Population structure of understory, canopy/emergent tree species in Brazilian Atlantic Forest remnants with different Conservation status

Estrutura populacional de espécies arbóreas de sub-bosque e dossel/emergentes em remanescentes de Mata Atlântica Brasileira com diferentes estados de conservação

Estructura de la población de especies arbóreas del sotobosque y del dosel/emergentes en los remanentes de la Mata Atlántica brasileña con diferentes estados de conservación

Abstract

The size and spatial structures of populations are a synthesis of demographic attributes and indicators of competitive ability, colonization, and survival. In this study, the objective was to analyze the height and spatial pattern of an understory and canopy/emergent tree populations group in two protected fragments of seasonal semideciduous forest, one with a history of selective logging and another without selective logging evidences. Six species with high importance values (IV) from different guilds were selected and height and spatial pattern analysis was realized in both areas. Then, comparison of results was realized in an area with history of selective logging and another without selective logging evidences. Differences in height and spatial pattern were found between the two areas, including species not directly exploited. In Logged Forest the size structure for all species presented a higher coefficient of skewness, showing a greater proportion of young trees. Random distribution was observed for the majority of species in both areas. Some emergent/canopy species had a deficit of individuals in the largest size classes and the majority of understory species showed more individuals in Logged Forest. Selective Logging changed the pattern of populations. Selecting species based on IV together with spatial patterns data contribute to demonstrating the impacts of exploitation. The Logged Forest is surrounded by an agricultural matrix, limiting arrival and dispersion of propagules of shade-tolerant species. Efforts to connect surroundings fragments to Logged Forest will be necessary.

Keywords: Forest fragmentation; Forest regeneration; Population ecology; Selective logging; Tropical forest.

Resumo

O tamanho e a estrutura espacial das populações são uma síntese de atributos demográficos e indicadores de capacidade competitiva, colonização, e sobrevivência. Neste estudo, o objetivo foi analisar o tamanho e a estrutura espacial de um grupo de populações arbóreas de sub-bosque e dossel/emergentes em dois fragmentos de Floresta Estacional Semidecidual, um com histórico de corte seletivo de madeira e outro sem evidências de corte seletivo. Seis espécies com altos valores de importância e de guildas diferentes foram selecionadas e a análise de tamanho e estrutura espacial foi realizada em ambas as áreas. Em seguida, compararamos os resultados das espécies na área com histórico de corte seletivo com a área que não sofreu corte seletivo. Diferenças de tamanho e estruturas espaciais foram encontradas entre as duas áreas, incluindo espécies que não exploradas diretamente. Na floresta em que ocorreu o corte seletivo, a estrutura de tamanho para todas as espécies apresentou um maior coeficiente de assimetria, mostrando uma maior proporção de
juvenis. O padrão de distribuição aleatória foi observado para a maioria das espécies em ambas as áreas. Algumas espécies do dossel/emergentes tiveram menor abundância nas maiores classes de altura. O corte seletivo alterou o padrão das populações. Seleccionar espécies baseado no VI juntamente com padrões de distribuição espacial contribuem em demonstrar os impactos da exploração. A área com histórico de corte seletivo é circundada por matriz agrícola, limitando a chegada e dispersão de propágulos de espécies tolerantes à sombra. Esforços para conectividade com fragmentos do entorno serão necessários.

Palavras-chave: Fragmentação florestal; Regeneração florestal; Ecologia populacional; Corte seletivo de madeira; Floresta tropical.

1. Introduction

The Brazilian Atlantic Forest has one of the highest levels of biological diversity and number of endemic species in the World (Lima et al., 2020; Ribeiro et al., 2009; Santo-Silva et al., 2016; Santos et al., 2018; Zucchi et al., 2018). However, this biome has a widespread devastation scenario in which most remaining forests are small isolated fragments and under intense anthropic pressure (Callaghan et al., 2019; Liebsch et al., 2016). Considering the anthropic pressures, selective logging has a major impact on these forests (Brocardo et al., 2018; Cunha et al., 2021; Eisenlohr et al., 2015; Lammertink et al., 2020; Lima et al., 2020; Rutishauser et al., 2016; Silva & Vibrans, 2019).

Selective logging may change the local microclimate, survival and species regeneration, resulting in a completely altered habitat (Guariguata & Ostertag, 2001). The direct effects of extracted individuals in association with the microclimatic changes cause variations in survival, growth, and reproduction rates of tree populations, which directly affect size and spatial structure (Solís et al., 2009; Tsingalia, 2010). The recovery success of the populations will determine the forest’s regeneration, defining forest regeneration as a process by which the disturbed forest reaches Mature Forest characteristics (Saldarriaga & Uhl, 1991; Tabarelli et al., 1999).

The size structure may be considered a synthesis of demographic attributes of recruitment, mortality, and individual growth rates (Kelly et al., 2001). The spatial structure (or spatial distribution) is an outcome of the competitive ability, colonization, and survival of populations (Maestre et al., 2008). Thus, these aspects of population structure play role as an important indicator of forest regeneration, despite not replacing the study of demography and the spatial distribution processes (Berry et al., 2008; Rodrigues et al., 2016).

Studies have used the population structure as a way to understand effects of natural (Batista & Platt, 2003; Coomes & Allen, 2007) and anthropic disturbances on species (Liebsch et al., 2021; Sapkota et al., 2009; Silva & Vibrans, 2019; Souza,
2007; Tsingalia, 2010). A higher proportion of juveniles than adult trees has been found in exploited forests (Souza, 2007) and the spatial pattern may change between exploited and unexploited forests (Sapkota et al., 2009) considering that gap recruitment has been shown to be important for individual tree placement (Plotkin et al., 2000).

Light plays a major role in plant dynamics (Tang & Dubayah, 2017; Valladares & Niinemets, 2008), particularly in areas with high heterogeneity like in selectively Logged Forests (Rodrigues et al., 2016, 2019). However, species may respond differently according to their characteristics, such as shade tolerance degree or forest stratum (Bianchini et al., 2010; Laurans et al., 2014; Swaine & Whitmore, 1988).

Size and spatial structure of understory and canopy/emergent tree populations in two forest fragments with different histories of human action were analyzed. Differences in tree populations structure between areas are expected based on selective logging occurred in one of studied fragments in comparison to an area without anthropogenic action signals. We tested the hypothesis that canopy species have a higher proportion of individuals in the first size classes and a higher aggregate distribution correlated with canopy openness in exploited areas. Understory species probably have lowest abundance in the exploited forest due to their dependence on shade throughout all their life cycle.

2. Material and Methods

Two Atlantic Forest fragments, classified as seasonal semideciduous forest (SOS Mata Atlântica & INPE, 2020; Veloso et al., 1991), were selected for study (Figure 1). The São Francisco Forest State Park (23º09’55” S, 50º33’51” W) has 832.58-ha localized in north of Paraná state, Brazil. This area suffered disorderly selective logging until 1994 when it became a protected area. Therefore, it has some environmental imbalances, such as wide gaps and excessive lianas and bamboos. It will be referred to as the “Logged Forest” in this paper. The Godoy Forest State Park (23º27’10” S, 51º15’11” W) has 680-ha currently connected to other fragments, totaling almost 2800-ha (Vicente, 2006). The Godoy Forest State Park is also localized in north of Paraná, Brazil, and it has no selectively logging history (Torezan, 2006). It is referred to as the “Mature Forest” in this paper.

According Köppen classification, the region's climate is characterized as Cfa - humid subtropical mesothermal (Alvares et al., 2013), with average rainfalls between 1200–1400 mm in Logged Forest and 1400–1600 mm in Mature Forest. Rainfalls is distributed unevenly throughout the year, in both cases (Nitsche et al., 2019). Both areas have high fertility soil. In Logged Forest the predominant soils are Eutroferric Red Latosols and Nitosols, with inclusions of Chernosols and Gleysols. Eutroferr Red Latosols and Nitosols in association with Entisols in Mature Forest (Santos et al., 2013).

The species were selected based on their importance values (IV) obtained from a phytosociological inventory performed in the study areas (Silva & Soares-Silva, 2000; Tomé et al., 1999; Zama et al., 2012) and field observations. They were divided into two groups regarding forest stratum: understory species - Actinostemon concolor (Spreng.) Müll. Arg. (Family: Euphobiaceae, popular name: Laranjeira do mato; IV: 9.79 (Soares-Silva & Barroso, 1992)), Sorocea bonplandii (Baill.) W.C. Burger, Lanj. & Wess. Boer (Family: Moraceae, popular name: Falsa espinheira; IV: 8.77 (Tomé et al., 1999)), and Inga marginata Willd. (Family: Fabaceae, popular name: Ingá-feijão; IV: 5.71 (Tomé et al., 1999)); canopy species - Campomanesia xanthocarpa O. Berg. (Family Myrtaceae, popular name: Guabiroba; IV: 3.77 (Tomé et al., 1999)) and Cabralea canjerana (Vell.) Mart. (Family Meliaceae, popular name: Canjarana; IV: 8.50 (Tomé et al., 1999)); and emergent species - Aspidosperma polyneuron Müll. Arg (Family Apocynaceae, popular name: Peroba-rosa; IV: 12.46 (Tomé et al., 1999). All selected are shade tolerant species (Silva; Soares-Silva, 2000; Zama et al., 2012). A. polyneuron and C. canjerana have high commercial value and were mainly exploited in Logged Forest (Carvalho, 1994; Tomé et al., 1999; Zama et al., 2012).
In each area, 30 plots of 100 m² (10 m × 10 m) were established and subdivided into 120 subplots of 25 m² (5 m × 5 m). The plots were allocated contiguously, totaling 3000 m² of sampled area per forest (50 m × 60 m). Nested sampling designs are preferred for identifying the spatial pattern without knowing the spatial scale of the process (Dale & Fortin, 2014).

The sampling area in Mature Forest is in the north portion of fragment that has been considered reference for Mature Forests (Haddad et al., 2016). In Logged Forest an area with similar characteristics to the Mature Forest sampling area were searched, with similar topography, away from edge effects and without excessive lianas or bamboos but with selective logging evidence (presence of sawn trunks of *A. polyneuron* nearby).

The total height (forest floor to top of crown, in meters) of all individuals of the six species within plots using a tape measure or Vernier caliper and a laser distance measurer. *Actinostemon concolor* and *Inga marginata* are abundant in small size classes. Therefore, for these species’ subplots of 4 m² were established in a corner of each 100 m² plot to sample individuals ≤50 cm (*A. concolor*) and ≤30 cm (*I. marginata*) in height and the relative density was used.

Frequency distributions of individuals in size classes were made to compare the size structure (height structure) of populations among areas. The size classes used are different for the species of understory and canopy due to the size characteristics of each group of species. The Kolmogorov-Smirnov test was used to compare the height structure of each species between areas (Brower & Zar, 1984; Siegel & Castellan Jr, 1975). The moment skewness coefficient was used to evaluate the symmetry of tree size distributions (Cramér, 1999). The moment skewness coefficient is positive for size distributions with many individuals in the first size classes and few individuals in the larger classes, and it is negative for size distributions with many individuals in the larger size classes and few individuals in the first size classes (Bendel et al., 1989; Wright et al., 2003). All tests were performed with BioEstat 5.0 statistic software (Ayres et al., 2007).

The number of individuals for subplot and subplot center coordinates was used to determine the spatial pattern of each species. The spatial pattern was analyzed using Moran’s I spatial autocorrelation coefficient (Legendre & Fortin, 1989), testing the null hypothesis that the Moran’s I coefficient, at each distance class, is not significantly different from zero, indicating randomness (Legendre; Fortin, 1989). Therefore, Moran's coefficient varies generally from -1 to 1; positive values of Moran's I
correspond to positive autocorrelation and negative values of Moran's I correspond to negative autocorrelation. A spatial correlogram was built based on I values as a function of the distance classes, and its significance was tested using the Bonferroni criterion (Oden, 1984).

The canopy cover index was evaluated in each plot using a spherical densitometer (Lemmon, 1956). Four measurements at breast level (1.30 m) taken from the center of the plot towards each corner were obtained for each plot for the average estimate. The relation between the spatial patterns of the individuals of each species and canopy cover was estimated with partial Mantel tests (Legendre; Fortin, 1989). The p-level for these tests was determined by a permutation procedure (999 interactions). The autocorrelation analyses and partial Mantel tests were performed with Passage Software (Rosenberg & Anderson, 2011). The average canopy cover index (CCI) for each area was calculated and compared by t-test using R-studio version 1.3.959 (RStudio, 2020). Maps of individuals distribution in plots and 3D scatter plots of species were made in Rstudio version 1.3.959 using ggplot2 and scatterplot3d packages (RStudio 2020).

3. Results and Discussion

The Analysis of height structure showed differences of each population of the selected species between the study areas (Kolmogorov-Smirnov test, p<0.05, Table 1), except for height distribution of C. xanthocarpa. The most of species had a greater proportion of individuals in the first size classes (seedlings and small saplings) in Logged Forest than in Mature Forest (moment skewness coefficient, Figure 2), except for the height structure of A. concolor and I. marginata.

Table 1. Results of the comparison of Height structure by Kolmogorov-Smirnov test (D) of understory (A. concolor, S. bonplandii, and I. marginata) and canopy/emergent tree populations (C. xanthocarpa, A. polyneuron, and C. canjerana) between two study areas: Godoy Forest State Park (Mature Forest) and São Francisco Forest State Park (Logged Forest), Paraná state, Brazil.

| Species/Stratum       | D     | p    |
|-----------------------|-------|------|
| **Understory species**|       |      |
| A. concolor           | 0.166 | <0.01|
| S. bonplandii         | 0.086 | <0.01|
| I. marginata          | 0.334 | <0.01|
| **Emergent/canopy species** |       |      |
| C. xanthocarpa        | 0.143 | >0.05|
| A. polyneuron         | 0.210 | <0.01|
| C. canjerana          | 0.243 | <0.01|

Source: Authors.
Figure 2. Height classes of understory (A. concolor, S. bonplandii, and I. marginata) and canopy/emergent tree populations (C. xanthocarpa, A. polynuron, and C. canjerana) in two study areas: Godoy Forest State Park (Mature Forest) and São Francisco Forest State Park (Logged Forest), Paraná state, Brazil. \( g_1 \) mf = The moment skewness coefficient in Mature Forest. \( g_1 \) lf = The moment skewness coefficient in Logged Forest.

All populations were represented in most of the size classes, except species with high commercial value, like A. polynuron. The highest classes of A. polynuron (> 7.0 meters of height) and the intermediate and highest classes of C. canjerana (> 0.50 meters of height) were underrepresented in Logged Forest, with one individual compared to nine in Mature Forest for A. polynuron and four individuals compared to 47 in Mature Forest for C. canjerana (Figure 2). The commercially valuable emergent/canopy species (A. polynuron and C. canjerana) have a deficit of individuals in the largest size classes in the exploited area, while C. xanthocarpa have a good development in both fragments.

Differences were observed when compared height and spatial structure between Logged and Mature Forests. Changes in size structure of species were found in other similar studies as a consequence of selective logging of tree species (Liebsch et al., 2021; Rodrigues et al., 2016, 2019). The understory species A. concolor and S. bonplandii showed more individuals in
Logged Forest while there were fewer of most of the other species. There were more individuals of *A. concolor* and *S. bonplandii* in Logged Forest, with a higher number of individuals in all size classes, mainly in the smaller ones. Primack and Lee (1991) observed that an understory shade-tolerant population had some tendency to increase in size 11 years after logging, suggesting that the growth may be associated with the building phase of that forest. Higher seedling growth was found by Montgomery and Chazdon (2002) for shade-tolerant species and by Pearcy (1983) for understory species in areas with moderate light increase.

The understory species *I. marginata* did not perform like other species of understory species group and there were fewer individuals in all size classes, mainly in the smaller classes in Logged Forest when compared to the Mature Forest. *S. bonplandii* and *A. concolor* have, respectively, 3.6 and 2.7 times more individuals in the exploited forest than in Mature Forest. On the other hand, *I. marginata* has 3.0 times fewer individuals in Logged Forest.

The canopy/emergent species *C. canjerana* (canopy) and *A. polyneuron* (emergent) also had fewer individuals in Logged Forest, both species being 1.6 times fewer individuals in Logged Forest. Although emergent/canopy species reach the canopy layer of the forest, they can compete with the understory species while they are occupying the lower strata of the forest (Laurans et al., 2014; Onoda et al., 2014). These results suggest competition between understory species with advantages for *S. bonplandii* and *A. concolor* in Logged Forest.

The plant size structure is different between areas in multiple strata (understory, and emergent/canopy species), showing a smaller proportion of larger individuals and a greater number of individuals smaller than 1 m tall and 1 cm in height in Logged Forest, an indication of regeneration process. These results can be interpreted by less competition in the canopy (Bertolini et al., 2020) due to the removal of adults and the consequent increased availability of light in the understory that can positively influence the rates of flower and fruit production, germination, seedling establishment, and sapling growth (Smith, 2000), stimulating the forest regeneration (Rodrigues et al., 2019).

Evident differences mainly were found when observing the lower number of individuals in the larger and intermediate size classes of *C. canjerana* and larger classes of *A. polyneuron* (canopy/emergent species) in Logged Forest, which are study species that have wood of high economic value (Carvalho, 1994; Tomé et al., 1999).

Nevertheless, changes were found in size structure of almost all species, including those that were not directly exploited. Disturbances lead to changes in environmental conditions, creating a new habitat with important variations in light, moisture, and temperature (Burton et al., 2009; Guariguata & Ostertag, 2001), which directly influence the birth and mortality rates of populations (Getzin et al., 2008; Poorter et al., 2008).

*Campomanesia xanthocarpa* was the only species that had the same height structure in both areas. The allometric relationship between trunk diameter and total height for individuals of this species in the same period also was also similar (Bovolenta, 2011). These observations suggest that *C. xanthocarpa* developed similarly in both areas. *Campomanesia xanthocarpa* seems to have a good development and plasticity in areas with different environmental resources and conditions, since it occurs in areas of rainforest and also in areas with higher luminosity, like in the Cerrado biome (Sobral et al., 2015).

The understory species in Mature Forest not showed spatial autocorrelation among individuals, suggesting a random spatial distribution (Table 2, Figures 3, 5-8). The same result was observed for the understory species in Logged Forest, except *S. bonplandii*, which had an aggregate spatial distribution in small clumps (5 m) and a negative autocorrelation at larger distances (27 and 60 m) (Figure 3, 5-8).
Table 2. Significance of autocorrelation by Bonferroni’s test (α <0.05) for understory species and canopy/emergent species in both study areas, Godoy Forest State Park (Mature Forest) and São Francisco Forest State Park (Logged Forest), Paraná state, Brazil. Values represents corrected significance of Bonferroni’s test (α) of Moran’s I. *** = (α <0.05); ns = not significant values.

| Species/Stratum          | Mature Forest | Logged Forest |
|--------------------------|---------------|---------------|
| **Understory species**   |               |               |
| Actinostemon concolor    | 0.5449<sup>ns</sup> | 0.3094<sup>ns</sup> |
| Inga marginata           | 0.1911<sup>ns</sup> | 0.6779<sup>ns</sup> |
| Sorocea bonplandii       | 1.0000<sup>ns</sup> | 0.0076***      |
| **Emergent/canopy species** |            |               |
| Aspidosperma polyneuron  | 0.0000***     | 1.0000<sup>ns</sup> |
| Cabralea canjerana       | 0.3389<sup>ns</sup> | 0.1176<sup>ns</sup> |
| Campomanesia xanthocarpa | 0.3321<sup>ns</sup> | 0.0266***      |

Source: Authors.

Figure 3. Spatial correlogram of understory species and canopy/emergent species in both study areas, Godoy Forest State Park (Mature Forest, red) and São Francisco Forest State Park (Logged Forest, blue), Paraná state, Brazil, respectively. Solid points represent significant correlations of Moran’s I (p < 0.05, Bonferroni corrected for number of distance classes). Unfilled points are non-significant values for correlograms. Dashed line represents zero autocorrelation.

In Mature Forest two species of the canopy/emergent group species, *C. xanthocarpa* and *C. canjerana*, presented a random spatial distribution (Figure 3, 5-8), while *A. polyneuron* had a spatial pattern with distribution in a gradient, where the species was positively autocorrelated at short distances and negatively autocorrelated at long distances (Figure 3, 5-8). In Logged
Forest *A. polyneuron* and *C. canjerana* had a random spatial distribution while *C. xanthocarpa* had an aggregate spatial distribution in clumps of ca. 12 m (Figure 3, 5-8).

The canopy cover index (Figure 4) as higher in Mature Forest, (93.96% ± SE = 0.36) compared to the Logged Forest (83.51% ± SE 0.85). The partial Mantel test did not indicate a correlation between the spatial structure of individuals and the canopy cover in each of the plots for all species in both areas (for all species p>0.05).

**Figure 4.** Canopy cover index of Mata São Francisco State Park (Logged Forest) and Mata dos Godoy State Park (Mature Forest). Boxes show median, the 95% confidence interval, 25th and 75th percentiles, the standard error (SE). Bars indicate range distribution. Letters indicate a statistically significant difference in canopy cover index (CCI) between areas.

The occupation of forest area by populations in both study areas was widespread, i.e., all populations had individuals in most of the plots and there were no correlations between canopy cover of each forest with the spatial distribution of any species. A random distribution was observed for three *A. concolor*, *I. marginata*, and *C. canjerana* of the six studied species between areas (Figure 3, 5-8).

*I. marginata* and *C. canjerana* had a wide distribution, represented mainly by seedlings and individuals of the first size classes, in both sampled areas. This result suggests that seed dispersal is effective, because the seedlings are also germinating far away from adult individuals. The results possibly indicate presence of a seed dispersing fauna even in Logged Forest, because *I. marginata* and *C. canjerana* are zoochoric species (note that *C. canjerana* has few adults in Logged Forest).

*A. concolor* occupied large continuous zones in both studied areas with many individuals in all size classes, indicating that this species occupies the forest understory in abundance. *A. concolor* may occur in larger agglomerations that the limits of our sample area. Thus, we suggest tests in other ranges for spatial distribution of that species.

*S. bonplandii* and *C. xanthocarpa* had random distribution in Mature Forest, but aggregate spatial distribution in small clumps in Logged Forest. *Sorocea bonplandii* was abundant in both areas, occupying the majority of plots with many individuals, but in Logged Forest there was a higher density of saplings in some sites. For example, in one subplot of 5 m × 5 m, 76 individuals from this species were found. *Campomanesia xanthocarpa* was less abundant in both areas, but the aggregate distribution in Logged Forest was also due to the higher density of individuals in the smaller size classes. A higher degree of aggregation in smaller individuals is common for tropical tree species (Condit et al., 2000; Fonseca et al., 2004; Morel et al., 2018). Condit et al., (2000) found that the aggregation of juveniles suggests habitat-related patchiness or dispersal limitation.

The spatial distribution of *A. polyneuron* in Mature Forest was typically a gradient distribution (see distribution in gradient in Legendre; Fortin, 1989). There was a high density of individuals in one of the ends of the sampled area that
progressively decreased toward the other end, where the largest specimens are (potential dispersers). *Aspidosperma polyneuron* is an anemochory species and the larger individuals of that species that exceed the canopy forest have their seed dispersal facilitated by greater exposure to wind, which takes their seeds farther away from the parent plant. Fonseca et al., (2004), studying *A. polyneuron* populations in the southeast of Brazil, found a negative correlation between the abundance of seedlings and adults.

This spatial pattern in Mature Forest can suggest the success of the seed dispersal process and the influence of natural enemies on the distance from parental plant (Brachtvogel et al., 2020; Chisholm & Fung, 2020; Jia et al., 2020).

On the other hand, *Aspidosperma polyneuron* had many individuals randomly distributed throughout the Logged Forest without the presence of large adult specimens inside or next to the sampled area and with few individuals in first height class (11 individuals lower than 0.25 meter). Probably the majority of individuals in the area were established before the logging. Seedlings and saplings of this species grow slowly and remain a long time in the shaded understory of the forest (Silva Ribeiro et al., 2020). The removal of adults and consequent low (or no) seedling recruitment is aggravated by such species characteristics as slow growth rate and anemochory syndrome (smaller range), which may make the recovery of *A. polyneuron* very slow and difficult.
Figure 5. Understorey species maps of individuals distribution (A. concolor, I. marginata and S. bonplandii) along the sample areas (50 m × 60 m) in both study areas, Godoy Forest State Park (Mature Forest) and São Francisco Forest State Park (Logged Forest), Paraná state, Brazil, respectively. Column on the left represents populations of Mature Forest and columns on the right represents Logged Forest.

Source: Authors.
Figure 6. Emergent/canopy species maps of individuals distribution (A. polyneuron, C. canjerana and C. xanthocarpa) along the sample areas (50 m × 60 m) in both study areas, Godoy Forest State Park (Mature Forest) and São Francisco Forest State Park (Logged Forest), Paraná state, Brazil, respectively. Column on the left represents populations of Mature Forest and columns on the right represents Logged Forest.

Source: Authors.
Figure 7. Understorey species 3D scatter plot distribution individual maps (A. concolor, I. marginata and S. bonplandii) along the sample areas (50 m × 60 m) in both study areas, Godoy Forest State Park (Mature Forest) and São Francisco Forest State Park (Logged Forest), Paraná state, Brazil, respectively. Column on the left represents populations of Mature Forest and columns on the right represents Logged Forest.

Source: Authors.
Figure 8. Emergent/canopy species 3D scatter plot distribution individual maps (A. polyneuron, C. canjerana and C. xanthocarpa) along the sample areas (50 m × 60 m) in both study areas, Godoy Forest State Park (Mature Forest) and São Francisco Forest State Park (Logged Forest), Paraná state, Brazil, respectively. Column on the left represents populations of Mature Forest and columns on the right represents Logged Forest.

4. Conclusion

Selectively logged areas have features different than the expected structure when compared to Mature Forest even after becoming a protected area. An abundance of understory species in the logged area was not expected and deserves greater attention.
in future studies, since it is poorly documented in the literature. The low occurrence of adults and saplings of *A. polyneuron* is a concern mainly because of the slow growth and limited dispersal of this species, which may have implications for the viability of this population. The importance value (IV) is an index that highlights the horizontal importance of each species in Tree Community. The index considers aspects population of Abundance, frequency and relative dominance in relation to the Tree Community, demonstrating which species are most successful in exploiting the resources. Therefore, selection of species with higher IV together with species spatial distribution patterns can help to demonstrate the impacts of selective logging more clearly in space and time. In addition, shade-tolerant species are more affected by selective logging since the main effect of logged species causes an increase in luminosity in the lower strata forest, favoring shade-intolerant species in comparison to shade-tolerant species. The Selectively logged area of study (SFFSP) is surrounded by agricultural matrix, which may impose more barriers to arrival and dispersion of shade-tolerant species propagules (group of species characteristic of forest interior), showing the importance of efforts to achieve connectivity with surrounding fragments.

**Acknowledgments**

We extend our appreciation to Maristela Y. Zama, Eloísa S. Carvalho, Ana P. Liboni and Carolina B. Virillo for their assistance and very useful suggestions and to Wayne Losano for an English review of the manuscript. Our profound thanks to the Postgraduate Program in Biological Sciences of the State University of Londrina for its support, the Water and Earth Institute (Instituto de Água e Terra - IAT) for authorizing the work in protected areas.

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