FLORISTIC-STRUCTURAL VARIATION OF NATURAL REGENERATION ALONG DIFFERENT TOPOGRAPHIC POSITIONS OF AN ECOTONAL FOREST IN SANTA CATARINA, BRAZIL[1]

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ABSTRACT – Studies on the natural regeneration of tree species communities are important for providing information on forest development capacity. This research aimed to evaluate the floristic-structural variations of the tree regenerative component along a topographic gradient in an ecotonal area between a Mixed Ombrophilous Forest and a Deciduous Seasonal Forest of Santa Catarina, Brazil. 30 sampling units of which all regenerating tree species individuals have been identified were allocated in the forest fragment. The sampling units were then distributed along a topographic gradient into lower, intermediate and upper sectors. Abundance, richness, Shannon's diversity index (H') and Pielou's evenness index (J) have been determined for both the whole community as for each sector. The community floristic-structural organization was verified by the means of the non-metric multidimensional scaling (NMDS), the indicator species analysis and the permutational multivariate analysis of variance (PERMANOVA). Abundance differences among sectors were analyzed through the Kruskal-Wallis test with post hoc multiple nonparametric test while richness differences were verified through rarefaction. Regenerating individuals density in the upper sector [129 (21.300 ind.ha^{-1})] was lower than both in the lower [401 (63.800 ind.ha^{-1})] and intermediary [241 (36.300 ind.ha^{-1})] sectors. There was variation in the floristic-structural composition ($p < 0.001$) among topographic positions; the lower sector was the most distinct one and showed the highest number of indicator species.

Keywords: **Regenerative component; Toposequence; NMDS.**

VARIAÇÃO FLORÍSTICO-ESTRUTURAL DA REGENERAÇÃO NATURAL EM DIFERENTES POSIÇÕES TOPOGRÁFICAS EM UMA FLORESTA ECOTONAL EM SANTA CATARINA

RESUMO – Estudos sobre a regeneração natural de comunidades de espécies arbóreas são importantes por fornecer informações sobre a capacidade de desenvolvimento da floresta. O presente trabalho objetivou avaliar as variações florístico-estruturais do componente arbóreo regenerativo ao longo de um gradiente topográfico, em uma área ecotonal entre Floresta Ombrófila Mista e Floresta Estacional Decidual em Santa Catarina. No fragmento florestal, foram instaladas 30 unidades amostrais, onde todos os indivíduos arbóreos regenerantes foram identificados. As unidades amostrais foram distribuídas em três setores ao longo de um gradiente topográfico: setor inferior, intermediário e superior. Para a comunidade como um todo e para cada setor, foram determinados a abundância, riqueza, índice de Shannon (H') e equabilidade de Pielou (J). A organização florístico-estrutural da comunidade foi verificada por meio do Escalonamento Multidimensional Não-Métrico (NMDS), análise de espécies indicadoras e Análise de Variância Multivariada Permutacional (PERMANOVA). Diferenças de abundância e riqueza entre os setores foram avaliadas, respectivamente, pela Análise de Kruskal-Wallis, com teste múltiplo não paramétrico, e rarefação. Houve baixa densidade de indivíduos regenerante

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*inferior e 241 (36.300 ind.ha^{-1}) no intermediário]. Observou-se que a composição florístico-estrutural foi variável entre as posições topográficas (*p *< 0,001), sendo o setor inferior o mais distinto dos demais e com maior número de espécies indicadoras.*

Palavras-Chave: Componente regenerativo; Topossequência; NMDS.

1. INTRODUCTION

The southern Brazil Atlantic forest has different formations, such as the Mixed Ombrophilous Forest (MOF) occurring at generally higher than 500 m altitudes and the Deciduous Seasonal Forest (DSF) occurring from 150 to 800 m high (Klein, 1978). In the altitudes where they overlap their contact results in the formation of ecotone areas. These ecotonal areas are not homogeneous and may be influenced by a number of local physical factors, such as edaphic and topographic variations.

A high terrain variation is observed in the ecotonal areas of the Upper Uruguay region where rivers are known for draining into "steep" valleys. In such places, there is a sequence of different types of soils spread along the landscape according to topography (Cunha et al., 2009). The organization of both adult and regenerating tree species communities developing in such environments are conditioned in a small spatial scale by environmental factors related to topographic gradients (Rodrigues et al., 2007; Scipioni et al., 2009; Budke et al., 2010; Souza et al., 2015; Braga et al., 2015; Guo et al., 2017; Mohammadi et al., 2017). According to Gandolfi (2000) and Jafari et al. (2003) this happens because declivity acts as a factor that produces a variety of environmental situations in soil particle transport and vertical canopy organization, such as moisture gradient. That explains the importance of topographic variations on the organization of tree vegetation, as reported in former studies (Rodrigues et al., 2007; Braga et al., 2015), including the adult component of the same area (Souza et al., 2015).

One of the most critical phases for the establishment of tree species in forest communities refers to their regeneration stage under the understory condition (Kitajima and Fenner, 2000; Poorter, 2007). Studies aiming to deepen the knowledge on the factors that influence this stage are therefore relevant as they allow a better understanding on the development of a forest under natural conditions. Upper Uruguay stands out among the Brazilian southern regions where studies of this nature are necessary for subsidizing both conservation and restoration strategies since its forests face a critical status of conservation due to its selective exploration and forest fragmentation history. In this sense, the main goal of this study was to investigate the floristic-structural organization of the regenerative component according to its topographic position in an ecotonal area between the Mixed Ombrophylous Forest and the Deciduous Seasonal Forest of Santa Catarina, Brazil. Considering the topographic gradient, a high floristic-structural variation is expected thus reinforcing the importance of conserving different microhabitats in a forest under such conditions.

2. MATERIALAND METHODS

The study was conducted in an advanced successional stage area previously inventoried (adult tree component) by Souza et al. (2015). It is an ecotonal area between the Mixed Ombrophilous Forest and the Deciduous Seasonal Forest in the municipality of Capão Alto, SC, Brazil (28º11'29"S and 50º45'34"L and altitude about 600 to 700 m). Its topography varies mainly from smooth to gentle slopes and its higher-sloped areas are near the main rivers of the region therefore forming steep valleys located in the sandstone-basalt plateau. It has a Cfa climate according to Köppen classification and its average annual rainfall varies from 1,200 to 1,900 mm well distributed along the year. According to the CRU CL 2.0 database (New et al., 2002) the average temperatures of its coldest and hottest months in the last 30 years (1985-2015) were 12.0ºC in July and 20.7°C in January, respectively (Grechka et al., 2016).

Data were collected in a hillside on the banks of the Barra Grande dam on Pelotas River, which reservoir is formed since 2005. Three sectors have been defined for the area: lower sector (near the generally less-sloped reservoir bank which shows moisture and areas subject to flooding), intermediate sector (highly sloped in the middle of the hillside), and upper sector (also highly sloped but at the top of the hillside). Each sector's slope was measured by Souza et al. (2015) who have observed about 14.38º (± 2.64), 19.74º (± 1.98) and 20.66º (± 1.24) for the lower, intermediate and upper sectors, respectively.

For characterizing the regenerative tree component (DBH lower than 5 cm and height higher or equal to 20 cm) we have used part of the plots allocated by Souza et al. (2015) – who have carried out a stratified-systematic sampling with 200 m^2 plots spaced 10 m apart from each other – for sampling the adult tree component (DBH higher than or equal to 5 cm). We have used 10 plots allocated in each of the three sectors, making 30 allocated plots (Figure 1) which were subdivided into different sized subplots according to the regenerating tree species height classification. Each smaller subplot was allocated within a larger plot according to Volpato's methodology (Volpato, 1994). Thus, the regenerating tree species class 1 has consisted of 20 cm to 1 m high plants sampled in 5 m^2 subplots; the class 2 has consisted of above 1 to 3 m high plants sampled in 10 m^2 subplots; and the class 3 has consisted of more than 3 m high plants with DBH less than 5 cm sampled in 20 m^2 subplots.

Regenerating individuals were tagged with metal tags so as to register each plant's height class. The individuals were collected and identified through both the literature and experts support. Species were classified by families arranged according to the APG III system (Angiosperm Phylogeny Group, 2009) so that their spellings were verified in the Brazilian Flora Species List website (http://floradobrasil.jbrj.gov.br/).

For data analysis, the species were arranged according to their presence and density in the sampling plots of all three sectors (lower, intermediate and upper). Abundance, Shannon diversity index (H') and Pielou's evenness index (J) were determined for each sector in order to analyze the existence of spatial heterogeneity of structural and diversity patterns due to environmental compartmentalization. Abundance values were evaluated for normality (Shapiro-Wilk test) and if data did not show normal distribution they were compared among sectors through the Kruskal-Wallis test followed by a post hoc nonparametric multiple test so the hypothesis of structural variation among sectors was tested. Richness was compared by the rarefaction technique in order to test the species number variation hypothesis according to topographic position. A multivariate ordering of non-metric multidimensional scaling (NMDS) type was performed by using Bray-Curtis as floristic-structural distance, from a species' abundance matrix related to each sector's plots, to verify the existence of floristic-structural composition variations due to topographic position. A nonparametric multivariate analysis of variance (NPMANOVA) was held through the same data matrix used in the NMDS in order to test the hypothesis of community variation in relation to topographic position. An indicator species analysis (IndVal) was carried out with the species' abundance matrix according to each sector's plots for verifying the existence of species associated to the sectors. All analyzes were held by the means of the statistical programming language R (R Development Core Team, 2015) together with the vegan (Oksanen et al., 2015) and labdsv (Roberts, 2015) packages.

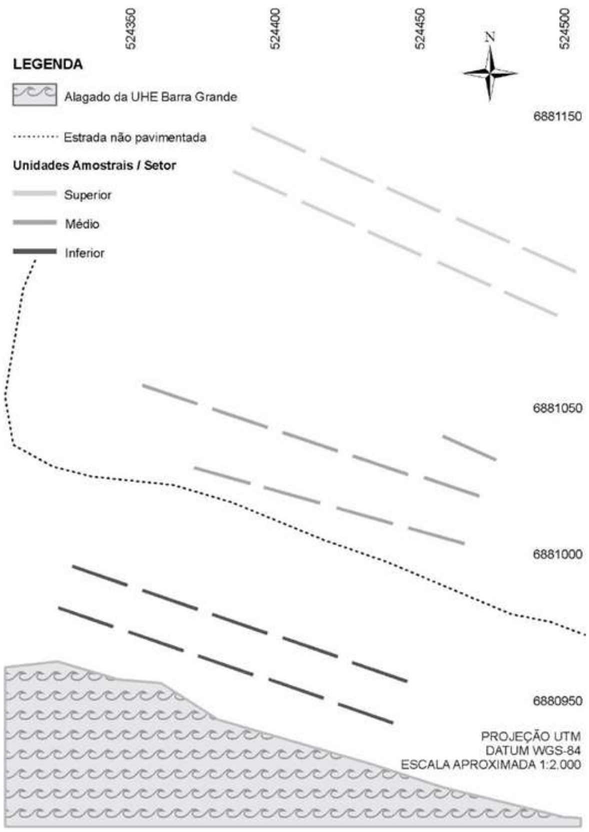

Figure 1 – Sample units' spatial distribution in the three sectors (lower, intermediate and upper) in a fragment of a transitional area between the Mixed Ombrophilous Forest and the Seasonal Deciduous Forest in the municipality of Capão Alto, Santa Catarina, Brazil.
Figura 1 – *Distribuição espacial das unidades amostrais nos três setores (inferior, intermediário e superior) em um fragmento em área de transição entre Floresta Ombrófila Mista e Floresta Estacional Decidual no município de Capão Alto, em Santa Catarina.*

3. RESULTS

A total of 771 individuals were sampled in 24 botanical families, 42 genera and 51 species along the different topographic positions (Table 1). One individual has not been identified for being too young for collection. The regenerating tree species abundance did not occur homogeneously along the hillside; the lower sector has shown more than half of the individuals [401 (251 from class 1 in 50 m^2, 122 from class 2 in 100 m^2, and 28 from class 3 in 200 m^2)] which has significantly differed from the upper sector which has shown only 16.8% sampled individuals.

Likewise, variations in richness and diversity were observed along the topographic gradient so that the lower sector has shown the lowest diversity (2.63), evenness (0.75) and standardized richness (23.12). This pattern has reflected in the ordering produced by the NMDS, which has shown a 0.18 stress value therefore indicating that the analysis was adequate for ecological interpretations. In the ordering, one can notice that the lower sector, which has shown the lowest diversity and the highest abundance and ecological dominance, has also been the most distinct and homogeneous from the floristic-structural point of view since its plots have shown the lowest dispersion (Figure 2). These differences in the lower sector are indicated by the segregation relative to the plots of the other two sectors along the NMDS axis 2, which significance ($p < 0.001$) has been confirmed by NPMANOVA.

Some species are widely distributed along the area, such as *Cupania vernalis* Cambess., which has occurred in all sectors. However, nine indicator species have been observed, mainly in the lower sector (six) (Table 2). The intermediate and upper sectors had only two and one indicator species, respectively. Results are in line with the multivariate ordering thus indicating a higher floristic-structural distinction in the lower sector.

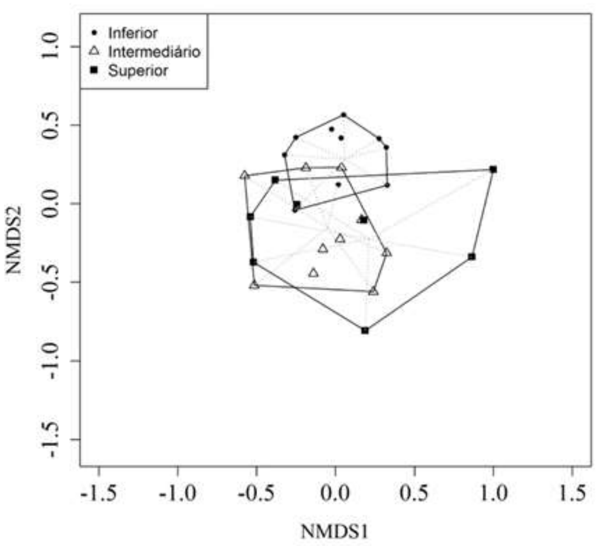

Figure 2 – Non-metric multidimensional scaling (NMDS) for species and sectors in a fragment of a transitional area between Mixed Ombrophilous Forest and Seasonal Deciduous Forest in the municipality of Capão Alto, Santa Catarina, Brazil.

Figura 2 – *Escalonamento Multidimensional Não-Métrico (NMDS) para as espécies e setores de um fragmento em área de transição entre Floresta Ombrófila Mista e Floresta Estacional Decidual no município de Capão Alto, em Santa Catarina.*

4. DISCUSSION

Results show that the environmental compartmentalization related to the terrain has proved to be an important source of floristic-structural heterogeneity for the regenerative component where the lower sector turned out to be the most distinct one in comparison to the other two sectors by showing the highest number of indicator species as well as the highest abundance with more than half of all 771 sampled individuals (121,400 ind.ha^{-1}) – which have opposed its low richness, diversity and evenness. Variations in environmental conditions due to topographic sectors may have influenced diversity patterns in different ways, such as: i) the existence of more selective environmental conditions in the lower sector therefore causing its low richness and the dominance of a group of adapted species; (ii) on the opposite side, the lower sector may show better environmental conditions (e.g. a higher fertility) so that ecological dominance results from the competitive exclusion for species more efficient in acquiring resources; and iii) a higher environmental heterogeneity in the intermediate and upper sectors, such as the presence of gaps, resulting in a larger distribution spectrum of species from different ecological groups.

The spatial heterogeneity in the abundance distribution of tree species individuals is a common behavior in forest ecosystems (Hubbel et al., 1999; Pitman et al., 1999) and results from a complex interaction

Table 1 – Number of individuals sampled for each species and sector (Low = lower; Int = intermediate; Upp = upper; T = whole community) in a fragment of a transitional area between the Mixed Ombrophilous Forest and the Seasonal Deciduous Forest in the municipality of Capão Alto, Santa Catarina, Brazil.
Tabela 1 – *Número de indivíduos amostrados para cada espécie e setor (Low = inferior; Int = intermediário; Upp = superior; T = toda a comunidade), em um fragmento em área de transição entre Floresta Ombrófila Mista e Floresta Estacional Decidual no município de Capão Alto, em Santa Catarina.*

Families/Species	Low	Int	Upp	T
ANNONACEAE				
Annona neosalicifolia H.Rainer	3	0	0	3
Annona rugulosa (Schltdl.) H.Rainer	1	7	0	8
APOCYNACEAE				
Aspidosperma australe Müll.Arg.	0	1	0	1
ARALIACEAE				
Oreopanax fulvus Marchal	0	0	1	1
ARAUCARIACEAE				
Araucaria angustifolia (Bertol.) Kuntze	2	1	0	3
ASTERACEAE				
Moquiniastrum polymorphum (Less.) G. Sancho	6	0	0	6
CARDIOPTERIDACEAE				
Citronella gongonha (Mart.) R.A.Howard	0	1	0	1
CELASTRACEAE				
Maytenus aquifolia Mart.	0	0	7	7
Schaefferia argentinensis Speg.	3	1	6	10
EUPHORBIACEAE				
Gymnanthes klotzschiana Müll.Arg.	3	1	0	4
Sebastiania brasiliensis Spreng.	0	15	12	27
FABACEAE				
Dalbergia frutescens (Vell.) Britton	1	4	0	5
Machaerium paraguariense Hassl.	2	6	1	9
Muellera campestris (Mart. ex Benth.) M.J. Silva & A.M.G. Azevedo	10	4	3	17
Myrocarpus frondosus Allemão	0	1	2	3
Parapiptadenia rigida (Benth.) Brenan	10	17	3	30
INDERTEMINED	0	0	1	1
LAURACEAE				
Nectandra megapotamica (Spreng.) Mez	96	19	17	132
Ocotea puberula (Rich.) Nees	25	0	0	25
Ocotea pulchella (Nees & Mart.) Mez	1	1	1	3
Ocotea sp. 1 2	0	0	2	
Ocotea sp. 2 0	1	0	1	
MELIACEAE				
Cedrela fissilis Vell.	0	0	1	1
Trichilia elegans A.Juss.	8	40	11	59
MYRTACEAE				
Blepharocalyx salicifolius (Kunth) O.Berg	5	5	1	11
Calyptranthes concinna DC.	0	1	0	1
Campomanesia xanthocarpa (Mart.) O.Berg	34	9	2	45
Eugenia uniflora L.	29	11	4	44
Eugenia uruguayensis Cambess.	1	2	0	3
Myrceugenia mesomischa (Burret) D.Legrand & Kausel	1	0	0	1
Myrcianthes gigantea (D.Legrand) D.Legrand	1	4	3	8
Myrcianthes pungens (O.Berg) D.Legrand	0	3	0	3
OLEACEAE				
Ligustrum lucidum W.T.Ait.*	3	0	0	3
PICRAMNIACEAE				

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PRIMULACEAE				
Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.	0	3	1	4
Myrsine lorentziana (Mez) Arechav.	0	0	1	1
RHAMNACEAE				
Scutia buxifolia Reissek	1	0	0	1
RUBIACEAE				
Coutarea hexandra (Jacq.) K.Schum.	0	14	2	16
Rudgea parquioides (Cham.) Müll.Arg.	0	0	1	1
RUTACEAE				
Pilocarpus pennatifolius Lem.	0	3	8	11
SALICACEAE				
Banara tomentosa Clos	6	2	1	9
Casearia decandra Jacq.	2	1	2	5
SAPINDACEAE				
Allophylus edulis (A.St.-Hil. et al.) Hieron. ex Niederl.	62	20	8	90
Allophylus guaraniticus (A.St.-Hil.) Radlk.	22	11	9	42
Cupania vernalis Cambess.	33	16	16	65
Matayba elaeagnoides Radlk.	17	5	2	24
SOLANACEAE				
Brunfelsia cuneifolia J.A.Schmidt	4	2	0	6
Cestrum intermedium Sendtn.	1	0	0	1
Solanum pseudoquina A.St.-Hil.	2	0	0	2
STYRACACEAE				
Styrax leprosus Hook. & Arn.	4	8	0	12
VERBENACEAE				
Duranta vestita Cham.	0	0	1	1
Total of individuals (total per hectare)	401^{a} (63800)	241^{ab} (36300)	129^{b} (21300)	771 (121400)
Richness	33	35	29	51
Richness measured by rarefaction	23.12	28.68	29	-
Shannon (H’)	2.63	3.02	2.91	3.06
Pielou (J)	0.75	0.85	0.86	0.78

*Exotic species. The values of total individuals by sector followed by different letters indicate significant differences by the nonparametric multiple test applied after the Kruskal-Wallis test.

Table 2 – Indicator species of the regenerative component for each topographic sector in a fragment of a transitional area between the Mixed Ombrophilous Forest and the Seasonal Deciduous Forest in the municipality of Capão Alto, Santa Catarina, Brazil.
Tabela 2 – *Espécies indicadoras do componente regenerativo para cada setor topográfico, em um fragmento em área de transição entre Floresta Ombrófila Mista e Floresta Estacional Decidual no município de Capão Alto, em Santa Catarina.*

Indicator Species	Class
Allophylus edulis	Lower
Campomanesia xanthocarpa	Lower
Nectandra megapotamica	Lower
Eugenia uniflora	Lower
Matayba elaeagnoides	Lower
Ocotea puberula	Lower
Trichilia elegans	Intermediary
Annona rugulosa	Intermediary
Maytenus aquifolia	Upper

between several ecological factors, which is related to both the species characteristics and the habitat's quality. For instance, the high density in the lower sector suggests that the species occurring in this environment, besides producing a high amount of propagules, have found favorable environmental conditions for germinating seeds and forming a bank of young plants. This is supported by the fact that the lower sector's class 1 has shown a higher number of individuals than larger size plant classes. On the other hand, the regeneration process seems to be more limited in the upper sectors due to limiting factors, such as low propagules production and/or not favorable environmental conditions for germinating and establishing young plants.

Some species were common to all sectors, demonstrating the high plasticity in habitats colonization, such as the hygrophilous species *Cupania vernalis*, which is however capable of supporting high slopes. Its higher ecological plasticity is reinforced by Meyer et al. (2013a,b) who have listed it among the most important species in the regenerative component both in areas of Mixed Ombrophilous Forest and Deciduous Seasonal Forest in Santa Catarina, Brazil. According to Via et al. (1995), high plasticity species adapt to unstable environments therefore increasing its environmental tolerance.

There were nine indicator species, most of which in the lower sector, therefore reinforcing its higher distinction. The indicator species from this sector can be considered as tolerant to water stress since some parts of the area are subject to flooding. In fact, some of these species, such as *Campomanesia xanthocarpa* (Mart.) O.Berg, *Matayba elaeagnoides* Radlk. and *Eugenia uniflora* L., were considered by other authors (Reitz et al., 1983; Lorenzi, 2000; Silva et al., 2007; Narvaes et al., 2008) to be tolerant to soils with excess water. Of the two indicator species from the intermediate sector, *Trichilia elegans* A.Juss. germinates in shaded places, thriving on wet and hillside soils (Schupp et al., 2002), which explains its place of highest abundance. According to a study by Scipioni et al. (2009) held in FED, Santa Maria, RS, Brazil, *Trichila elegans* also belongs to the sectors influenced by high slopes. Yet *Annona rugulosa* (Schltdl.) H. Rainer is considered as an early secondary to late species (Lorenzi, 2000). The representative species from the upper sector, *Maytenus aquifolia* Mart., usually occurs in well-drained soils typical of hillside tops (Lorenzi, 2000).

5. CONCLUSION

It is concluded that the terrain's position is an important source of floristic-structural heterogeneity for the regenerative tree component as far as the small spatial scale under analysis is concerned, where the lower sector has proved to be the most distinct among sectors. Topographic variations probably make room for the existence of micro-habitats due to edaphic and microclimatic factors quality. The presence of indicator tree species in each sector reinforces the idea of considering the floristic groups' terrain position when indicating them in programs for recovering degraded areas.

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