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Original Article

Effect of slope on the forest structure of the Atlantic Forest domain in southern Brazil

Efeito da inclinação na estrutura de uma floresta do domínio Mata Atlântica no sul do Brasil

D. C. Souza[a]*, L. R. Souza[b], E. V. Couto[a], M. G. Caxambú[a] and A. P. Peron[a,c]

[a]Universidade Tecnológica Federal do Paraná – UTFPR, Departamento de Biodiversidade e Conservação da Natureza – DABIC, Campo Mourão, PR, Brasil

[b]Universidade Tecnológica Federal do Paraná – UTFPR, Curso de Engenharia Ambiental, Campo Mourão, PR, Brasil

[c]Universidade Tecnológica Federal do Paraná – UTFPR, Programa de Pós-graduação em Inovações Tecnológicas – PPGIT, Campo Mourão, PR, Brasil

Abstract

The mosaic landscape composition of forest fragments located on high slopes, shallow soils hinder ecological interactions and the survival of plant species. This study aimed to show, in an environment with these characteristics, the effect of the environmental gradient relating the soil, slope, and vegetation of a fragment of the Montane Seasonal Semideciduous Forest. The forest structure was sampled in 12 continuous rectangular plots, with 30 X 20m, totaling 0.72ha. Soil samples were taken by drilling every 20m along the hydrographic divisor and opening of three trenches used as soil sampling sites for in situ determination of soil color, horizon, and nutrients. Horizons were classified as O/A/Cr in the altered rock with a marked presence of gravels, and the soil was classified as Litholic Neosol. The area has a steep slope, from 18.05% to 36.99%. Linear regression analysis indicated an opposite pattern for species richness in relation to slope and a positive relationship between slope and the number of standing dead individuals. Species richness was also positively related to the distance from forest edges. The evaluation evidenced the strong influence of slope and human activities in forest remnant as common to several high-altitude remnants, and small conservation actions can guarantee their maintenance.

Keywords: biodiversity, phytosociology, edge effect.

Resumo

Efeito da Inclinação na Estrutura de uma Floresta do Domínio Mata Atlântica no Sul do Brasil. A composição da paisagem em mosaico de fragmentos florestais localizados em encostas altas, solos rasos dificultam as interações ecológicas e a sobrevivência de espécies vegetais. Este estudo teve como objetivo mostrar em um ambiente com essas características o efeito do gradiente ambiental relacionando o solo, a declividade e a vegetação de um fragmento de Floresta Estacional Semidecidual Montana. A estrutura da floresta foi amostrada em 12 parcelas retangulares contínuas, com 30X20m, totalizando 0,72ha. As amostras de solo foram coletadas por perfuração a cada 20m ao longo do divisor hidrográfico e abertura de três trincheiras usadas como locais de amostragem de solo para determinação *in situ* da cor do solo, horizonte e nutrientes. Os horizontes foram classificados como O/A/Cr na rocha alterada com presença marcante de cascalhos, e o solo foi classificado como Neossolo Litólico. A área apresenta declive acentuado, de 18,05% a 36,99%. A análise de regressão linear destacou o padrão oposto de riqueza de espécies em relação à inclinação e uma relação positiva entre a inclinação e o número de indivíduos mortos em pé. A riqueza de espécies também foi positivamente relacionada à distância das bordas da floresta. A avaliação evidenciou que a forte influência do declive e das atividades antrópicas no remanescente florestal são fatores comuns a diversos remanescentes de altitude, e pequenas ações de conservação podem garantir sua manutenção.

Palavras-chave: biodiversidade, fitossociologia, efeito de borda.

1. Introduction

The removal of native vegetation for disordered land use for purposes of agriculture and urban expansion has the consequence of forest fragmentation and reduction of habitats, which in turn, has a direct effect on the dynamics of vegetation and the ecosystem (Ferreira et al., 2019). The main effect of fragmentation on the landscape is the reduction of continuous habitats and the appearance of a mosaic composed of smaller environments, generally causing changes and losses of ecological functions. As a result of this change, in addition to the reduction in

*e-mail: dcsouza@utfpr.edu.br
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size of a forest patch, there is an increase in the number of transition environments between the center of the fragment and its surrounding matrix, directly influencing the interaction of local biodiversity (Ferreira et al., 2019).

One of the effects of the fragmentation process is known as the edge effect, which is due to the formation of a border zone between the fragment center and its surrounding matrix, with a strong influence on the fragment environmental quality as it affects biotic and abiotic factors of the landscape structure (Hardwick et al., 2015; Laurance et al., 2018).

Among the Brazilian domains, the Atlantic Forest can be considered one of the most fragmented ecosystems, and of the 150 million hectares that make up this heterogeneous domain, only 11.4 - 16% remains as forest remnants that are mostly (80%) smaller than 50 ha (Ribeiro et al., 2009). The deforestation of domains that make up the state of Paraná has become accelerated due to the intense occupation that occurred since the 1930s by colonizing activities for the implantation of coffee crops (Ferreira et al., 2018), currently replaced with soybean and corn crops. The state of Paraná deforested 2,049 ha of this domain, the third largest deforestation of this domain among the Brazilian states (Fundação SOS Mata Atlântica, 2017).

One of the phytophysiognomies comprising this domain is the Seasonal Semideciduous Forest that originally covered 37.7% territory of the state of Paraná. However, it has been drastically reduced, and is currently a threatened and fragmented phytophysiognomy with only 3.4% native vegetation (Gris and Temponi, 2017). The major causes of the degradation of this phytophysiognomy are due to monocultures and selective logging in the state of Paraná (Rodrigues et al., 2016; Dettke et al., 2018). Estevan et al. (2016) compared several studies conducted on this phytophysiognomy in the state of Paraná and found that there is low floristic similarity among the remnants. These authors point out the local environmental factors, such as proximity to water resources, as the cause of the difference from nearby remnants. In addition, isolation negatively interferes with the structural functionality of vegetation, disfavoring the ability of plant individuals to develop and reproduce (Marcon et al., 2020).

The central western region of the state of Paraná has a steep slope and thus several small forest remnants at high slopes were maintained after agricultural colonization. Small fragments can have great ecological benefits, when strategically used as resting sites by the fauna in movement. In this way, they contribute to the connectivity of distant fragments (Ferreira et al., 2018).

The municipality of Corumbataí do Sul, state of Paraná, is in this region and is part of the Seasonal Semideciduous Forest and Mixed Montane Rainforest and has only 6% native vegetation (Roderjan et al., 2002; Fundação SOS Mata Atlântica, 2017). Its territory has inherent edaphic characteristics, such as low soil depth, high contents of gravel, steep slopes, with good fertility and at altitudes above 500 meters. Understanding the physical properties of soils is essential for the safe management of natural resources. And these characteristics involve quantitative analysis and the interpretation of physical and physical-water properties, and the main changes in soil quality (Stefanoski et al., 2013).

The landscape, as a mosaic of forest fragments located at high slopes, is an important source of information about the forest structure, interactions, and the survival of plant species. This knowledge can be based on management actions for the conservation of the Atlantic Forest domain. It is known that shallow soils and high slopes contribute to the loss of local diversity. Thus, this study aimed to show the environmental gradient related to the soil, the slope, and the vegetation of the forest fragment of the Montane Seasonal Semideciduous Forest of the region of Corumbataí do Sul. Furthermore, we intend to answer the following question: How does the altitude gradient affect the structure and composition of a montane semideciduous seasonal forest fragment?

2. Material and Methods

2.1. Study area

The study was carried out in a fragment of Montane Semideciduous Seasonal Forest, in the rural perimeter of the municipality of Corumbataí do Sul, in the Central-Western Mesoregion of the state of Paraná at the coordinates 24°8’ 19.81” and 24°8’ 0.38” South latitude and 52°8’ 41.35” and 52°8’ 27.57” West longitude (Figure 1). The region climate is the mesothermal humid subtropical (Cfa), with temperature averages of 16.0 °C in winter and 23.3 °C in summer, according to the Köppen-Geiger classification, with average annual rainfall of 1,100-1,600 mm, no defined dry season (Alvares et al., 2013).

As for the geological and geomorphological aspects, the area is characterized by the Morphostructural Unit of the Paraná Sedimentary Basin, the morphosculptural Unit of the Third Plateau of Paraná and a morphosculptural Sub-Unit belonging to the High/Middle Piquiri Plateau on basaltic rocks of the São Bento Group, with the Predominant Serra Geral formation (Santos et al., 2009). The relief is strongly undulating, with rocky outcrops and a thin layer of soil. In these regions, the predominant soil characteristics are slopes of 10 to 45%, with rocky outcrops and shallow soils (ITCG, 2008). The soil class of the area is characterized as TYPICAL EUTROPHIC LITHOLIC NEOSOL (Campiolo et al., 2014).

When considering the representativeness of the forest fragment, the study region is an isolated fragment, with an area of 58 ha. The distance between its right and left flanks is 1,359 meters. The edge area is surrounded by human activities where the cultivation of temporary and permanent crops, livestock farming and forestry have been shown to directly influence the forest in terms of structure and dynamics.

2.2. Physical-chemical analysis of soils

Soil samples were taken within the plots for analysis of macro- and micro-nutrients, starting with the first collection in high slope (plateau) and the last collection in medium slope, where vegetation no longer occurs and

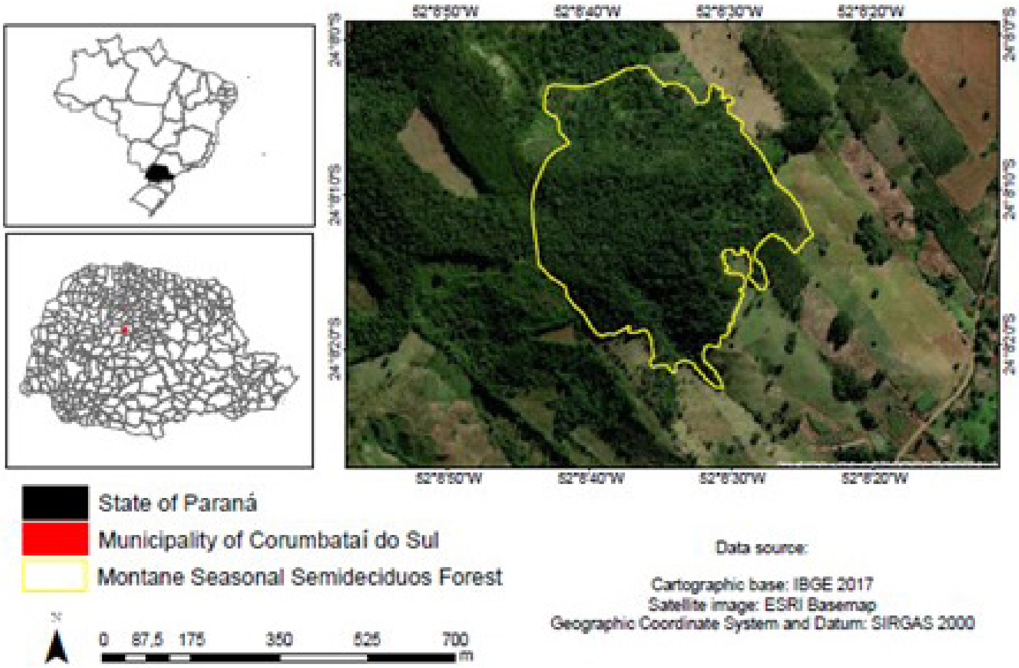

Figure 1. Forest Fragment of Montane Seasonal Semideciduous Forest – Corumbataí do Sul, state of Paraná, Brazil.

the temporary crop begins, being these collections every 20 meters along the slope. In these samples, macro- and micro-nutrients were analyzed.

The physical analysis of the remaining soil was carried out through three trenches called T1, T2 and T3; T1 located at high slope, and T2 and T3 at medium slope. Soil particle size analyses were made for each trench, for soil classification according to the Brazilian Soil Classification System (Embrapa, 2006). In the trenches, color and horizon were determined in situ. As for the color, the Munsell Color Chart was used as a reference (USDA, 1988). The slope of the area was determined along a transect that covered all the plots, using GNSS spectra promark 220, accurate to 0.06m. The same equipment was used to fix the four vertices of the plots, so in future studies the same plots can be used.

2.3. Phytosociology

The forest structure was sampled in 12 continuous rectangular plots, with 30 X 20 m, totaling 0.72 ha. The representative individuals for this study comprised tree species with circumference at breast height (CAP) greater than or equal to 15 cm; we also visually estimated the height of individuals.

Through quantitative data, phytosociological parameters of Absolute Frequency (FA), Relative Frequency (FR), Absolute Density (DA), Relative Density (DR), Absolute Dominance (DoA), Relative Dominance (DoR), Value Index of Importance (IVI) in addition to: Shannon diversity index (H') and Pielou evenness (J) (Pielou, 1969). All these parameters were calculated using the FITOPAC 2.1 software (Shepherd, 2006).

2.4. Data analysis

Species were analyzed for clusters according to their distribution in the area by means of a Detrended Correspondence Analysis (DCA). These distribution data were used together with soil chemical properties to set some pattern between the plots. These were analyzed by Canonical Correspondence Analysis (CCA), which allows associating species distribution with abiotic variables. Pedological variables with the greatest pressure on phytosociological characteristics were tested for patterns in the environmental gradient by Regression Analysis to identify the influence of the variable and creating prediction models. All analyses were run in the R program. To test normality and perform regression analysis, the shapiro.test function and the lm function of the R base were used (R Core Team, 2020). For multivariate analysis, the decorana and cca functions of the vegan package were used (Oksanen et al., 2020).

3. Results and Discussion

Based on the guiding question, this study aimed to highlight the gradient of slope related to the soil, slope, and vegetation of the forest fragment. As well as subsidizing useful information for the conservation and restoration of the vegetation and soil of properties and Seasonal Forest fragments Montane semideciduous in the municipality of Corumbataí do Sul, state of Paraná, Brazil.

3.1. Physical-chemical analysis of soils

The forest soil was classified as a typical EUTHROPHIC LITHOLIC NEOSOL and was characterized by not showing significant changes in relation to the source material, besides having little depth associated with more sloping reliefs. Horizons were classified as O/A/Cr on altered rock with a marked presence of gravels. Soils presenting the characteristics observed in this remnant are considered limiting to the development of plant species (Alho et al., 2007).

The study of trenches allowed to relate the species composition with soil properties along the altitude gradient. The area of the first trench (T1), composed of the first four plots and located at 660m altitude, presented A/C horizons, 0-20 cm deep, in which the organic matter layer is small (5 cm), followed by low mineralized soil and gravels 10 cm in diameter. In addition to color 5YR3/1 (very dark gray), it has many roots with reduced diameter and low presence of sclerenchymatous tissues. This region was marked by a strong influence of human activities in view of the structure of vegetation and land use, as the area has a moderate slope (18.05%) and allows the development of agriculture, livestock production, and silviculture. The first two plots are at a recovery state, observed by the predominance of *Parapiptadenia rigida*, this species is an aggressive pioneer with a high capacity to compete with lianas due to its rapid growth (Baldin et al., 2015).

In the T2 trench, located at 678m altitude, the greatest slopes are mainly found in plots five and six. The horizon is O/W, 0-30 cm deep, diffuse apparent crust, and large amount of organic matter, with decomposing leaves and stems. These data may indicate that the high slope generates transport of upstream sediment to the base of the forest. The soil was classified as 5YR2.5/1 (black) clayey texture, with 8 cm diameter gravels; presence of macrofauna, roots and underground stems were also observed. The greater depth of the soil associated with a large amount of organic matter made it possible to record the third highest average height (9.95 m), mainly in plot nine, which among the others in this region, is less influenced by lianas and harbors the greatest species richness in this area.

The T3 trench, located at 714 m altitude, presented an A/Cr horizon, with a depth of 0-20 cm, presence of very fibrous organic matter of 10 cm, with roots and leaves and marked stony. There was a predominance of the color 5YR2.5/2 (black) and gravel diameter of 12 cm, which may be associated with the export of finer sediments down the slope. In this area, the effect of soil and topographic conditions on vegetation is evident, as it confers greater density and richness to the vegetation in plots ten, eleven and twelve. Plot ten was the most significant in relative density, 16.23%, plot eleven had 15 species, and plot twelve registered 20 species and the lowest mortality rate (1.72%) among all plots. The average height in these plots was as low as in the sloping areas, and this can be explained by the effect of shallow soils on plant roots.

3.2. Phytosociology aspects

In the phytosociological study, 1,195 individuals were evaluated, of which 182 are standing dead individuals and the rest were distributed in 42 species belonging to 23 families. Few families showed high relative density: Fabaceae (30.88%) with six species, Rutaceae (13.31%) with four species, Sapindaceae (5.69%) with two species, Moraceae (5.19%) with two species, Anacardiaceae (4.77%) with two species and Annonaceae (4.18%) with two species. Total density was 1,659 individuals per hectare, the Shannon Wiener Diversity Index (H') was 2.794 and the Piellou evenness (J') was 0.743. The evenness value was strongly influenced by five species with more than 50% sampled individuals and by the high number of standing dead individuals in plots five, six, and ten (Table 1).

The low soil depth and the steep slope observed (Table 1) are factors that directly influence the development of many plant species, mainly due to limitation to root system growth (Venturoli et al., 2010), which favors the low species richness (Velazco et al., 2015). Consequently, diversity was also low, as observed by the Shannon Winner index H' = 2.794, which was below that found in other studies in Montane Seasonal Semideciduous Forest, which presented H' values between 3.31 and 3.9 (Estevan et al., 2016). According to Souza et al. (2017), the Montane Seasonal Semideciduous Forest showed higher diversity than montane forests, probably because of deeper and more stable soils.

The species that most occurred in the sampled plots, in decreasing order, were: *Parapiptadenia rigida* (Benth.) Brenan (7.79%), Dead (7.79%), *Eucalyptus* sp. (4.55%), *Zanthoxylum rhoifolium* Lam. (3.90%), *Calliandra brevipes* Benth. (3.90%) and *Trichilia elegans* A.Juss. (3.90%), these species stood out in IVI because of the highest values of relative frequency, relative density and relative dominance. Species with the highest IVI were: *Parapiptadenia rigida* 61.66, Dead 34.45, *Zanthoxylum rhoifolium* 27.03, *Eucalyptus* sp. 15.90 and *Astronium graveolens* Jacq. 12.51.

Considering all the forest formation, in the upper layer, with average height of 15.2m, the predominant native species were *Schizolobium parahyba* (Vell.) Blake (pioneer), *Sapium glandulosum* (L.) Morong (pioneer), *Anadenanthera colubrina* (Vell.) Brenan (non-pioneer) and *Helietta apiculata* Benth. (non-pioneer). In the middle layers, with a height of 10.9m, native *Eugenia uniflora* L. (non-pioneer), *Cupania vernalis* Cambess. (non-pioneer), *Machaerium stipitatum* Vogel (non-pioneer) and *Syagrus romanzoffiana* (Cham.) Glassman (non-pioneer) were found. And in the lower layer, with an average height of 7.5 meters, individuals of the native species: *Allophylus edulis* (A.St.-Hil. et al.) Hieron. ex Niederl. (pioneer), *Astronium graveolens* (non-pioneer), *Maclura tinctoria* (L.) D.Don ex Steud. (non-pioneer), *Calliandra brevipes* (pioneer) and *Pilocarpus pennatifolius* Lem. (non-pioneer) were observed.

Eucalyptus sp. stood out for its high relative dominance (9.68%) and for the highest maximum and minimum height, reaching 25 meters in height. This species reflects the human silvicultural activities developed on the site. Eucalyptus trees are recognized for subjecting the forests of the state of Paraná to intense disturbance and degradation (Blum and Oliveira, 2003). Therefore, the management measure for this species is the girdling of standing dead individuals, so that it does not affect the consolidated forest structure (Rodrigues et al., 2015).

Allophylus edulis had a median frequency in the area; as it is a species occurring naturally in the Seasonal Semideciduous Forest, it could have had a high frequency

Table 1. List of edaphic, topographic, and phytosociological variables evaluated in the plots of a Montane Seasonal Semideciduous Forest fragment, Corumbataí do Sul, state of Paraná.

Plot	Horizon	Slope (%)	Depth (cm)	Species Richness	Relative Density	Average Height	Number of individuals	Dead individuals (%)
1	A/C	18.05	0-20	3	6.28	10.45	75	6.6
2	A/C	19.38	0-20	4	3.6	8.28	43	2.3
3	A/C	28.52	0-20	6	0.67	5	8	12.5
4	A/C	31.33	0-20	15	12.55	8.13	150	6
5	O/A	35.22	0-30	12	6.28	7.32	75	28
6	O/A	36.99	0-30	5	9.21	5.49	110	39.09
7	O/A	35.86	0-30	12	6.69	7.29	80	15
8	O/A	32.91	0-30	15	7.95	9.95	95	16.8
9	A/Cr	29.92	0-20	21	11.55	10.36	138	10.86
10	A/Cr	29.22	0-20	24	16.23	8.33	194	25.25
11	A/Cr	26.94	0-20	16	9.29	7.54	111	8
12	A/Cr	26.14	0-20	21	9.71	8.01	116	1.72

in the fragment, but the altitude should have influenced its distribution, as it is not a species associated with the altitude gradient (Cortines et al., 2011; Souza et al., 2017). The other species that stood out among the 10 highest IVI are important for the balance and good development of the forest remnant. Among them, *Zanthoxylum rhoifolium, Maclura tinctoria, Astronium graveolens*, for their relationship with the characteristics of the relief and the dispersion (Backes and Irgang, 2004).

Other species of great occurrence in this area was *Tecoma stans* (L.), which is characterized by aggressive development that makes it difficult to install other species on the site. The influence of invasive exotic species in these plots reflects the low average altitude of the individuals (5 meters) and the lower relative density among all plots (0.67%) (Table 1). *T. stans* sprouts after drastic pruning and has a high potential to spread over extensive areas in Seasonal Semideciduous Forests; in addition, its allelopathic effect prevents the development of other species around it, which slows down the natural regeneration of the environment (Madire et al., 2011).

In plot four, 150 individuals were recorded, belonging to 14 species (Table 1). Due to the distance from the agricultural area, this plot had a higher density (12.55%), characterizing a region with higher diversity, despite the influence of microclimate changes and liana infestation. The maintenance of original characteristics of the forest is directly associated with the shape and size of the fragment and not only its distance from the edge, as the size allows for a greater number of habitats and with this, greater conditions for the preservation of species (Ferreira et al., 2018).

The area showed the largest number of standing dead individuals and the massive presence of the exotic species *Merostachys speciosa* Spreng. in plots seven and eight, which may be related to the slopes of 35.85% and 32.91% in these plots (Table 1) and the dynamics of the species. This species tends to be concentrated in more favorable areas, as is the case of sloping areas, and although erect at the beginning of its growth, adult stems are supported by other trees to reach the forest canopy. In this process, small and medium-sized trees on which the stems rest are damaged, and the high concentration of stems can apply an excessive weight on the supporting trees, which may fall. Without support, stems fall on smaller plants in the understory, opening clearings and forming a biomass that blocks the passage of light and physically suppresses the recruitment of other trees. The open clearings are occupied by new bamboo stalks, which maintain a dynamic cycle of forest disturbance (Ferreira, 2014).

Along with plant composition, the characteristics of the forest canopy indicate its successional stage. The forest canopy of this fragment had heights ranging from 1.5 meters (minimum) to 25 meters (maximum), total basal area of 15.6 m^2/ha and average forest height of approximately 8 meters, which according to the CONAMA Resolution 2 of 1994 classifies the fragment successional stage as Secondary.

3.3. Detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA)

Soil limitations combined with human exploration favored the dominance of few species and this is reflected in the distribution pattern in the area, although some species are in certain regions of the forest, these have low coverage value and do not characterize the region. The same can be observed with respect to nutrients on species distribution, the Canonical Correspondence Analysis was not able to set patterns of species distribution in relation to macro- and micro-nutrients of the soil (Figure 2). The species had a scattered distribution in the area with low explanatory power for the axes of the Detrended Correspondence Analysis, 27% in axis one, and 5% in axis two, and only the

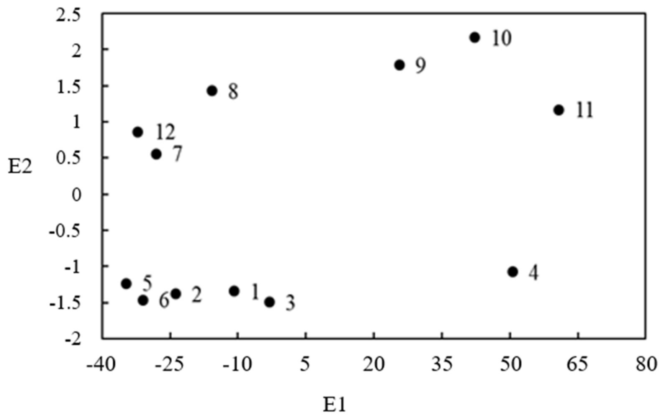

Figure 2. Patterns of distribution of the species pointed out by Canonical Correspondence Analysis between species distribution and soil chemical variables.

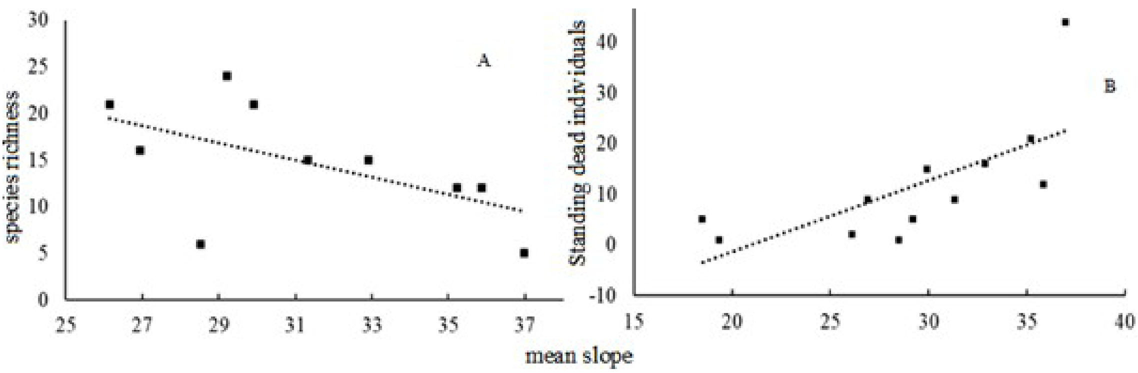

Figure 3. Patterns of distribution of the species pointed out by Canonical Correspondence Analysis between species distribution and soil chemical variables.

cluster of plots with less species occurrence (plots two, five and six) was observed.

The area showed a steep slope, from 18.05% to 36.99% (Table 1). The topography of the terrain showed variations in slope with the formation of small plateaus. These plateaus receive the sediment carried from the most sloping areas and present better conditions for the development of forest species. Linear regression analysis (r^2=0.47; p=0.009) highlighted the opposite pattern of species richness in relation to slope (Figure 3A).

Plots with higher slopes (five and six) and those with the lowest richness and the greatest edge effect (one, two and three) were closer in the ordination (Figure 2). The species distribution on the slopes is a response to environmental variations on a local scale (Cortines, et al., 2011). The relationship between the slope and the number of standing dead individuals is not limited to only three plots, with a significant relationship by regression analysis (r^2 = 0.5; p = 0.001) (Figure 3B).

This loss of species in slopes is supported by other studies that highlight, in addition to shallow soils, the leaching process that carries essential nutrients for plant development (Souza et al., 2013; Velazco et al., 2015). Arboreal individuals face limitations to full development imposed by soil and topographic factors, such as: depth, particle size and slope (Souza et al., 2017), characteristics observed mainly in plots five and six, which are located at average slopes of 35.22% and 36.99%, respectively, which may explain the greater number of standing dead individuals (Figure 3B).

Species richness was also positively related to the distance from forest edge (Figure 4), with the highest value of r^2 = 0.71 (p = 0.0005). The greatest richness was found in plots located in the highest portions further from human activities (Table 1).

The edge effect occurs with greater intensity over the first 50 m from the edge to the interior of the forest (Figueiró, 2015). In areas of intense human activity, this effect goes far beyond this limit, influencing the species distribution in the forest (Campos et al., 2018). In forest fragments, influence on richness is related to the period in which the last intervention occurred (Turchetto et al., 2017). Natural or human disturbances can alter the diversity and composition of species in short periods (Marcuzzo et al., 2013), which can have major consequences for the succession, dynamics and functioning of the ecosystem.

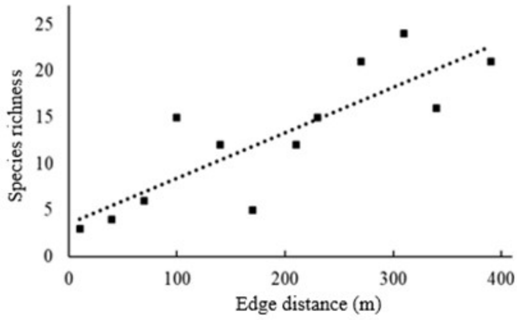

Figure 4. Graphical representation of regression analysis of the influence of mean slope on (A) species richness; (B) Standing dead individuals.

4. Conclusion

This study showed how the structure and composition of the forest fragment is influenced by physiographic aspects, including soil depth and slope. Soil depth is an important physical factor that limits the growth of tree species. On the other hand, slope stood out in the multivariate and regression analysis as the element with the strongest influence on species composition of the studied fragment. These aspects are common to several forest fragments of the Atlantic Forest domain, are important in forest dynamics, and should be considered in restoration or conservation actions in the domain.

Despite the limitations and isolation, this fragment is important due to species diversity characteristic of the seasonal forest, which is related to fauna, such as *Zanthoxylum rhoifolium, Maclura tinctoria* and *Astronium graveolens*. Some maintenance measures, such as banning access to the site by cattle in the region, and the monitoring and control of the alien species *Tecoma stans* and the exotic species *Merostachys speciosa*, would contribute to the conservation of the fragment.

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