DISTRIBUTION AND MAINTENANCE OF VEGETATION ADJACENT TO HIGH VOLTAGE TRANSMISSION LINES, SOUTHERN BRAZIL

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Abstract. Vegetation is the main cause of power outages; therefore, it is fundamental to carry out maintenance to prevent the interruption of electric power. In general, the maintenance of transmission lines is performed without previous studies on floristic composition. In this sense, it is necessary to establish the floristic composition and the factors that influence the establishment of the species to determine the best practices of maintenance. In this study, we evaluated which environmental and spatial factors influence species distribution in order to improve the maintenance of vegetation adjacent to high voltage transmission lines. The vegetation was sampled in 25 plots of 300 m^2, distributed randomly and prioritizing the main span of the power transmission line. The main factors that influenced species distribution were elevation, leaf area and Mg/K ratio, all associated with the spatial factor. Therefore, maintenance along transmission lines should prioritize species associated with higher elevations and leaf area, considering a risk height of 7 meters.

Keywords: *Atlantic Forest, environmental variables, electrical energy, power outages, RDA*

Introduction

The Atlantic Forest is the second largest tropical pluvial forest on the American continent, it covers approximately 1,300,000 km^2 in Brazil, being more representative in the south (Ribeiro et al., 2011; Rocha and Silva, 2013). This unit includes different forest types, climatic zones and it presents high species richness and endemism (Rocha and Silva, 2013). The Atlantic Forest is currently fragmented, with only 11.7% of its original coverage (Ribeiro et al., 2011). These forests are priority areas for the conservation of biological diversity, due to the exploitation processes and advanced stage of degradation (Ribeiro et al., 2011; Silverio Neto et al., 2015).

The process of degradation of the Atlantic Forest is usually associated with logging and conversion of Forests to agricultural and livestock areas. In addition to these activities, the installation and maintenance of power transmission lines has been causing severe environmental damage. For example, vegetation removal to build power transmission lines exposing the soil to erosive processes, as well as fragmenting ecosystems and altering natural succession (Dupras et al., 2015). Among the aspects to be evaluated in the maintenance of power transmission lines, we have metal structures

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and the objects that can cause power cuts (e.g., arboreal vegetation) (Matikainen et al., 2016). Accidents associated with vegetation are common, both in the urban and rural areas, and it is fundamental to carry out maintenance to prevent the interruption of electric power (Ahmad et al., 2014).

Usually, previous monitoring for maintenance of transmission lines is performed by aerial and visual survey (Matikainen et al., 2016), without previous studies about the floristic composition under the transmission lines. Thus, the improvement of vegetation maintenance techniques can benefit the electrical companies and the consumer (e.g., costs and risks reduction) (Kuntz et al., 2002). In addition, the use of pruning and vegetation cutting techniques can minimize the impacts generated by transmission networks, reducing the loss of natural habitats and forest fragmentation (Young, 2010).

Regardless of the maintenance technique used, it should be considered that the vegetation maintains growth variations throughout the year (Lopes, 2013). Therefore, it is essential to analyze the floristic composition and density, annual increments and growth rates (Lopes, 2013). For example, species growth is associated with several factors, such as luminosity, elevation and soil properties (e.g., fertility, depth and soil types) (Jurinitz et al., 2013; Moraes et al., 2013; Maçaneiro et al., 2016, 2019). In this way, the relationship between environmental variations and floristic composition can positively affect the frequency and intensity of vegetation maintenance, directly influencing the practice and the cost for the company.

Therefore, it seems reasonable to evaluate the environmental and spatial factors that influence the distribution of species in order to determine the best practices of maintenance (e.g., pruning) of vegetation adjacent to the power transmission lines. Thus, the goal of this study was to evaluate the influence of environmental and spatial variables on the distribution of species of forest fragments adjacent to power transmission lines and to determine the best practices of maintenance.

Material and Methods

Study area

The object of the study is forest remnants in distinct stages of succession located in an area adjacent to the power transmission line. This transmission line was installed in 1978. Along these areas, the responsible company for the transmission line regularly performs maintenance in the vegetation. In general, pruning and removal of trees or branches that may cause a power outage are performed. The maximum height that the vegetation can be to the electrical cables is 7 meters.

The transmission line is 65 km long and it covers 14 municipalities in the state of Rio Grande do Sul, southern Brazil (*Figure 1*). The region is part of the *Guaíba* river basin and it presents an altitude variation between 90 and 600 meters.

The climate of the region, according to the classification of Köppen, is of the type humid subtropical – Cfa, without dry season and with hot summer. The annual mean temperature fluctuates between 9°C to 26°C, annual mean precipitation from 1,600 to 2,200 mm, and relative humidity between 60 and 85% (Alvares et al., 2013).

The geology of the region is formed by the *Botucatu* Formation and *Serra Geral* Formation, presenting sandstones and basalts, respectively. The predominant soils are Litholic Neosols and Regolithic Neosols (Brazilian Classification) (Santos et al., 2018), and in general have high fertility (V% > 70%).

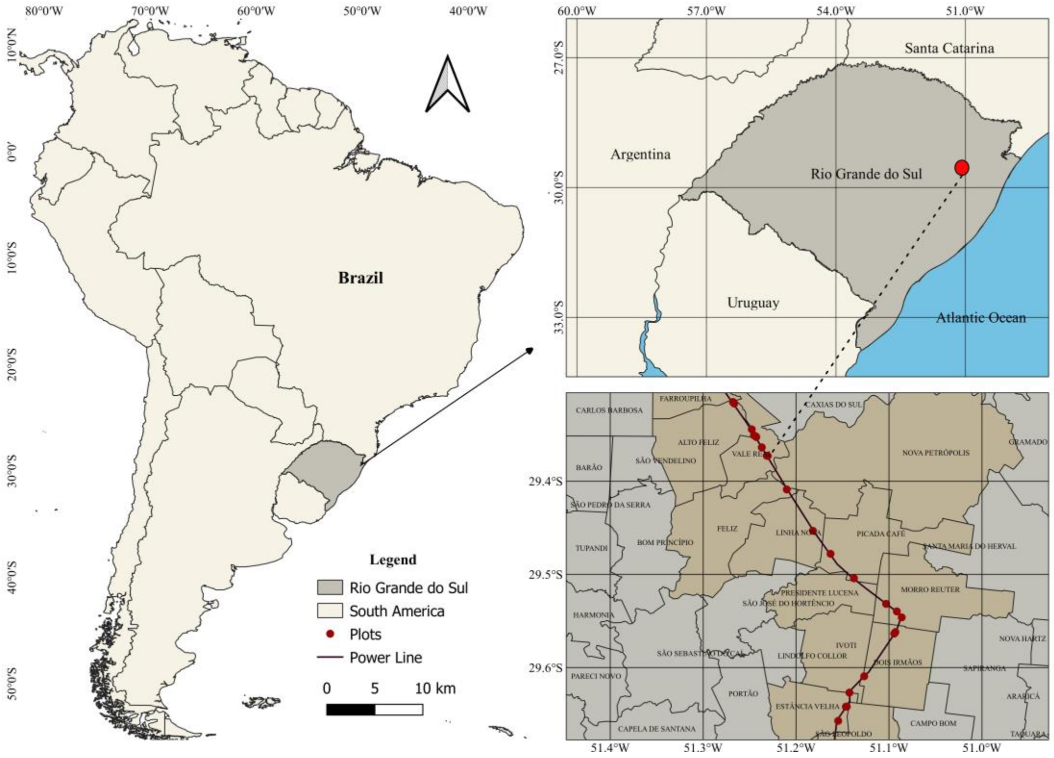

Figure 1. *Location of the study area and plots in a power transmission line, southern Brazil*

The predominant forest type is subtropical deciduous forest in distinct stages of succession. The structure of the vegetation that represents this formation is linked to the altitudinal and climatic variations, which according to Scipioni et al. (2013) guarantee heterogeneity of species in different Brazilian forest formations. Among the most representative species are *Apuleia leiocarpa* (Vogel) JF Macbr., *Trichilia claussenii* C. DC., *Sorocea bonplandii* (Baill.) WCBurger et al., *Nectandra megapotamica* (Spreng.) Mez.

Data collection

To characterize forest structure and determine environmental and spatial variables we sampled vegetation in 25 plots 300 m^2 (10 m x 30 m), parallel to the main span of the power transmission line. In each plot we sampled all arboreal individuals with diameter at breast height – DBH ≥ 5 m and height > 1.3 m. We collected the data between March/2018 and October/2018. We identified the collected botanical material by comparison with exsicates deposited in the Herbarium *Dr. Roberto Miguel Klein* and by consulting the taxonomic literature and the specialists the U*niversidade Regional de Blumenau (FURB)*.

To obtain the chemical properties of the soil, in each plot we collected soil samples in the depth of 0 - 20 cm, i.e. we collected five points per plot and stirred the soil. Then, we stored the samples in plastic bags and sent them to the Laboratory of Soil Analysis of *EPAGRI (Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina)* to obtain the chemical variables: clay content (m/v - %), pH, phosphorus (P – mg/dm^3), potassium (K – mg/dm^3), organic matter (%), aluminum (Al – $cmolc/dm^3$), calcium (Ca – $cmolc/dm^3$), magnesium (Mg – $cmolc/dm^3$), SMP index, potential acidity (H+Al –

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cmolc/dm^3) and calculated the cation exchange (CTC – cmolc/dm^3), aluminum saturation (m%) and base saturation (V%), base sum (S), and relation Ca:Mg, Ca:K and Mg:K (Santos et al., 2018).

To obtain the physical properties of the soil, we collected samples with volumetric rings of the Kopecky type of known volume, i.e. we collected three points per plot. After these collections, we stored and weighed the samples for later drying them in a drying kiln (105°C). With these samples, we determined the soil humidity (%) through the volumetric method and total porosity (%) and soil density (g.cm^{-3}) according to Teixeira et al. (2017).

To verify the luminosity condition of the arboreal stratum, we evaluated through the hemispherical photographies the canopy opening (Parker and Russ, 2004). In each plot we took four hemispherical photographs. We use a Nikon D3100 digital SLR camera and Nikon Fisheye Nikkor 10.5 mm lens. The camera was attached to a tripod and was facing the forest canopy at a height of 1.30 m from the ground (Silva, 2016). The photos were analyzed in the software *Hemisfer 2.2* to obtain the values of canopy opening (%) and leaf area (m^2.m^2) (Thimonier et al., 2010).

We obtained the elevation through a GPS Garmin 62CSx. We obtained the bioclimatic variables (Annual Mean Temperature, Mean Diurnal Range, Isothermality, Temperature Seasonality, Max Temperature of Warmest Month, Min Temperature of Coldest Month, Temperature Annual Range, Mean Temperature of Wettest Quarter, Mean Temperature of Driest Quarter, Mean Temperature of Warmest Quarter, Mean Temperature of Coldest Quarter, Annual Precipitation, Precipitation of Wettest Month, Precipitation of Driest Month, Precipitation Seasonality, Precipitation of Wettest Quarter, Precipitation of Driest Quarter, Precipitation of Warmest Quarter, Precipitation of Coldest Quarter), for each plot, in the data base of Fick and Hijmans (2017).

Data analysis

We calculated the values of relative density (% individuals of a species in the community) and frequency (% absolute frequency of a species in the community) through the phytosociological parameters described by Mueller-Dombois and Ellenberg (2002). During this process, we used the “spacemakeR” package in R environment (R Core Team 2013), according to the recommendations of Borcard et al. (2011) and Eisenlohr (2014).

After that, we removed collinear environmental variables through principal component analysis (PCA) in PC-ORD 6.0 (McCune and Mefford, 2011). After this procedure, the environmental variables that remained in the analysis were clay content (m/v – %), pHH_2O, SMP index, aluminum (Al – cmolc/dm^3), calcium (Ca – cmolc/dm^3), magnesium (Mg – cmolc/dm^3), potassium (K– mg/dm^3), phosphorus (P – mg/dm^3), organic matter (MO%), potential acidity (H+Al – cmolc/dm^3), cation exchange (CTC – cmolc/dm^3), aluminum saturation (m%), base saturation (V%), base sum (S), and relation Ca:Mg, Ca:K and Mg:K, soil humidity (%), soil density (g.cm^{-3}), canopy opening (%), leaf area (m^2.m^2), elevation (m), annual temperature (°C) and annual precipitation (mm).

Subsequently, we used a species composition matrix. To correct the distinct units of measure, the environmental matrix was standardized (`standardized score` transformation). The spatial matrix (MEMs) was established through the geographic coordinates (latitude and longitude). In this procedure we used the Environment R, with the package “spacemakeR” (Borcard et al., 2011). The MEMs (Moran’s Eigenvector

Maps) were selected through the “forward” method. The environmental variables were selected through the canonical analysis of RDA. Finally, the last RDA was processed in the PC-ORD 6.0 (McCune and Mefford, 2011), using the composition matrix with the environmental (standardized) and spatial (MEMs) variables selected to verify the effect of these variables in the distribution pattern of the species in the study site. The statistical significance of the RDA ordering axes was verified by means of 999 Monte Carlo permutations (Legendre and Legendre, 2012).

Then, we performed the partitioning of the variance into the data set in order to separate the fractions relative to the environment [a], the spatially structured environment [b], only the space [c] and the undetermined variables [d]. In this analysis, we used the “vegan”, “packfor”, “spacemakeR” and “spdep” packages in the R Environment (R Core Team 2013).

Results

In the 25 plots along the power transmission line, a total of 1,444 individuals (total absolute density= 1,925 ind/ha) were sampled, belonging to 101 species and 38 botanic families (*Table 1*). The species with the highest density and frequency values were *Cupania vernalis*, *Nectandra megapotamica*, *Sambucus australis*, *Trema micrantha*, and *Allophylus edulis*.

Table 1. *Species with the highest density and frequency values in the arboreal stratum adjacent to power transmission line in southern Brazil*

Family	Specie	*DR*	*FR*
Sapindaceae	*Cupania vernalis* Cambess.	12.9	5.9
Lauraceae	*Nectandra megapotamica* (Spreng.) Mez	6.4	5.9
Adoxaceae	*Sambucus australis* Cham. & Schltdl.	6.3	2.6
Cannabaceae	*Trema micrantha* (L.) Blume	5.1	3.4
Sapindaceae	*Allophylus edulis* (A.St.-Hil. et al.) Hieron. ex Niederl.	5.1	4.6
Malvaceae	*Luehea divaricata* Mart. & Zucc.	5.0	3.7
Primulaceae	*Myrsine umbellata* Mart.	4.8	3.7
Lauraceae	*Persea americana* Mill.	3.5	1.4
Escalloniaceae	*Escallonia bifida* Link & Otto	3.4	0.6
Fabaceae	*Machaerium stipitatum* Vogel.	3.0	3.1
Euphorbiaceae	*Alchornea triplinervia* (Spreng.) Müll.Arg.	2.6	2.3
Salicaceae	*Casearia sylvestris* (Vell.) Mart.	2.4	4.0
Meliaceae	*Trichilia clausseni* C.DC.	2.1	1.7
Rubiaceae	*Psychotria suterella* Müll.Arg.	2.1	0.3
Fabaceae	*Parapiptadenia rigida* (Benth.) Brenan	1.8	3.1
-	Others species	33.5	53.7
-	**Total**	**100**	**100**

DR = relative density (%), FR = relative frequency (%)

In the redundancy analysis (RDA) (*Figure 2*, *Table 2*), the plots differed according to the variation in environmental and spatial variables. The eigenvalues of the first two ordering axes explained 14.6% of the data variance (axis 1 = 8.2%, axis 2 = 6.4%) and presented significance by the Monte Carlo test ($p \leq 0.05$). The environmental and spatial variables that correlated with axis 1 were MEM 1 and MEM 5, while for axis 2 were leaf area (LAI), elevation, Mg:K content and MEM 2.

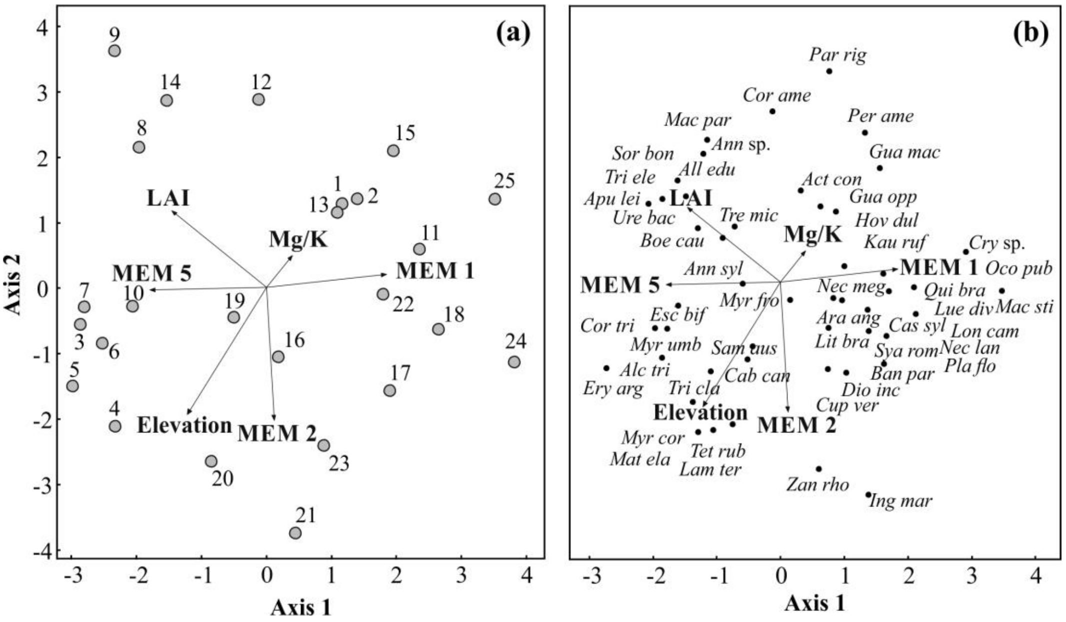

Figure 2. *Redundancy analyzes (RDA) produced by plots, species and environmental and spatial variables in forest fragments under power transmission lines in southern Brazil*

Table 2. *Environmental and spatial variables produced by the RDA for forest fragments under power transmission lines in southern Brazil. R² adjusted, F and p were obtained by ANOVA after partitioning the variance*

Predictor	*R*² adjusted (%)	*F* (ANOVA)	*p* (ANOVA)
Elevation	7.0	1.74	0.001
MEM 1	5.8	1.41	0.02
LAI	5.7	1.45	0.02
MEM 2	5.7	1.43	0.02
MEM 5	5.6	1.43	0.02
Mg/K	5.5	1.42	0.01

In the ordination diagram of the plots, we verified that the first two axes had a strong relation between area leaf and elevation and the spatial variable MEM 1, MEM 2 and MEM 5. The axes formed three groups of plots, the first one being related to the leaf area. These groups are influenced directly to the spatial variable MEM 5. The second group had strong relation with the elevation, and it was influenced by the spatial variable MEM 2. We verified the formation of a gradient between MEM 1 and the plots. In addition, we observed the formation of a short gradient related to the Mg:K relation (*Figure 2a*).

In the diagram of species ordination, we verified a strong association with the leaf area and the density of arboreal individuals of *Apuleia leiocarpa* (Vogel) J.F.Macbr., *Sorocea bonplandii* (Baill.) W.C.Burger, *Trichilia elegans* A.Juss., *Allophyllus edulis* (*Figure 2b*), therefore, distinct levels of luminosity will affect the density of these species. While in areas with open canopy we found other predominant species, like *Araucaria angustifolia* (Bertol.) Kuntze, *Nectandra megapotamica*, *Syagrus romanzoffiana* (Cham) Glassman, *Banara parviflora* (A.Gray) Benth., *Platymiscium floribundum* Vogel.

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In the same sense, the formation of two gradients was observed between species with preference to soils with high Mg:K relation and areas with low elevation (e.g., *Actinostemon concolor* (Spreng.) Müll.Arg., *Persea americana*, *Guarea macrophylla* Vahl., and *Guapira opposita* (Vell.) Reitz). The species associated with higher elevation are influenced directly by the spatial variable MEM 2. Thus, some biotic variation can influence directly on the species distribution. On the other hand, the species *Sambucus australis* Cham. & Schltdl., *Trichilia clausseni, Myrsine coriacea* (Sw.) R.Br. ex Roem. & Schult., and *Matayba elaeagnoides* Radlk, are associated to areas of higher elevation and lower Mg/K relation.

Partitioning of variance revealed that fractions [a] "pure" environment (F = 1.34, p = 0.007) and [c] "pure" space (F = 1.24, p = 0.04) were significant (*Figure 3*). The fraction [b], related to space + environment, indicated that part of the analyzed environmental variables (2%) is structured in space, while the [a] "pure" environment (5%) and [c] "pure" space (3%) stood out among fractions. However, the fraction [d] relative to the undetermined variables explained most of the vegetation variation in the study area (90%).

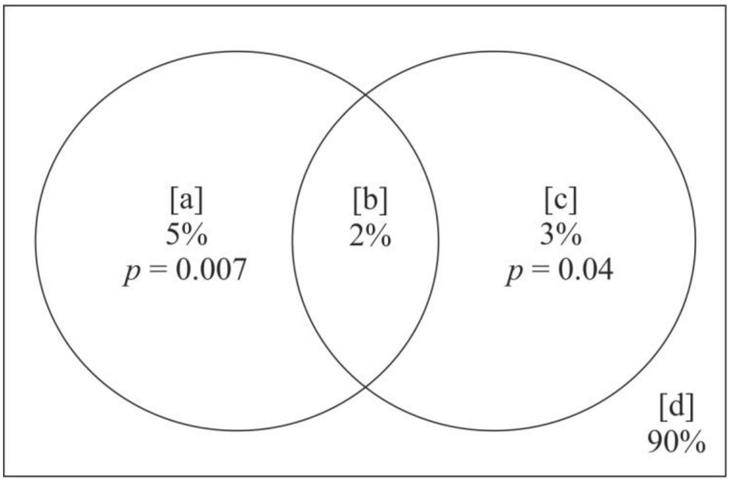

***Figure 3.** Partition of the variance by the redundancy analysis to determine the fractions "pure" environment [a], space + environment [b], "pure" space [c] and undetermined variables [d] for forest fragments under power transmission line in Southern Brazil*

Discussion

In the present study we observed that some environmental variables have influence the distribution of species present in forest fragments adjacent to transmission lines. In addition, the spatial structure had a direct influence on the environmental variables, presenting a relevant role in the species distribution.

The elevation was the predictor that most influenced the distribution of the species. Studies indicate that elevation is an indirect environmental variable that influences vegetation distribution and characterization of forest types in the Atlantic Forest (Nettesheim et al., 2010; Maçaneiro et al., 2016; Duarte et al., 2019). In this study, not just the elevation has influence in the distribution of the species, but local features can directly influence the vegetation within the same altitudinal level (e.g., wind actions, watercourse) (Sanchez et al., 2013). Thus, higher elevation directly affects the floristic composition and, consequently, the maintenance of power transmission lines.

We observed that *Sambucus australis* has high density in plots that were inserted in the highest elevation. Generally, this specie is in slopes areas (Grings and Brack, 2009). In this study, we identified a strong relation between the species distribution and the elevation variation, probably related to the environmental heterogeneity presenting in the power transmission line. In this same sense, the species distribution is associated to the elevation, luminosity and soil properties, granting predominance of certain species (Cardoso and Schiavini, 2002).

Considering the influence of the environmental variables in the present study, we observed that the leaf area positively affects the distribution of certain species (e.g., *Apuleia leiocarpa, Sorocea bonplandii, Allophyllus edulis*). The leaf area is associated with mass and energy changes, and is directly related to evapotranspiration, hydrology and ecology of the species (Wang et al., 2005; Galvani and Lima, 2014). Studies indicate that leaf area vary according to species composition, local conditions, successional stage, forest dynamics and light conditions, among others (Leblanc and Chen, 2008). According to Moraes et al. (2013), the leaf area is associated with ecological variations in the environment, influencing the productivity, growth, and reproduction of the species. Therefore, the application of the maintenance in species adapted to higher luminosity directly affects its growth and, consequently, if carried out in the vegetative period, the growth will be positively affected, increasing the cost and number of times to be performed the maintenance.

In the same way, the Mg:K relation in the soil is associated with the presence of some species. In areas with more fertile soils, there are differences in floristic composition, density of dominant species, and lower fertility in the soil selects species with low nutritional requirements (Moreno et al., 2007). Unlike to the present study, floristic composition is generally associated with soil pH, moisture, fertility and texture (Mélo et al., 2013). According to Maçaneiro et al. (2019), floristic richness increases in relation to water availability and soil depth. In this way, shallower soils may have lower floristic richness. In addition, nutritional availability will directly affect plant growth. Overall, the area exhibits high fertility rates affecting plant growth positively.

In addition to elevation, leaf area and Mg:K content in the soil, the spatial factors were also predictors that influence the distribution of the species in fragments adjacent to power transmission lines. We observed that generally the spatial component is associated with the environmental variables that are related to the distribution of the species. We believe that it is possible that the soils variations, luminosity and elevation are conditioned to biotic and/or stochastic processes (e.g., such as dispersion and competition) (Diniz-Filho et al., 2012; Lewis et al., 2014). In this study the spatial component revealed a significant fraction on the floristic component, indicating the importance of the neutral processes on the vegetation.

In this study the distribution of *Cupania vernalis* is directly associated with biotic factors. This species presented the highest density and, therefore, is one of the species that must be taken into consideration for maintenance practices. This species is generally found in different topographic variations, but in higher density at high altitudes (~ 700 m) (Souza et al., 2015) and its growth is directly affected by the luminosity level (de Castro Lima et al., 2006). The association between the spatial predictor MEM 2 and elevation evidence that the specie can be observed in areas of higher elevation and it is being influenced of spatial component and linked to the altimetric quotes.

The biotic variations are usually attributed to the spatial component, like the dispersion that provides different distribution patterns of species, such as anemocory that provides a random pattern, for example the fruits and seeds are distributed randomly in space (Urbanetz et al., 2003; Maçaneiro et al., 2018). The dispersion is among the most affected ecological processes in the life cycle of the plants, besides playing a fundamental role in the colonization and evolution of the species, it varies according to the elevation (Wang and Smith, 2002; Urbanetz et al., 2003; Almeida-Neto et al., 2008; Neuschulz et al., 2016). This justifies the relation of spatial factors to elevation, whereas the processes of facilitation and competition do not depend on the physical factors of the environment and on different climatic conditions (Mélo et al., 2013). Environments with more adversity (e.g., practice of maintenance of the vegetation) directly affects the species performance providing the facilitation process and acting like an ecological filter and influencing in the floristic composition (Temperton and Hobbs, 2004). Others processes that affect the species distribution are polinization and the seeds predation, being responsible for the species maintenance and presenting adversity for the establishment of the plants (Wang and Smith, 2002). Considering this, we observed that each specie has particularities, like polinization, dispersion, and it will be directly associated to the distribution and consequently to the density/frequency that the species will be found in certain place, influencing in the intensity of the maintenance of the power transmission line. In this case, the association of the spatial factors and environmental variables in the comprehension in how the vegetation is distributed in the power transmission line to determine the best maintenance practices (e.g., pruning intensity and cutting) which may avoid the fragmentation of the forests remnants and then reducing the costs for the electrical company.

The partitioning of the variance indicated that the highest percentage of factors that interfered in distribution patterns is related to unknown fractions (90%). According to Lewis et al. (2014), variation of species composition along the plots and heterogeneity are factors that increase the unknown fractions. In addition, the environmental variables used are not necessarily the predictors that best explain the species distribution variations (Soininen, 2014). Another reason is the weakening of environmental responses when using a variance partition (Angeler et al., 2013). However, it revealed that purely environmental (5%) and purely spatial (3%) factors were statistically significant and could account for part of the distribution of species along in the power transmission line. The purely environmental fraction indicates that environmental variables are strongly related to the composition of species, while the purely spatial fraction presented a low explanation, justified by the high variation along the power transmission line. Nevertheless, the spatial component was significant in explaining species distribution patterns. In this sense, the inclusion of variables such as dispersion factors, water and light are necessary to determine the unknown fractions. In addition, the species respond interactively to environmental conditions, evidencing the complexity of the soil-plant-environment relationship (Siqueira et al., 2009).

Another hypothesis for the low environmental explanation is related to the maintenance practices that are performed in the vegetation adjacent to the transmission line, which may affect the forest structure and ensure greater homogeneity along the transmission line.

The spatially structured environment (2%) affects the spatial distribution of the species, influencing where species are distributed, i.e., the greater the distances between the samples, the more floristic differences will be observed (Diniz-Filho et al., 2012). This fact is evidenced in the present study, since the power transmission lines cover an extension of 65 km, that is, the sites sampled are generally separated at great distances, with a distinction being made between ecological sequences and floristic differences. The indeterminate variables presented high percentage, this fact occurred due to the great environmental heterogeneity and not to include all the variables that can act in the distribution of the species. Therefore, the inclusion of new biotic and abiotic factors would possibly increase the explanation of the variables on species distribution (Maçaneiro et al., 2016), or the inclusion of new plots to reduce floristic and site variability.

Conclusion

In our study, given the relationship found between vegetation and spatial/environmental variations, we suggested to perform selective maintenance in the vegetation. Thus, species such as *Araucaria angustifolia, Nectandra megapotamica, Syagrus romanzoffiana, Banara parviflora, Platymiscium floribundum*, which are associated with high luminosity should be managed with pruning or, if necessary, tree suppression, before reaching the height of risk. In addition to these species, *Sambucus australis, Trichilia clausseni, Myrsine coriacea, Matayba elaeagnoides*, which are associated with elevation, must also be managed when they reach the height of risk.

Although soil (Mg:K) ratio is associated with species distribution, due to homogeneity of soil fertility along the transmission line, this factor was not used as a criterion for species selection for maintenance. Given the difficulty of selective management, it is recommended at least to manage vegetation when it reaches 7 meters in height, thereby reducing the intensity of maintenance of areas under power transmission lines, minimizing costs with this activity. and minimizing the impacts generated.

In addition, this study was developed on a local scale, in this sense, we suggest the development of other studies with complementary information such as competition, dispersion and microclimate, since the addition of these variables can increase the predictive power of floristic patterns in subtropical forests, and offers indicators to improve or plan the management of native forests under electric power lines.

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