

## Dynamics of natural regeneration in a remnant of araucaria forest

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**ABSTRACT:** The aim of the study was to evaluate the dynamics of vertical distribution of natural regeneration in a remnant Mixed Ombrophilous Forest. Two surveys were conducted for the study, in 2012 and subsequently in 2017, in a remnant forest area that has not been interfered for decades and is located in Santa Catarina (SC), Brazil. The experimental area comprised 20 circular plots of 2.5 m radius, where was it performed where the quantification of the regenerants, measurement of individual tree heights, and identification of the ecological group that each surveyed species belonged. We found natural regeneration in the remnant forest showed decreasing density values with the advancement of altimetric classes. In the survey carried out in 2012, the altimetric classes I, II and III recorded 48, 17 and 8 species, respectively. In the subsequent survey in 2017, the aforementioned classes recorded 60, 29 and 7 species, respectively. The distribution of regeneration guilds according to height classes revealed a predominance of individuals demanding light and a reduction in shade tolerants during the studied period. This result was probably influenced by specific disorders that occurred in the area during the study.

**Key words:** ecological groups; height classes; mixed ombrophilous forest

## Dinâmica da regeneração natural em um remanescente de Floresta de Araucaria

**RESUMO:** O objetivo do presente trabalho foi avaliar a dinâmica vertical da regeneração natural em um remanescente de Floresta Ombrófila Mista, no período entre 2012 e 2017. O remanescente analisado não sofre intervenções há décadas e localiza-se em Santa Catarina (SC), Brasil. A área experimental foi composta por 20 parcelas circulares de 2,5 m de raio, onde foi realizada a quantificação dos regenerantes; a medição das alturas individuais das árvores e a identificação do grupo ecológico ao qual cada espécie pesquisada pertencia. A regeneração natural apresentou valores decrescentes de densidade com o avanço das classes altimétricas. No levantamento realizado em 2012, as classes altimétricas I, II e III contaram com 48, 17 e 8 espécies, respectivamente. Já, no levantamento realizado em 2017 as classes citadas contaram com 60, 29 e 7 espécies, respectivamente. A distribuição das guildas de regeneração em função das classes de altura revelou predominância de indivíduos exigentes em luz e redução de tolerantes a sombra no período estudado. Tal resultado provavelmente foi influenciado por distúrbios pontuais ocorridos na área durante o estudo.

**Palavras-chave:** grupos ecológicos; classes de altura; floresta ombrófila mista

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## Introduction

The Mixed Ombrophilous Forest (Araucaria Forest) is considered one of the most ecologically valuable forest types globally due to unique biological attributes including rare and endemic species (Oliveira-Filho et al., 2015). However, Mixed Ombrophilous Forests have become a threatened typology due to factors such as fire events, deforestation (i.e., for agriculture and the replacement of vegetation with pasture), reforestation using exotic species, and ongoing urban expansion (Souza et al., 2014).

Given the current threatened status of the Mixed Ombrophilous Forest, understanding the recovery dynamics of those remnant presents a challenge. This can be achieved through research into measures that can enhance the restoration and sustainable management of species belonging to this forest typology. Accordingly, a greater understanding of plant succession processes in areas with contrasting disturbance histories is essential. This information can be used to identify where natural regeneration actions are required, as well as help generate subsidy for the recovery of other similarly degraded areas (Larsen et al., 2019). In addition to assisting identification of limiting environmental factors, and inferring about the future dynamics of the forest (Dalla Rosa et al., 2016), an increased understanding of plant succession processes will also assist in predicting community assembly processes (Silva et al., 2016).

Therefore, research into natural regeneration processes and spatial organization in native forests is essential for determining how tree communities function (Higuchi et al., 2015; Silva et al., 2017; Vefago et al., 2019), and the resilience of forest fragments (Santos et al., 2018), to assist in the development of effective forest management strategies (i.e., sustainable exploitation of timber and non-timber resources) (Higuchi et al., 2015). In this context, changes in a plant community over time, as well as the spatial patterns of demographic events, can provide information about the orientation of the plant succession process (Larsen et al., 2019).

Despite substantial research into natural regeneration in Mixed Ombrophilous Forests (Souza et al., 2012; Ribeiro et al., 2013; Santos et al., 2015; Silva et al., 2017; Vefago et al., 2019), surprisingly little attention has been given to the dynamics of vertical distribution of natural regeneration of these forests. Therefore, the objective of this study was to evaluate the dynamics vertical of natural regeneration in a Mixed Ombrophilous Forest remnant without interventions for decades.

## Materials and Methods

### Study area

The study was conducted in a forest remnant located in the Private Natural Heritage Reserve "Emílio Einsfeld Filho," in the municipalities of Campo Belo do Sul and Capão Alto, Santa Catarina (SC), Brazil (28°02'55.00"S and 50°45' 59.56"W).

The remnant covers an area of 3,365 ha, with approximately 72% forest cover characterized by several successional stages. The Private Natural Heritage Reserve is essentially formed by Mixed Ombrophilous Forest. Much of the vegetation in the study area has suffered anthropogenic action through selective logging in the past, mainly of high commercial value woods. However, these interventions have been suspended for decades (Zeller, 2010).

In the remainder evaluated, there are two dominant geomorphic units: the Planalto dos Campos Gerais and the Planalto Dissecado of the Iguaçu River / Rio Uruguai. The main soils identified at the site are the Litossol Neosols, the Ultisol and the Nitisols most present in the vicinity of the Pelotas and Canoas / Caveiras rivers (Embrapa, 2006). The predominant climate in the region is characterized as Cfb, according to the Köppen climate classification with temperature and average annual precipitation of 15.8 °C and 1,742 mm, respectively (Alvares et al., 2013).

### Data collection

In the study area, 20 circular sample units with 2.5 m radius were randomly allocated, totaling a sample area of 392.5 m<sup>2</sup> (Figure 1). Trees with a circumference at breast height (CBH) <15 cm and height ≥ 50 cm were measured.

Two surveys were undertaken for the study; the first survey was conducted in 2012 (carried out by Schorn et al., 2012), and the second in 2017. Surveys involved; quantification of the natural regenerants, measurement of individual tree heights and identification of the ecological group of species.

### Data analysis

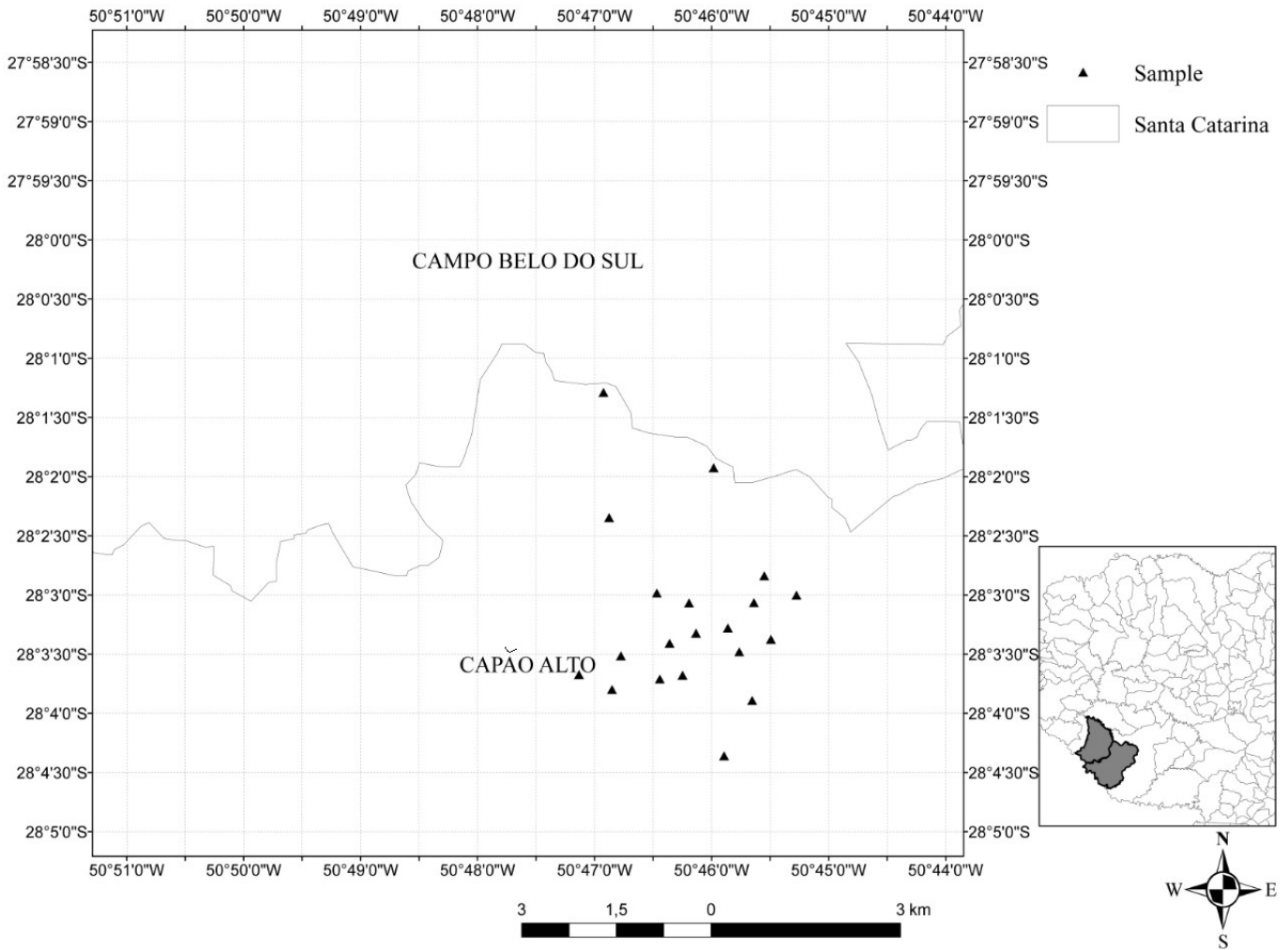
Natural regeneration was distributed in three height classes: classe I (0.5 - 2.4 m); classe II (2.5 - 4.4 m); e classe III (4.5 - 6.5 m). In each height class, changes in species density were analyzed using the paired t-test (alpha was set at = 0.05) and also in regeneration guilds (ecological groups) using the Mann Whitney's nonparametric test (alpha was set at = 0.05).

Species identification was carried out through expert opinions and specialized literature. The species were classified at family level according to the APG IV system (APG IV, 2016). For the classification of species in regeneration guilds, the following classes were used: pioneer (P), climax demanding light (CL), and climax tolerant to shadow (CS) (classifications are based on those described by Oliveira-Filho (1994).

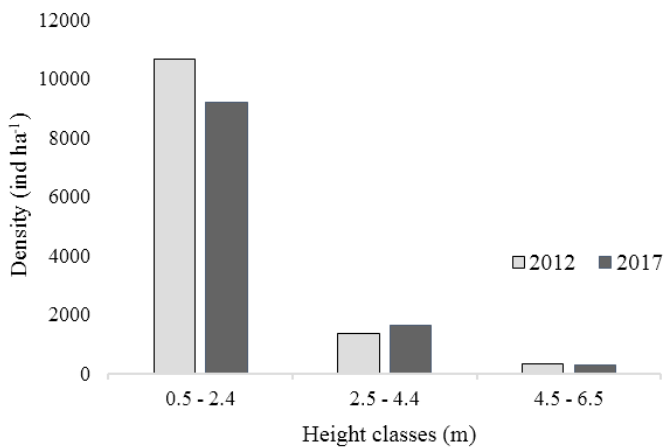
## Results and Discussion

### Vertical distribution of natural regeneration

In both surveys (2012 and 2017), the distribution of the number of individuals by height class showed a decrease in the number of seedlings with increased height class (Figure 2). According to Silva et al. (2017), the decreasing distribution in the number of individuals in size classes represents a classic pattern for uneven aged natural forests, in which there are more individuals of smaller sizes due to factors that limit its



**Figure 1.** Geographic location of the sample units in a Mixed Ombrophilous Forest remnant in Santa Catarina, Brazil.



**Figure 2.** Height distribution of the density of natural regeneration in a remnant of the Mixed Ombrophilous Forest in Santa Catarina, Brazil, for two survey periods; 2012 and 2017.

development and survival, such as herbivory and competition, therefore enabling only a smaller ratio to reach higher size classes.

The community was divided into three height classes. Class I contains the largest contingent of regenerants (heights

range 0.5 to 2.4 m); class II has an intermediate density of individuals (heights range 2.5 to 4.4 m); and class III has a reduced population size, but individual trees have a better chance of reaching the canopy (heights range 4.5 to 6.5 m).

Therefore, the observed pattern shows a tendency toward negative exponential type hypsometric distribution. Similar results to the present study, in the same forest typology, were observed in a study by Higuchi et al. (2015), Duarte et al. (2017), Silva et al. (2017) and Souza et al. (2018), in which the authors found increased numbers of individual trees in smaller tree height classes.

Results showed there was no significant difference (paired t-test;  $p < 0.05$ ) in the density distribution of regenerating individuals between survey years 2012 and 2017 for the three height classes. Class I recorded the highest number of individuals per hectare of the three described classes for both survey years; 86% in 2012 and 82% in 2017, compared to class II which recorded 11% of regenerating individuals in 2012 and 15% in 2017. Notably, class III had the lowest density of individuals of the three classes, recording only 3% regenerating individuals for both survey years. The reduction in wealth due to size classes indicates that the factors that control the density of the community also act as a filter,

reducing the number of species in the larger size classes (Higuchi et al., 2015).

### Most representative species among height classes

In the survey carried out in 2012, the height classes I, II and III recorded 48, 17 and 8 species, respectively. In the subsequent survey in 2017, the aforementioned classes recorded 60, 29 and 7 species, respectively. Based on these results classes I and II showed an increase in the samples number of species in the natural regeneration at the study site in the period between 2012 and 2017. According to Higuchi et al. (2015), the difference in density of individuals between the class of smallest and largest size indicates the existence of a strong demographic bottleneck. Vefago et al. (2019), evaluating the dynamics of the natural regeneration of remnants of Mixed Ombrophilous Forest in the Santa Catarina, observed that the natural regeneration was characterized by structural instability, as well as richness stability.

Floristic richness was found to be highest for class I in both survey periods. In 2012 the main floristic representatives of this class were the species; *Myrcia multiflora* (1,325 ind ha<sup>-1</sup>), *Allophylus guaraniticus* (968 ind ha<sup>-1</sup>), and *Matayba elaeagnoides* (917 ind ha<sup>-1</sup>), constituting 13%, 10%, and 9% of the total number of individuals per hectare, respectively (Table 1). During the same survey period, 51% of the density of individuals for class II were represented by the species; *Casearia decandra* (357 ind ha<sup>-1</sup>), *Sebastiania brasiliensis* (357 ind ha<sup>-1</sup>) and *Myrcia multiflora* (255 ind ha<sup>-1</sup>). The most representative species for class III in 2012 were: *Sebastiania brasiliensis* (102 ind ha<sup>-1</sup>), *Myrcine coreacea* (76 ind ha<sup>-1</sup>) and *Allophylus guaraniticus* (51 ind ha<sup>-1</sup>), constituting 22%, 17%, and 11% of the total number of individuals, respectively.

In the 2017 survey, class I recorded minimal floristic change compared to the 2012 survey. The species; *Allophylus guaraniticus*, *Casearia decandra* and *Myrcine coreacea* increased their representativeness by 12%, 18% and 30%, respectively. Conversely, *Myrcia multiflora* and *Matayba elaeagnoides* decreased representativeness by 19% and 36%, respectively. Interestingly, *Ocotea pulchella*, which was recorded in the 2012 survey for this class, was no longer present.

In the same survey year the number of more representative species was quantitatively distinguished for class II compared to the previous survey in 2012. Notably, *Casearia decandra* remained as the highest density species as was found in the 2012 survey. However, there was a reduction in its representativeness (43%). Additionally, the species *Myrcia multiflora* and *Sebastiania brasiliensis* reduced to 50 and 64% respectively, in 2017. In class III, *Casearia decandra* was the most representative species, as was observed in class II for the same survey period. *Allophylus guaraniticus* remained the same as in the prior 2012 survey for class III. In the 2017 survey, class III also recorded *Cabralea canjerana* for the first time among the most representative species.

According to Higuchi et al. (2015), the variation of the most abundant species among the size classes can be explained due to their different life strategies and respective capacities to develop in the forest understory. Some species may produce more propagules; however, they are inefficient competitors, tending to decrease their participation in the larger classes. Other species may produce few propagules, but with good competitive capacity, with an increase in their participation in the larger classes.

As identified in the survey conducted in 2017, *Allophylus guaraniticus* expanded in representativeness in classes I and II, and *Casearia decandra* in classes I and III. It may be that these changes in species representativeness among classes occurred due to natural factors that favored the development of these particular species in the surveyed forest. It is worth noting that both *Allophylus guaraniticus* and *Casearia decandra* are light demanding species and therefore disturbances in the canopy would likely make the forest environment more conducive to their growth.

Interestingly, shade tolerant species *Myrcia multiflora* (Class I and II) and *Matayba elaeagnoides* (Class I) occupied the smaller tree height classes in both the 2012 and 2017 surveys. The ecological group that both species belong to is characterized by the formation of a seedling bank which may, in part, explain the permanence of these species in the same lower altimetric classes in both survey periods. However, according to Narvaes et al. (2005) the Mixed Ombrophilous

**Table 1.** Most representative species of natural regeneration by height class in a remnant of Mixed Ombrophilous Forest in Santa Catarina, Brazil, for two survey periods; 2012 and 2017.

Species	2012				2017			
	Class I	Class II	Class III	Total	Class I	Class II	Class III	Total
	(ind ha <sup>-1</sup> )							
<i>Myrcia multiflora</i> (Lam.) DC.	1325	255	-	1580	1070	127	-	1197
<i>Allophylus guaraniticus</i> (A. St.-Hil.) Radlk.	968	-	51	1019	1096	178	51	1325
<i>Matayba elaeagnoides</i> Radlk.	917	-	-	917	586	-	-	586
<i>Casearia decandra</i> Jacq.	688	357	-	1045	841	204	76	1121
<i>Myrsine coriacea</i> (Sw.) R.Br. ex Roem. & Schult.	662	-	76	738	943	-	-	943
<i>Ocotea pulchella</i> (Nees & Mart.) Mez	459	-	-	459	-	-	-	-
<i>Sebastiania brasiliensis</i> Spreng.	-	357	102	459	-	127	-	127
<i>Eugenia</i> sp.	-	-	-	-	-	153	-	153
<i>Dalbergia frutescens</i> (Vell.) Britton	-	-	-	-	-	127	-	127
<i>Allophylus edulis</i> (A.St.-Hil. et al.) Hieron. ex Niederl.	-	-	-	-	-	76	-	76
<i>Cabralea canjerana</i> (Vell.) Mart.	-	-	-	-	-	-	17	17

Forest environment is under significant dynamic processes; an isolated change in the forest can lead to successive changes that allow many light-demanding tree species to remain in the forest community.

**Species representativeness in regeneration guilds according to height classes**

In the 2012, the climax species demanding light (CL) and climax species tolerant to shade (CS) were the most abundant regeneration guilds in class I (41 and 37%, respectively) (Figure 3), while in class II, CS (43%) and pioneers (P) (30%) were more abundant. Class III recorded highest abundance for P guild, while CL and CS had an equal number of species (23%). In contrast, in the 2017, in class I CL (47%) and P (33%) were the most abundant guilds; in class II, CL (35%) was dominant, and in class III, P and CS were the predominant regeneration guilds (42% and 25%, respectively).

It is worth noting, in both survey periods, the highest density of CL species was found in the lowest tree height class (class I). The pioneers, on the other hand, were the most represented guild in the tallest tree class (class III). This finding may relate to the life habits of these regeneration guilds. Given the first group (climax demanding light species) forms a seedling bank, and the second group (pioneer species) is

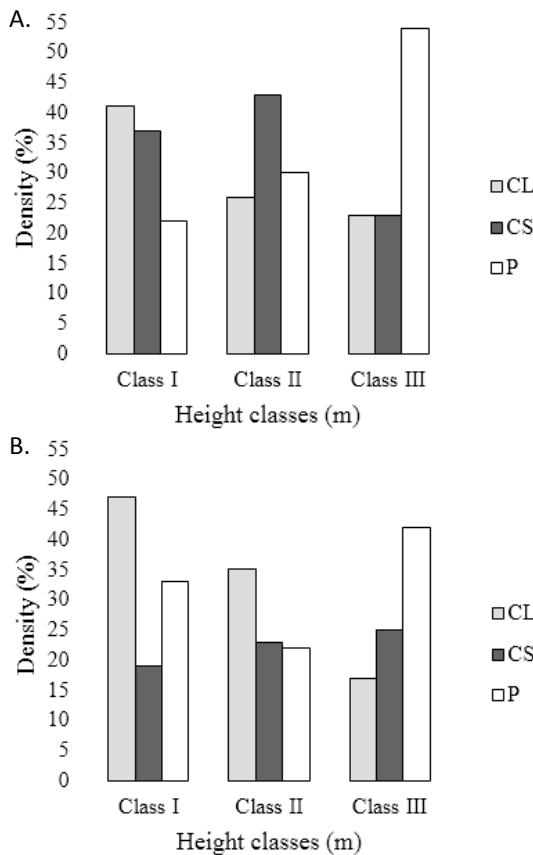
fast growing; these traits might allow increased resistance to factors that limit development in the open environment.

In the survey carried out in 2017, there was a reduction in CS species, and an increase in CL species in classes I and II, and an increase in P species in classe I. Additionally, in both the 2012 and 2017 surveys, classes with a higher density of pioneer species, such as class III, showed a reduction in climax demanding light species, and vice versa. This result may relate to both guilds been light demanding (Swaine & Whitmore, 1988) which could subsequently lead to a possible competition for luminosity.

The rate of change that occurred between the survey years, 2012 and 2017, was significant for shade tolerant species; CS reduced significantly between survey periods in classes I and II (Mann Whitney test;  $p < 0.05$ ) which indicates, according to Schorn & Galvão (2006), that the forest is still in process of recomposition of the structure, altered in decades passed by the selective exploration (Table 2). The other ecological groups did not show significant change between surveys, however P species in class I and CL in class II demonstrated positive changes in density (15% and 64%, respectively). In contrast, negative changes were observed in CL species in class I (-14%) and III (-33%), and in P, in classes II and III (-13% and -29%, respectively). In study of Dallabrida et al. (2017), also in the Mixed Ombrophilous Forest, regeneration guilds have shown different dynamics patterns, where the pioneers have shown the greatest mortality (20%) and recruitment (16%) proportion and reduced representativeness in shade-tolerant climax species.

The significant reduction in the group of shade tolerant species may be linked to the fall of large trees that occurred in the study area between the two survey periods. Fallen trees, caused by windstorms, created openings in the canopy that would have benefited light demanding species occupying lower forest stratum. These findings are consistent with prior research that has identified CL and P species require high levels of radiation for growth, in addition to being favored by disturbances that affect the forest canopy (i.e., fallen trees). Shade tolerant species, on the other hand, require little, or no light; seedlings are able to settle, and grow slowly, in the shade of the forest understory (Swaine & Whitmore, 1988).

Although other factors have not been evaluated for the current study, we suggest that disturbances in the canopy during the period between survey years may have induced the



**Figure 3.** Representation of ecological groups in height classes of natural regeneration in a remnant of Mixed Ombrophilous Forest in Santa Catarina, Brazil, surveyed in 2012 (A) and 2017 (B). CL – climax species demanding light; CS – climax species tolerant to shade; P – pioneer species.

**Table 2.** Rate of change in natural regeneration that occurred between two survey years (2012 and 2017) in relation to species density by ecological group and height class in a remnant of Mixed Ombrophilous Forest in Santa Catarina, Brazil.

Ecological group	Class I	Class II	Class III
	%		
CL	-14	64	-33
CS	-60	-35	0
P	15	-13	-29

CL – climax species demanding light; CS – climax species tolerant to shade; P – pioneer species.

higher density of light demanding species observed in 2017, and conversely, the significant mortality of shade tolerant species.

The forest dynamics do not cease in advanced stages, rather they deviate toward localized disturbances such as tree falls (Chazdon, 2012). According to Dallabrida et al. (2017), although the disturbances do not always result in structural degradation, they have the potential to delay the succession process and cause a floristic homogenization. However, chronic disorders can influence the definition of the species ecological strategies (Vefago et al., 2019).

According to Larsen et al. (2019), plant succession is a highly complex process that can vary in the time it takes to occur, and in the space in which it occurs. In this context, the Mixed Ombrophilous Forest can be viewed as a large mosaic formed from; environments of different ages, microclimates within the forest, and the floristic composition of the forest (Kageyama, 1987). In keeping with the findings of the present study, Kageyama (1987) postulated that there is no one moment when the forest actually becomes stable due to ongoing natural disturbances, even in late stages of forest succession.

## Conclusions

In the time interval between the two surveys, the forest did not show significant changes in relation to the density of individuals in natural regeneration.

The distribution of the number of individuals by height class showed a tendency to decrease the number of seedlings with the increase in classes.

The species with the highest density in the community have greater potential for survival with the advancement in ontogenetic classes.

The distribution of regeneration guilds according to height classes revealed a predominance of individuals demanding light and a reduction in shade tolerants during the studied period. This result was probably influenced by specific disorders that occurred in the area during the study.

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## Compliance with Ethical Standards

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**Conflict of interest:** There is no conflict of interest.

**Author contribution:** Conceptualization: LAS, SNOG; Data curation: SNOG; Formal analysis: SNOG; Funding acquisition: LAS; Investigation: SNOG, LAS; Methodology: LAS, SNOG; Project administration: LAS; Resources: LAS; Software: SNOG; Supervision: LAS, PH; Validation: LAS, SNOG; Visualization: SNOG, LAS, KFS, PH; Writing - original draft: SNOG, KFS, LAS; Writing - review & editing: SNOG, LAS, KFS, PH.

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