.

Pearson's correlation analysis shows that Fisher's alpha Diversity and Shannon's Diversity were negatively correlated with the distance to the mature forest fragment (p ≤ 0.05) and with the distance from the houses (p ≤ 0.01). Tree richness and total abundance were positively associated with the distance to the main paved road (p ≤ 0.01) and negatively associated with the distance to the unpaved secondary road (p ≤ 0.05). Tree richness was also negatively associated with distance to the mature forest fragment (p ≤ 0.01). On the other hand, the richness of shrubs was positively associated with the distance to the unpaved secondary road (p ≤ 0.01) (Table 2).

Table 2. Pearson's correlation coefficients between forest habitat variables and some landscape metrics, Vanguardia Protected Forest Reserve.

Tabela 2. Coeficientes de correlação de Pearson entre variáveis de habitat florestal e algumas métricas de paisagem, Reserva Florestal Protetora Vanguardia.

Variables	Dv	Dp	Dfb	Dvp	Dvs	Ds
Fisher alpha diversity	-0.71*	-0.34	-0.53**	-0.09	0.11	-0.13
Shannon diversity	-0.67*	-0.35	-0.57**	0.16	0.02	-0.13
Shrub richness	0.09	0.25	0.33	-0.48	0.51*	-0.003
Small tree richness	-0.36	-0.19	-0.37	0.31	-0.22	0.03
Tree richness	-0.36	-0.4	-0.55*	0.63*	-0.62**	-0.11
Total abundance	-0.004	-0.19	-0.21	0.5*	-0.3*	-0.07
Plant cover (m2)	-0.43	-0.29	-0.42	-0.24	0.19	-0.12
Height (m)	-0.0008	-0.06	-0.24	0.36	-0.18	0.23

Legend: Dv: Distance to the nearest house; Dp: Distance to the nearest pasture edge; Dfb: Distance to the edge of the nearest mature forest fragment; Dvp: Distance to the nearest paved main road; Dvs: Distance to the nearest unpaved country road; Ds: Distance to the nearest trail.
* with significance at p ≤ 0.01; ** with significance at p ≤ 0.05.

Figure 5 illustrates the spatial distribution of the sampling plots over two main components, which together accounted for 88% of the total variability of the data. Most of the habitat variables and landscape metrics were positively correlated with respect to component 1, while coverage and distance to the forest fragment (Dfb) were negatively correlated. With respect to component 2, Fisher's alpha diversity, seedling richness and cover were positively correlated, while the rest of the metrics and variables were negatively correlated.
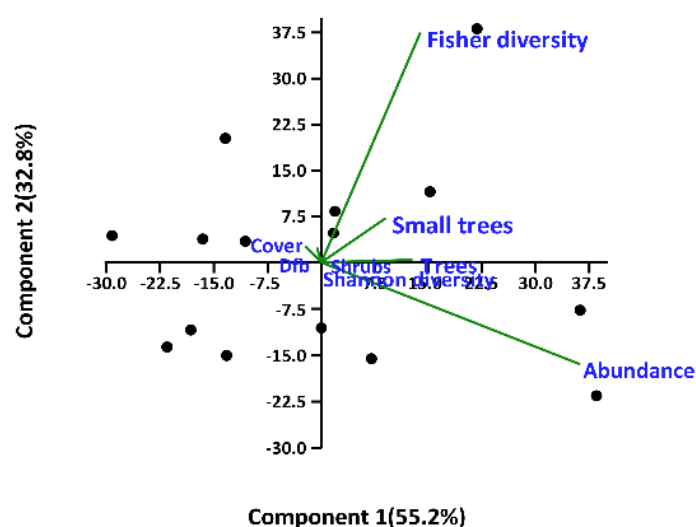

Figure 5. Principal components analysis of habitat variables and landscape metrics, and their relationship with the distribution of 16 sampling plots in forest areas of the Vanguardia Reserve.

Figura 5. Análise de componentes principais de variáveis de habitat e métricas de paisagem, e sua relação com a gfdistribuição de 16 parcelas de amostragem em áreas florestais da Reserva Forestal Protectora Vanguardia.

DISCUSSION

The floristic richness found in the foothill forests in an area of 0.16 ha (550 - 830 m altitude) of the Vanguardia Protected Forest Reserve (range: 22 - 58, average: 38, Table 1) was lower than that recorded in studies previous of sub-Andean forests in plots of 0.1 ha (950 - 2400 m altitude) on the Orinoquía slope of the Andes (range: 51 - 84, average: 66) (TRUJILLO; HENAO-CÁRDENAS, 2017). However, the richness values reported in this study (231 plant species in an area of 0.16 ha) are higher than those recorded in other ecosystems such as the Riparian forests (130 - 190 m altitude) of the Orinoquía slope (185 species in an area of 0.9 ha) (CABRERA-AMAYA; RIVERA-DÍAZ, 2016). Unpublished studies of floristic richness in the foothills of the plains have reported values between 82 - 91 species which are greater than the wealth range reported in this study (Table 1). This situation seems to show that, locally, the Vanguardia Forest Reserve has lost part of the species richness, as a result of the different human activities that still subsist within the area and those that take place in adjacent areas.

The floristic composition at the family level is adjusted to what was previously reported for the Colombian Orinoquía where the Leguminosae family was the most diverse in foothill forests below 1000 m (MINORTA; RANGEL, 2015); this coincides with that established by Gentry (1995) who recognizes it as one of the richest families in species in lowland forests in the neotropics. It can also be seen that families such as Rubiaceae, Melastomataceae, Lauraceae, Euphorbiaceae and Myrtaceae are shared (Table 1), considered as representative of the neotropic lowlands in samples of 0.1 ha, indicating a low variation in composition at this taxonomic level (GENTRY, 1995). Coincidences are also generated in the diversification at the genus level, since this study and other previous ones highlight the *Inga* and *Miconia* genera as the taxa with the greatest number of species in areas of the Orinoquense region such as the departments of Arauca and Casanare (CÓRDOBA *et al.*, 2011).

Concerning the composition of species, there are few coincidences regarding the richness between the comparative studies. This study stands out for its abundance, the high ecological importance of *Anaxagorea dolichocarpa, Casearia javitensis, Mabea piriri, Pseudolmedia laevis* and *Virola sebifera* in the tree stratum*; Memora cladotricha* Sandwith*, Acalypha cuneata* Poepp.*, Cordia nodosa* Lam. and *Gustavia* sp. stand out in the shrub layer. Regarding the importance of palms in the foothills of the plains, this study highlights their relevance as floristic elements given their high diversity and abundance; the Arecaceae family with 10 species (Figure 2), was one of the most diversified in this study and two species (*Wettinia praemorsa*, and *Euterpe precatoria*) presented high abundances per unit area, confirming its importance as a structural and functional component not only of the forests of the Orinoquía, but also of the Amazon (CABRERA-AMAYA; RIVERA-DÍAZ, 2016).

The high percentage of species turnover between sampling units, particularly among the differentiated groups in the dendrogram in Figure 2, indicates that closely distributed plant assemblies tend to have a high similarity between them and a low similarity with respect to assemblies distributed in distant areas. Thus, the geographical distance between plots is apparently a factor that promotes differentiation in plant assemblies in the study area. The limitations on dispersion imposed by geographic distance have been proposed as a good predictor of floristic turnover in foothill forests of the Orinoquia (TRUJILLO; HENAO-CÁRDENAS, 2018). At the local level, floristic differentiation in composition and structure between distant groups can also be generated by particular topographic and edaphic conditions, and by the disturbance regime that drives differential successional trajectories, previously proposed in different studies (VARGAS, 2011; BACCA; BURBANO, 2018).

The greater coverage and number of species in the tree stratum is similar to that found in mature gallery forests of the Colombian eastern plains (CORREA-GÓMEZ; STEVENSON, 2010). The decrease of these variables in the lower strata (small tree and shrub) in the study area and the similarity in the concentration of individuals between the strata, suggests that forests have not been severely affected for at least the last 30 years and that they still maintain samples of the original vegetation; however, the absence of trees with DBH greater than 20 cm indicates that selective logging of large individuals in the forest may have occurred in the past. The dominant species with heights greater than 25 m were *Virola sebifera, Pseudolmedia laevis* and *Euterpe precatoria* among the palms. They are probably species of the original vegetation that can still be found in secondary forests after a fragmentation process.

Pearson's correlation analysis shows that tree richness and total abundance tend to increase positively with increasing distance to the main paved road ($p \leq 0.01$), that is, as the distance from this metric increases, tree richness and abundance are greater. The other significant positive relationship was between bush richness and distance to the secondary unpaved road. Also a significant negative relationship derived from Pearson's correlation analysis was between Fisher's alpha diversity and Shannon's diversity with the distance to the closest mature forest fragment ($p \leq 0.05$), that is, as the distance to the forest fragment decreases species diversity is greater. This

situation highlights the importance of conserving mature forest fragments that can serve as a source of propagules that increase the diversity of secondary forests in early succession phases (LAURANCE *et al*., 2011).

The above relationships are an indication that the primary and secondary communication routes are a factor for the extraction of trees and bushes for firewood, construction of houses, establishment of paddocks, and also for the operation of broilers located in areas neighboring the reserve. This coincides with other studies where the effect of agricultural activities and urbanization on the composition and diversity of the vegetation, soil and buried seed bank has been demonstrated (ALIGNIER *et al*., 2021; JINMING *et al*., 2021; MORENO-JIMENEZ *et al*., 2019; VELOSA *et al*., 2018). Some metrics of spatial landscape configuration at a local scale, particularly the number of fragments and the average size of the fragments, have also been related to the variation in the floristic composition and structure of plant communities in different studies (ANNISSA; EYASU, 2021; MANGUEIRA *et al*., 2021; METZGER, 2000). In this study, the PCA - Principal Component Analysis is a reflection of the correlations between the included landscape metrics and variables related to vegetation structure and diversity. Since most of the sampling units are distanced from the included infrastructures (houses, roads, trails), they are similar to mature forests, tending to improve the richness and diversity of associated species.

The high degree of species turnover among the sampling units recorded in this study (82.4%) may reflect the differentiating effect of the distance to the road infrastructure on the composition and diversity of the plant community; the greater the distance, the greater the richness and diversity of species and vice versa. This implies that changes in the configuration of the landscape can potentially affect the composition and diversity of the plant community (ANNISSA; EYASU, 2021). This initial analysis can serve as the basis for evaluating and monitoring the effect of fragmentation and subsequent natural recovery of the foothill forests in the Colombian Orinoquía region.

CONCLUSIONS

- The Vanguardia Forest Reserve is in some places facing different levels of disturbance, causing variation in some ecological attributes such as plant cover, DAP, species richness and diversity.
- The construction of the main paved road that connects the municipalities of Villavicencio with Restrepo bordering the limits of the reserve, and the unpaved secondary roads that cross some sectors of the reserve, are influencing the wealth of trees and shrubs, which may influence the future of foothill forests in the sector. The shorter the distance from primary and secondary roads, the lower the richness and diversity of plant species in the forest fragments.
- Greater control of anthropogenic factors, such as settlement expansion and overgrazing, should be carried out to minimize the potential impacts on the reserve's flora and fauna.
- Given the good level of recruitment in the initial stages of the ecological succession process, with abundances greater than 20 individuals / 1.6 ha, it is suggested that the following tree species can be considered in the future restoration programs of the reserve: *Anaxagorea dolichocarpa, Casearia javitensis , Mabea piriri, Pseudolmedia laevis, Virola sebifera, Schizocalyx bracteosus, Matisia ocrhocalyx, Myrcia paivae, Tovomita umbellata, Iriartea deltoidea, Wettinia praemorsa* and *Euterpe precatoria*.

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