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RESEARCH ARTICLE

# Structure and tree diversity of an inland Atlantic Forest–A case study of *Ponte Branca* Forest Remnant, Brazil

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**Abstract.** The Atlantic Forest is the most fragmented and threatened domain in Brazil. The main remnants are in the coastal regions. This paper describes a study performed at a protected federal reserve in Brazil located in western of São Paulo state, which is a transition with the Savannah. A forestry survey was made for understanding the forest structure, diversity, and floristic composition of an inland Atlantic Forest area. A total of 3,181 individuals with a Diameter at Breast Height over 3.5 cm were sampled. The data sample was composed of 29 families and 64 species from 15 plots. Forty-seven percent of the species were classified as a pioneer, 42% as secondary, and 11% as climax. The species Eugenia uniflora presented the highest importance value index. The values of Shannon-Weaver diversity and Pielou equitability index indicate the area has less diversity than others in the same phytophysiognomy and was dominated by a few species with many individuals. Several anthropogenic disturbances altered the forest cover of the Ponte Branca Forest remnant, which is in the process of secondary succession.



## 1. Introduction

The Atlantic Forest domain is the second largest rainforest in America, with high biodiversity rates and a unique biota with a very rich endemicity, which is second only to those of the Amazon Forest (Carvalho Júnior et al., 2008; Fiaschi & Pirani, 2009). The Atlantic domain occurs along the Brazilian coast, extending far inland in some areas of south and south-eastern Brazil (Fiaschi & Pirani, 2009) and encompassing a huge variety of formations and forest ecosystems with very different structures and floristic compositions, which have been conditioned by the edaphoclimatic and topographic characteristics of the region (SOS Mata Atlântica & INPE, 2019). More than 70% of the Brazilian population lives in the Atlantic Forest domain; as a result, it is the most threatened biome in Brazil (Scarano & Ceotto, 2015).

Logging, disordered urban growth, agricultural encroachment, and industrialization have contributed to the deforestation and fragmentation of the Atlantic Forest, reducing the original coverage to only 11.6% of the original natural environment; the remaining forest is distributed in small areas (Haddad et al., 2015; Hargreaves, 2008; Ribeiro et al., 2009) in the secondary successional stage that have been modified from their original vegetation cover (Fonseca et al., 2013), with biological evidence that mature forests with climax species are being replaced and dominated by pioneer species, in a process called “secondarization” (Joly et al., 2014; Leao et al., 2014; Scarano & Ceotto, 2015). The current forest remnants are insufficient to maintain the biodiversity, which has led to borderline situations, such as isolation of fauna and flora populations, genetic impoverishment, and growing edge effects (Guerra et al., 2013; Scarano & Ceotto, 2015). Thus, the Atlantic Forest is considered one of the world’s priorities for biodiversity conservation, with approximately 14,000 vascular plant species distributed in 208 families, of which approximately 8,000 are classified as endemic (Werneck et al., 2011).

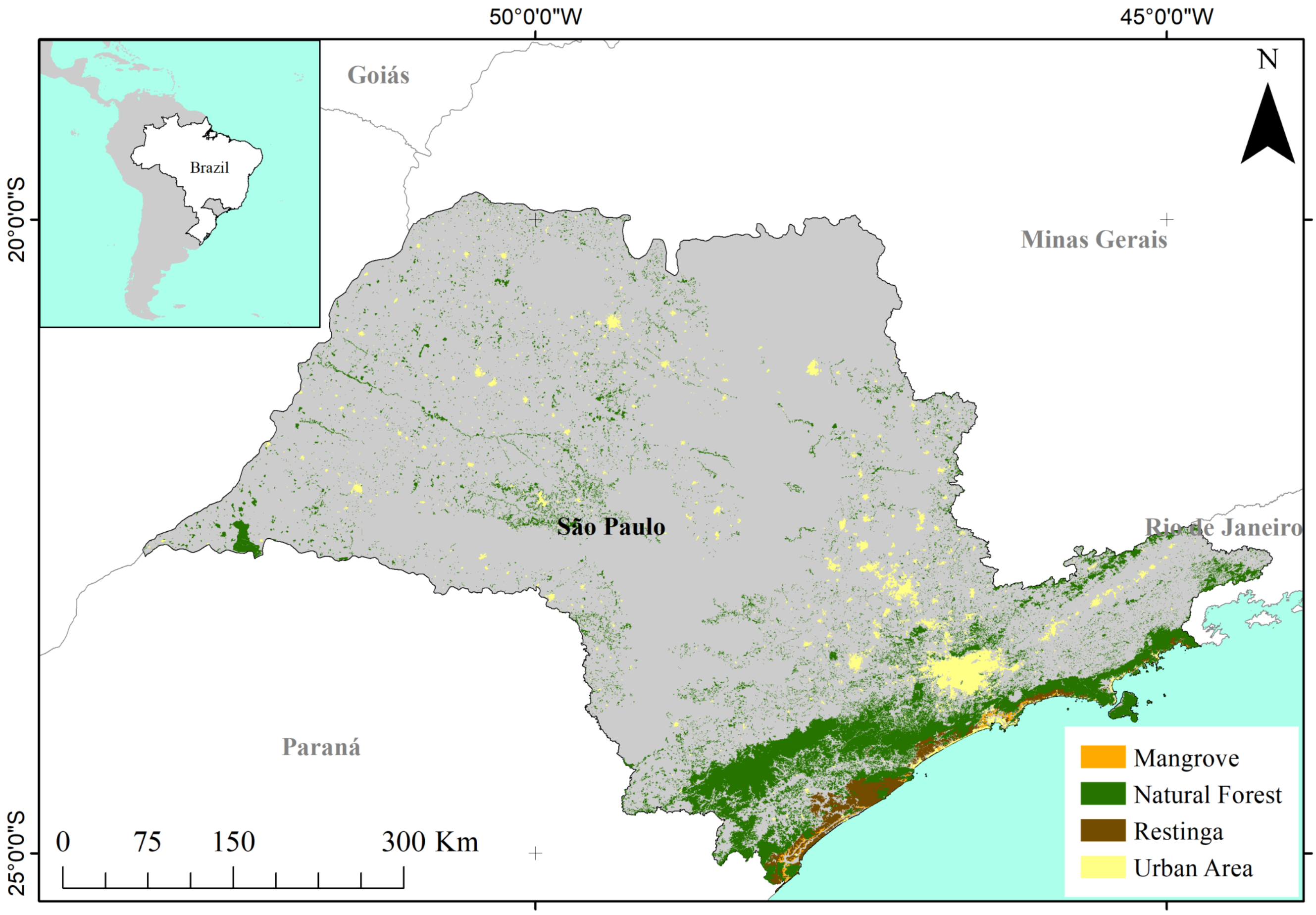


Figure 1. Remnants of the Atlantic Forest in São Paulo state
Source: Adapted from SOS Mata Atlântica & INPE. (2019).

Currently, an average of 170 unpublished species are being identified each year (Fiaschi & Pirani, 2009; Myers et al., 2000). Therefore, this biome is a biodiversity hotspot because it has already lost more than 75% of its original coverage and still shows a high degree of endemism (Myers et al., 2000; Williams et al., 2011).

Currently, the state of São Paulo, Brazil, has a remnant of approximately 16.3% of the original area of the Atlantic Forest in the state (Figure 1) that is located mainly along the coast and in the nearby areas, which are represented by dense ombrophiles forest and mixed ombrophiles forest, respectively (SOS Mata Atlântica & INPE, 2019). In the western region of the state, called *Pontal do Paranapanema*, there are a few remnants of the seasonal semideciduous forest: those in the *Morro do Diabo* state park and the *Mico-Leão-Preto* (Black Lion Tamarin - *Leontopithecus chrysopygus*) ecological station. Even though these remnants are small, they are recognized for their importance in the strategies for conservation of the Atlantic Forest due their extreme biological importance for endangered specimens of flora and fauna (MMA et al., 2007).

The seasonal semideciduous forest, which is also known as the inland Atlantic Forest, is influenced by dual climatic seasonality. In tropical regions, the dry and rainfall periods are well defined and have an average annual temperature of 21°C, but in the subtropical region, there is a short period of drought with a temperature that decreases to below 15°C in winter (Ditt, 2002). Due to the decrease in precipitation and humidity in winter, the presence of epiphytes is not very noticeable, but these weather conditions significantly increase the number of lianas (Roderjan et al., 2002). These climatic features affect the upper canopy layer by inducing dormancy; 20 to 50% of the trees in the forest are deciduous and lose their leaves in seasons with unfavorable conditions (Campanili & Schäffer, 2010).

Few studies have described the forest structure and composition of the inland Atlantic Forest remnants in western of São Paulo state because most of the protected areas for conservation of the Atlantic Forest are located on the coast (as seen in Figure 1). In this context, the objective of this study was to characterize the composition, floristic diversity, and forest structure of the tree component in an area of the *Mico-Leão-Preto* ecological station, a significant protection area of the inland Atlantic Forest in western of São Paulo State. This study will contribute to a better understanding of the succession processes in an inland Atlantic Forest, which will enable the design of strategies for the maintenance and conservation of the most fragmented phytophysiognomy of the Atlantic Forest in Brazil.

## 2. The Methods

### Study Area

The *Mico-Leão-Preto* ecological station is a federal protected reserve located in the county of *Euclides da Cunha Paulista*, which is in western of São Paulo state, Brazil (Figure 2), and consists of four remnants: *Santa Maria, Água*

*Sumida, Ponte Branca,* and *Tucano*. The study was conducted in the *Ponte Branca* Forest remnant, which has an area of approximately 13 km². This area is predominantly covered by forest in the early to late successional stages that has previously experienced fires and deforestation. The surrounding vegetation is composed of pasture and sugar cane plantations (Berveglieri et al., 2016). This region is known as *Pontal do Paranapanema*, and it is a transition zone between the inland Atlantic Forest and the Savannah (Cerrado), where species of both domains share the space in variable proportions throughout the transition zone (Veloso et al., 1991).

The field data collection was performed between 2014 and 2016. The location of the plots was based on the interpretation of aerial photographs of the study area from 1962 and 2010. The objective was to include the areas that suffered disturbances over time and the areas that remained preserved, so it was possible to cover all successional stages from the initial successional stage, which is characterized by pioneer species, to the advanced successional stage, which is characterized by climax species. Pioneer species are undemanding in terms of environmental conditions, resources and are fast-growing (Laurance et al., 2006). Climax species present long-life cycles and slow growth, and they are very dependent on the environmental conditions, resources, and the associated fauna for seed dispersal (Leao et al., 2014; Sobral-Souza et al., 2017).

According to the Köppen climate classification, the climate of the *Ponte Branca* Forest remnant is defined as Aw – tropical savannah climate with dry winter. The average precipitation is 1.382 mm, which mostly occurs during the warmest months (September to April) when temperatures reach up to 40°C. In winter, the temperatures range from 15°C to 20°C. Due to the low precipitation in the driest months (May to August), 20–50% of the species in the forest lose their leaves (Ditt, 2002), and the elevation ranges from 336 m in the southern part (more humid, alluvial forest) to 440 m in the northern part (submontane forest) (Berveglieri et al., 2016).

## Forest Inventory

For arboreal stratum sampling, 15 plots were established with two different designs (Figure 2): seven square plots measuring approximately 40 m x 40 m (P1 to P7) and a transect composed of 8 contiguous plots with sizes of 80 m x 20 m (T1 to T8). The corners of these plots were located using a measuring tape, and their coordinates were acquired by a double frequency GNSS (global navigation satellite system) receiver (HIPER). All plots were at a minimum distance of 100 m from the forest borders to avoid edge effects. The sampling area was 0.2% of the total forest area.

All trees with a diameter at breast height (DBH – measured at 1.30 m above the ground) larger than 3.5 cm were measured with a caliper, labeled, and identified at the species level, whenever possible (or at least to the genus level). The identification of species was made based on the dendrological attributes of the trees by a specialist in the identification of species in our study area, which was performed in all field surveys and consultations in the relevant literature. The classification system used was APG IV (Chase et al., 2016).

Due to the high density of trees and the large abundance of lianas, which hindered a clear view of the treetops, the variable tree heights were not measured, instead, the height was obtained from the canopy height model (CHM) obtained from airborne laser scanner (ALS) data. The ALS data were collected in 2017 at a flight height of 900 m using Riegl LMS – Q680i equipment, which records up to seven returns per pulse emitted. The density of the ALS point cloud was 19 points.m$^{-2}$ and the data processing consisted in the classification of the point cloud into the ground and nonground (vegetation) points and it was used to generate a

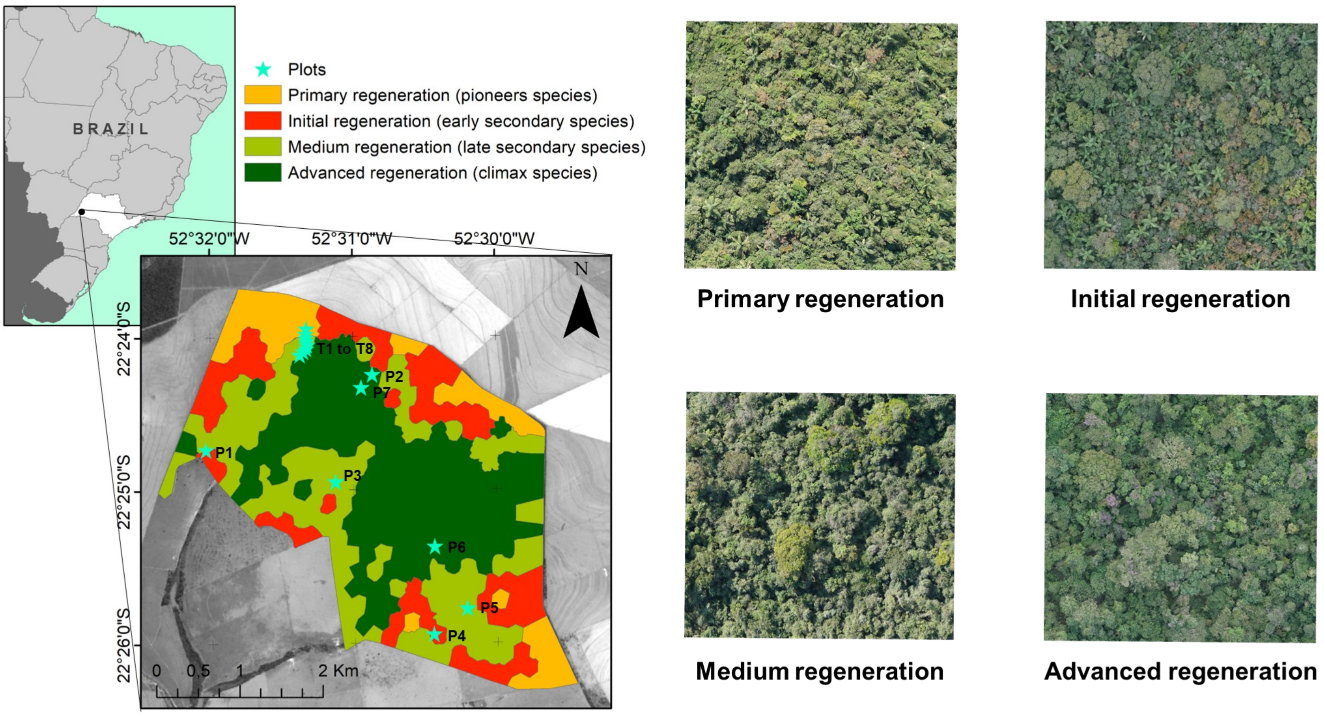


Figure 2. "*Ponte Branca*" forest remnant, in the west of the state of São Paulo with the location of the plots surveyed in the field and aerial RGB images representing the different successional stages found in the area. Source: Adapted from Berveglieri et al. (2018).

digital terrain model (DTM) and digital surface model (DSM) of the area. The DTM and DSM were used to compute the tree heights and to produce a CHM with a ground sample distance (GSD) of 50 cm.

### Vegetation Analysis

Data analysis was performed in the R environment (R Core Team, 2017) with the *vegan* package version 2.5 -5 (Oksanen, 2019). The statistical significance of the samples was checked to characterize the *in situ* floristic compositions. The species accumulation curve was built by using a method that randomizes the samples for a number of selected iterations and plots the species accumulation curve and then fits a model to the curve (Oksanen, 2019; Ugland et al., 2003). In this study, a threshold of 1,000 iterations was chosen.

The number of trees (N), average DBH (DBHm), total basal area (BAt) were calculated for each species sampled along with the following phytosociological parameters as described by Mueller-Dombois & Ellenberg. (1974): absolute density (AD), relative density (RD), relative frequency (RF), relative dominance (RDo), and importance value index (IVI).

The diversity of the tree species in the whole sample was expressed by the Shannon-Weaver index (H'), which considers the logarithmic transformation of species density, and it is most influenced by low density or "rare" species sampled (Magurran, 1988). The Pielou equability evenness index (J) was calculated to estimate the uniformity of the community, measuring how close the diversity H' obtained would be to maximum hypothetical H' diversity (Brower et al., 1984; Magurran, 2013; Moreira & Carvalho, 2013).

The diametric distribution was analysed for all species sampled from the *Ponte Branca* Forest remnant, and for those with higher IVI values. The number of diameter classes and their range was calculated by Sturges formula:

$$k = 1 + 3{,}322 * \log_{10}(N)$$

Where: k is the number of classes and N is the number of observations.

$$a = \frac{Upper\ limit - Inferior\ limit}{k}$$

Where: a is the range of each class.

## 3. Results and Discussion

In the *Ponte Branca* Forest remnant, four successional stages were found: primary regeneration stage, which showed a predominance of primary species and a very low number of secondary and climax trees; initial regeneration stage, which was characterized by primary species and growing secondary and climax species in the understory; medium regeneration stage, which had a very high abundance of secondary and climax species that had not yet reached the maturity; and advanced regeneration areas, which had trees that had reached the highest canopy layer, such as tall secondary and climax trees (Berveglieri et al., 2016).

We verified a near stabilization with the increase in the density of sampled individuals (Figure 3). This meant that if more individuals were sampled, there would be no significant increment in the number of species, suggesting that the number of samples was adequate. In our study we used large plots, with an area of 1,600 m². Some authors like Seidling et al. (2020) comment that small dispersed plots (such as 4 m² subplots) contain the same or even greater number of plant species than single and large plots. Thus, for future studies, the use of smaller plots can better capture diversity with less effort than the use of very large plots.

A total of 3,181 trees were sampled, which corresponded to a density of 1,277 ind.ha$^{-1}$, and were distributed in 29 botanical families and 64 species. Of these species, 58 were identified to the species level, and six were undetermined. Forty-seven percent of the total sampled species were classified as a pioneer, 42% as secondary, and 11% as the climax. The families with the highest species richness were Fabaceae (12 species), Myrtaceae (7 species) and Apocynaceae (5 species). Two families (Bignoniaceae and Rutaceae) presented three species each. The families Anacardiaceae and Meliaceae presented two species each, and the other families were represented by only one species (Table 1).

The four species with the highest IVIs were *Eugenia uniflora* (24.58%), *Dendropanax cuneatus* (13.12%), *Copaifera langsdorffii* (6.32%) and *Syagrus romanzoffiana* (6.02%). However, considering the relative levels of dominance, the *S. romanzoffiana* species had higher values than C. *langsdorffii*, since the *S. romanzoffiana* species presented more individuals with higher DBH values (DBHm of 10.31 cm), which occupied a larger basal area (BA 17.40 m².ha$^{-1}$) in the forest. The diametric distribution for all individuals had an inverted J-shaped curve, which is characteristic of unequal natural forests (Rocha et al., 2018), with 79.8% of individuals in the smaller diameter classes (3.5 cm to 13.5 cm) and a progressively fewer individuals with increasing diameter class. The same pattern was observed for species with higher IVIs, except for *S. romanzoffiana*, which had an almost normal distribution, with most individuals in the middle diameter classes (Figure 4).

The value of the Shannon-Weaver diversity index (H') was 2.08. Heterogeneous forests usually have values between 1,5 and 3,5 for this index (Turner, 1989). In some studies in Indian tropical forests, similar values were found

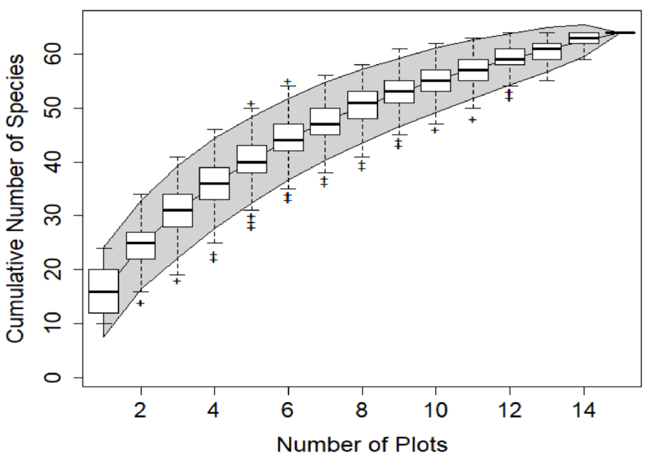


Figure 3. Species accumulation curve with a boxplot of each plot. The dotted lines represent the confidence interval of 95%

Table 1. Phytosociological parameters of the tree species sampled in the *Ponte Branca* Forest

| FAMILY/Species | N | DBHm (cm) | BAt ($m^2$) | AD ($ind.ha^{-1}$) | RD (%) | RF (%) | RDo (%) |
|---|---|---|---|---|---|---|---|
| ANACARDIACEAE | | | | | | | |
| *Astronium graveolens* | 5 | 14.60 | 0.1529 | 2.0080 | 0.1572 | 1.2712 | 0.3583 |
| *Tapirira guianensis* | 5 | 9.52 | 0.0500 | 2.0080 | 0.1572 | 1.2712 | 0.1172 |
| APOCYNACEAE | | | | | | | |
| *Aspidosperma cylindrocarpon* | 40 | 10.53 | 0.4025 | 16.0638 | 1.2575 | 1.2712 | 0.9432 |
| *Aspidosperma macrocarpon* | 56 | 12.50 | 0.9106 | 22.4894 | 1.7605 | 5.0847 | 2.1337 |
| *Aspidosperma polyneuron* | 21 | 41.84 | 4.0188 | 8.4335 | 0.6602 | 2.9661 | 9.4162 |
| *Aspidosperma ramiflorum* | 3 | 12.99 | 0.0474 | 1.2048 | 0.0943 | 1.2712 | 0.1111 |
| *Aspidosperma riedelii* | 2 | 10.19 | 0.0171 | 0.8032 | 0.0629 | 0.4237 | 0.0400 |
| ARALIACEAE | | | | | | | |
| *Dendropanax cuneatus* | 672 | 8.68 | 5.2530 | 269.8724 | 21.1254 | 5.9322 | 12.3079 |
| ARECACEAE | | | | | | | |
| *Syagrus romanzoffiana* | 120 | 22.04 | 4.8289 | 48.1915 | 3.7724 | 2.9661 | 11.3144 |
| ASTERACEAE | | | | | | | |
| *Gochnatia polymorpha* | 12 | 24.26 | 0.6444 | 4.8191 | 0.3772 | 0.8475 | 1.5099 |
| BIGNONIACEAE | | | | | | | |
| *Tabebuia heptaphylla* | 3 | 16.50 | 0.0788 | 1.2048 | 0.0943 | 0.4237 | 0.1846 |
| *Tabebuia ochracea* | 1 | 5.41 | 0.0023 | 0.4016 | 0.0314 | 0.4237 | 0.0054 |
| *Zeyheria tuberculosa* | 2 | 28.49 | 0.1536 | 0.8032 | 0.0629 | 0.8475 | 0.3599 |
| BORAGINACEAE | | | | | | | |
| *Cordia trichotoma* | 3 | 12.02 | 0.0347 | 1.2048 | 0.0943 | 1.2712 | 0.0813 |
| BURSERACEAE | | | | | | | |
| *Patagonula americana* | 1 | 6.20 | 0.0030 | 0.4016 | 0.0314 | 0.4237 | 0.0071 |
| BURSERACEAE | | | | | | | |
| *Patagonula americana* | 1 | 6.20 | 0.0030 | 0.4016 | 0.0314 | 0.4237 | 0.0071 |
| CLUSIACEAE | | | | | | | |
| *Garcinia gardneriana* | 1 | 18.00 | 0.0254 | 0.4016 | 0.0314 | 0.4237 | 0.0596 |
| COMBRETACEAE | | | | | | | |
| *Terminalia glabrescens* | 2 | 7.01 | 0.0087 | 0.8032 | 0.0629 | 0.4237 | 0.0204 |
| EUPHORBIACEAE | | | | | | | |
| *Actinostemon concolor* | 39 | 8.42 | 0.2581 | 15.6622 | 1.2260 | 1.6949 | 0.6048 |
| *Croton floribundus* | 10 | 11.69 | 0.1199 | 4.0160 | 0.3144 | 2.1186 | 0.2808 |
| *Mabea fistulifera* | 1 | 11.00 | 0.0095 | 0.4016 | 0.0314 | 0.4237 | 0.0223 |
| FABACEAE - CAESALPINIOIDEAE | | | | | | | |
| *Apuleia leiocarpa* | 22 | 18.22 | 0.7375 | 8.8351 | 0.6916 | 2.1186 | 1.7280 |
| *Bauhinia forficata* | 1 | 7.50 | 0.0044 | 0.4016 | 0.0314 | 0.4237 | 0.0104 |
| *Copaifera langsdorffii* | 175 | 13.92 | 3.5797 | 70.2793 | 5.5014 | 5.0847 | 8.3874 |
| *Guibourtia hymenifolia* | 8 | 21.25 | 0.3633 | 3.2128 | 0.2515 | 1.2712 | 0.8513 |
| *Hymenaea courbaril* | 31 | 22.28 | 1.6400 | 12.4495 | 0.9745 | 3.8136 | 3.8425 |
| *Pterogyne nitens* | 2 | 55.52 | 0.5172 | 0.8032 | 0.0629 | 0.4237 | 1.2118 |
| FABACEAE - FABOIDEAE | | | | | | | |
| *Machaerium aculeatum* | 4 | 8.80 | 0.0257 | 1.6064 | 0.1257 | 0.8475 | 0.0602 |
| *Machaerium scleroxylon* | 1 | 43.61 | 0.1494 | 0.4016 | 0.0314 | 0.4237 | 0.3500 |
| *Pterodon pubescens* | 18 | 33.99 | 2.2320 | 7.2287 | 0.5659 | 4.2373 | 5.2297 |
| FABACEAE - MIMOSOIDAE | | | | | | | |
| *Anadenanthera peregrina* | 41 | 19.42 | 1.9248 | 16.4654 | 1.2889 | 4.6610 | 4.5100 |
| *Inga vera* | 12 | 13.50 | 0.2372 | 4.8191 | 0.3772 | 1.6949 | 0.5557 |
| *Piptadenia gonoacantha* | 2 | 9.55 | 0.0143 | 0.8032 | 0.0629 | 0.8475 | 0.0336 |
| FLACOURTIACEAE | | | | | | | |
| *Casearia gossypiosperma* | 3 | 17.19 | 0.0888 | 1.2048 | 0.0943 | 1.2712 | 0.2080 |

| FAMILY/Species | N | DBHm (cm) | BAt (m²) | AD (ind.ha$^{-1}$) | RD (%) | RF (%) | RDo (%) |
|---|---|---|---|---|---|---|---|
| LAURACEAE | | | | | | | |
| *Endlicheria paniculata* | 6 | 13.99 | 0.1492 | 2.4096 | 0.1886 | 1.6949 | 0.3496 |
| *Cariniana estrellensis* | 7 | 16.17 | 0.1869 | 2.8112 | 0.2201 | 1.2712 | 0.4379 |
| MAGNOLIACEAE | | | | | | | |
| *Talauma ovata* | 4 | 17.35 | 0.0982 | 1.6064 | 0.1257 | 0.4237 | 0.2301 |
| MALVACEAE | | | | | | | |
| *Luehea grandiflora* | 24 | 10.26 | 0.2572 | 9.6383 | 0.7545 | 2.1186 | 0.6026 |
| MELIACEAE | | | | | | | |
| *Cedrela fissilis* | 5 | 17.83 | 0.1389 | 2.0080 | 0.1572 | 1.2712 | 0.3255 |
| *Guarea macrophylla* | 1 | 23.20 | 0.0423 | 0.4016 | 0.0314 | 0.4237 | 0.0990 |
| MONIMIACEAE | | | | | | | |
| *Mollinedia elegans* | 9 | 7.04 | 0.0362 | 3.6144 | 0.2829 | 0.4237 | 0.0848 |
| MORACEAE | | | | | | | |
| *Ficus insipida* | 1 | 5.73 | 0.0026 | 0.4016 | 0.0314 | 0.4237 | 0.0060 |
| MYRTACEAE | | | | | | | |
| *Campomanesia xanthocarpa* | 6 | 8.01 | 0.0336 | 2.4096 | 0.1886 | 0.8475 | 0.0788 |
| *Eugenia psidiiflora* | 3 | 8.91 | 0.0198 | 1.2048 | 0.0943 | 0.4237 | 0.0464 |
| *Eugenia pyriformis* | 10 | 8.37 | 0.0705 | 4.0160 | 0.3144 | 1.2712 | 0.1651 |
| *Eugenia speciosa* | 2 | 5.89 | 0.0055 | 0.8032 | 0.0629 | 0.8475 | 0.0128 |
| *Eugenia uniflora* | 1447 | 7.89 | 9.3458 | 581.1091 | 45.4888 | 6.3559 | 21.8978 |
| *Eugenia uvalha* | 7 | 9.37 | 0.0530 | 2.8112 | 0.2201 | 2.1186 | 0.1242 |
| *Myrciaria ciliolata* | 24 | 8.06 | 0.1697 | 9.6383 | 0.7545 | 1.2712 | 0.3977 |
| PHYTOLACCACEAE | | | | | | | |
| *Gallesia integrifolia* | 1 | 24.51 | 0.0472 | 0.4016 | 0.0314 | 0.4237 | 0.1105 |
| ROSACEAE | | | | | | | |
| *Prunus sellowii* | 3 | 6.90 | 0.0126 | 1.2048 | 0.0943 | 1.2712 | 0.0294 |
| RUTACEAE | | | | | | | |
| *Balfourodendron riedelianum* | 3 | 25.78 | 0.1932 | 1.2048 | 0.0943 | 0.8475 | 0.4527 |
| *Helietta apiculata* | 37 | 11.74 | 0.5059 | 14.8590 | 1.1632 | 4.2373 | 1.1853 |
| *Zanthoxylum rhoifolium* | 8 | 16.26 | 0.2006 | 3.2128 | 0.2515 | 1.2712 | 0.4701 |
| SAPINDACEAE | | | | | | | |
| *Dilodendron bipinnatum* | 92 | 10.19 | 0.9432 | 36.9468 | 2.8922 | 5.0847 | 2.2100 |
| SAPOTACEAE | | | | | | | |
| *Pouteria ramiflora* | 8 | 12.40 | 0.1200 | 3.2128 | 0.2515 | 2.1186 | 0.2812 |
| ULMACEAE | | | | | | | |
| *Celtis iguanaea* | 137 | 8.74 | 1.2937 | 55.0186 | 4.3068 | 0.4237 | 3.0311 |
| VERBENACEAE | | | | | | | |
| *Vitex montevidensis* | 6 | 11.78 | 0.0668 | 2.4096 | 0.1886 | 0.4237 | 0.1565 |
| VOCHYSIACEAE | | | | | | | |
| *Qualea multiflora* | 1 | 12.10 | 0.0115 | 0.4016 | 0.0314 | 0.4237 | 0.0269 |
| UNIDENTIFIED | | | | | | | |
| Indeterminate 1 | 3 | 5.33 | 0.0068 | 1.2048 | 0.0943 | 0.8475 | 0.0158 |
| Indeterminate 2 | 2 | 19.26 | 0.0587 | 0.8032 | 0.0629 | 0.4237 | 0.1376 |
| Indeterminate 3 | 2 | 12.73 | 0.0259 | 0.8032 | 0.0629 | 0.8475 | 0.0606 |
| Indeterminate 4 | 1 | 22.92 | 0.0413 | 0.4016 | 0.0314 | 0.4237 | 0.0967 |
| Indeterminate 5 | 1 | 9.55 | 0.0072 | 0.4016 | 0.0314 | 0.4237 | 0.0168 |
| Indeterminate 6 | 1 | 4.46 | 0.0016 | 0.4016 | 0.0314 | 0.4237 | 0.0037 |

Where: N is the number of trees; DBHm is the mean diameter at breast height; BAt is the total basal area; AD is absolute density; RD is relative density; RF is relative frequency; RDo is relative dominance and IVI is importance value index.

for the Shannon-Weaver index (H'), as in Akash & Bhandari. (2019) with a H' value of 2.06 and Bhandari. (2018) with a H' value of 2.16, indicating dominance of few species caused by the various forms of anthropogenic pressures in past, however with a strong potential for generation, mainly due to the protection of these areas and the reduction of anthropic actions.

The value of Pielou equability evenness (J) was 0.50, i.e., 50% of the hypothetical maximum H' was reached. In a tropical forest located in the northeaster of Brazil, Barbosa et al. (2012); Júnior & Drumond. (2011); Melo et al. (2019) found J values very close to those found in our study (0.57; 0.50 and 0.56 respectively) which is also indicative of the predominance of one or a few species over the others in the

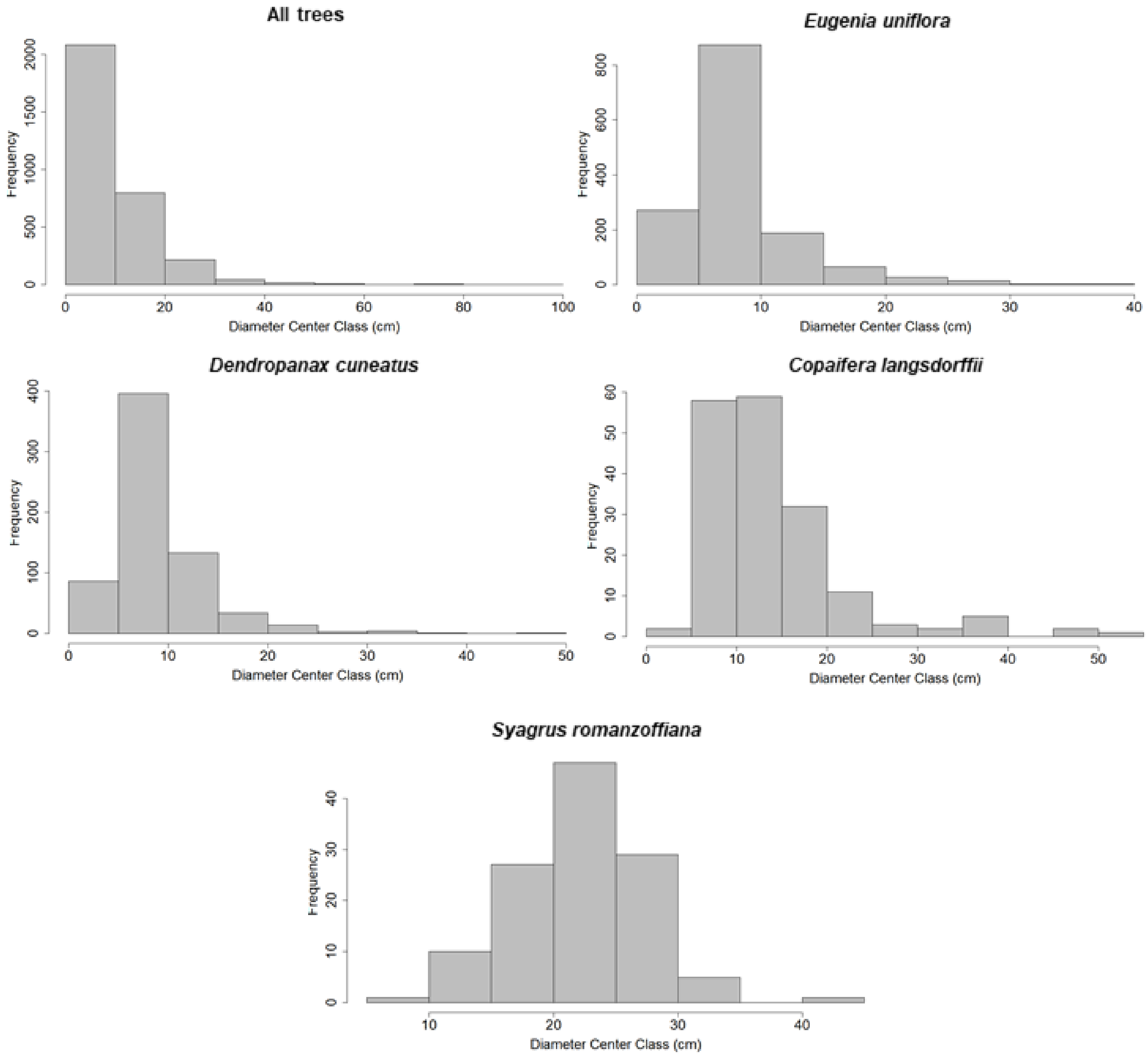


Figure 4. Diametric distribution for all trees and species with higher IVIs.

arboreal stratum. This can be proven with a high IVI value (Table 1) of the *Eugenia uniflora* species, which will be discussed in the next paragraphs.

Figure 5 shows the distribution of heights from the CHM (canopy height model) of the study area with a class interval of 6.4 m. The tallest tree had a height of 31.95 m, and more than 50% of the trees were concentrated in the height classes between 6.41 and 12.78 m. These values are similar to those found for other inland Atlantic Forest remnants in Brazil. De Paula et al. (2004) found an average height of 8.7 m and more than 80% of arboreal individuals are concentrated in the class between 4.21 m to 13.1 m. Curto et al. (2013) used several methods to stratify the tree and heights. In their study, the height of the tallest tree found was 29.20 m and approximately 75% of the trees were in the height class between 6.40 m and 15.64 m (average of 10.14 m).

The areas in the primary regeneration (parts 1 through 3 of the transect), (see Figure 2) were characterized by low-diameter trees that were smaller than 13.5 cm, a large presence of lianas and a lower canopy height, with an average of 13 m. There was a predominance of pioneer species of the Myrtaceae family, mainly *E. uniflora*, and a high density of *Dendropanax cuneatus*. However, some sparse secondary and climax tree species were found, such as *Aspidosperma polyneuron*, *Copaifera langsdorffii* and *Machaerium scleroxylon*, with DBH values between 40 and 50 cm.

An initial regeneration stage was found in plot 1 and plot 4 (Figure 2). The average DBH of the trees measured at plots 1 and 4 was higher (up to 17 cm) than that observed in the plots in the primary regeneration stage. The upper canopy had a height between 13 and 20 m. Palm trees (*Syagrus romanzoffiana*) with DBH values ranging from 19 cm to 42 cm were found. In the understory, individuals of the secondary and climax species, such as *Aspidosperma macrocarpon* and *Copaifera langsdorffii*, were appearing. The presence of *Aspidosperma polyneuron* in the upper stratum was also verified, indicating that there had been more canopy-height individuals of this climax species in the

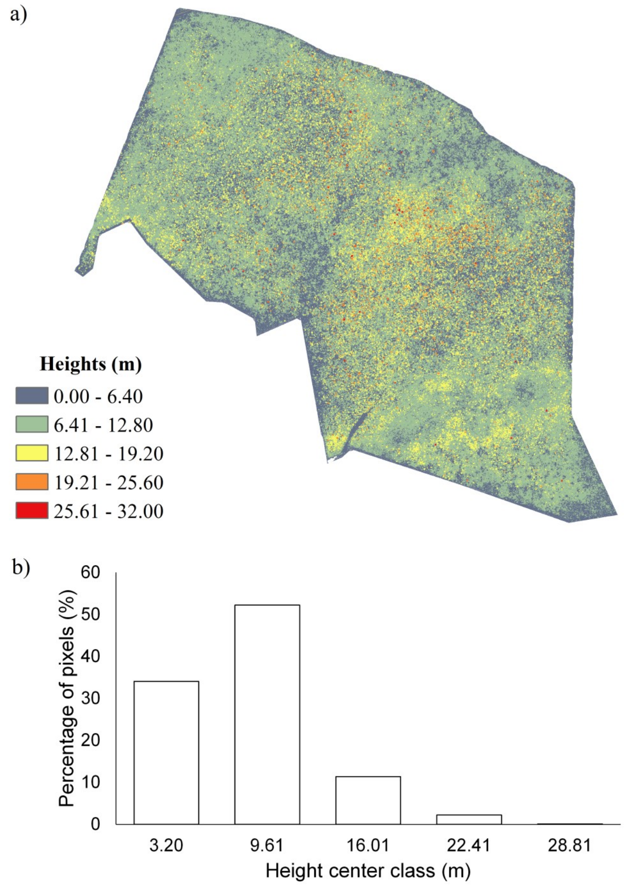


Figure 5. a) Canopy height model of *Ponte Branca*; b) Frequency distribution of tree heights.

past. There were sparsely distributed trees with large DBHs (between 30 and 60 cm), such as *Anadenanthera peregrina*, *Hymenaea courbaril* and *Copaifera lanfsdorffii*. Plot 1 showed a particular feature: a riparian zone was found near a small stream with very distinct species, such as *Endlicheria paniculata*, *Mollinedia elegans*, *Talauma ovata*, and *Vitex montevidensis* (MMA et al., 2007), and a very dense understory of *Celtis iguanaea* (137 individuals). These species are typical of humid areas of the Atlantic Forest, such as gallery forests (forests that form corridors along rivers and wetlands) and formations closer to the coast (Dias et al., 1998; Felfili et al., 2000).

Parts 4 to 8 of the transect and plots 3 and 5 (see Figure 2) showed a medium regeneration successional stage. The canopy height varied between 18 and 21 m and had a low presence of lianas. Species of the Myrtaceae family, *Dendropanax cuneatus* and the palm tree *Syagrus romanzoffiana* predominated in the understory and medium strata, with heights of approximately 8 m. A larger abundance of secondary and climax species of higher commercial value was found in the lower and middle strata, including *Aspidosperma cylindrocarpon*, *A. macrocarpon*, *A. polyneuron*, *Cariniana estrellensis* and *Copaifera langsdorffii*. The tree individuals had diameters of approximately 25 cm; some representatives of the climax species had diameters larger than 35 cm.

Plots 2, 6 and 7 represented mature forest areas in advanced regeneration. Large trees (23 m to 29 m in height) and a continuous understory canopy of approximately 12 m were present. Secondary and climax species with high economic value appeared in the emergent and canopy layers, such as *Pterodon pubescens*, which was the species with the highest DBH value found in the survey (97.40 cm); *Aspidosmerma polyneuron,* which had individuals with DBH > 60 cm; *Pterogyne nitens*; *Copaifera langsdorffii*; *Balfourodendron riedelianum*; *Cedrella fissilis* and *Zeyheria tuberculosa.* In the understory, many individuals of *Actinostemon concolor* (22 individuals), *Dendropanax cuneatus* (147 individuals) and *Eugenia uniflora* (306 individuals) were found.

The tree DBHs were concentrated in the first diameter class, as shown in Figure 4, forming an inverted J-shaped curve and indicating a balanced distribution trend due to the self-regenerative capacity of plant species, in which younger individuals are able to replace the older and larger diameter trees that produce larger amounts of seeds and continue forest regeneration. This concentration also suggested that the forests were now in the early stages of regeneration due to the high density of thinner trees (Harper, 1990; Moreira & Carvalho, 2013; Uhl & Murphy, 1981). Also in an inland Brazilian Atlantic Forest, Lisboa et al. (2019) found the same pattern for diametric distribution, corroborating the self-generative capacity of communities between mortality and recruitment of arboreal individuals.

Some typical species of Brazilian Savannah, such as *Anadenanthera peregrina*, *Celtis iguanaea* and *Qualea multiflora* were found, which emphasized the transition between inland Atlantic Forest and Savannah in western of São Paulo state. Other remnants of seasonal semideciduous forests in Brazil also present this characteristic of floristic similarity with the savannah (Cerrado), due to the vast transition zone between the biomes and a greater distance to the sea, which is a striking feature of the Brazilian Cerrado (Oliveira Júnior et al., 2021) .

All plots had high concentrations of Myrtaceae in the understory, especially *Eugenia uniflora*, which were a species with a higher IVI value (Table 1). This species had a wide distribution and a large regrowth capacity, mainly colonizing open woods in the intermediate stratum (Lorenzi, 1992). Because *E. uniflora* is a pioneer species, a higher concentration of individuals with smaller diameters and absence of individuals in the upper classes are expected (Figure 4). The largest *E. uniflora* tree found in the *Ponte Branca* area had a diameter of 38.20 cm. Another species that occurred frequently in the understory and that had similar characteristics was *Dendropanax cuneatus*, a widely dispersed pioneer species that inhabits mainly secondary formations and open wooded areas (Lorenzi, 1992). As this species fruiting in the dry season, it becomes an important provider of food for fauna during resource scarcity (Almeida & Viani, 2021). The largest individual found had a DBH of 50 cm.*Copaifera langsdorffii* is a climax species with large ecological flexibility that can be found in many habitats. This flexibility or plasticity can be reflected in changes in the shape patterns of the populations of

this species, according to the existing environmental conditions during their colonization in different areas (Costa et al., 2012). Young individuals frequently appear in areas in the regeneration stage and those with secondary vegetation (Carvalho, 2003). These species were noticed in almost all plots, and it was possible to verify in Figure 4 that there were a relevant number of trees in the middle diameter classes, indicating the succession of this species, with individuals migrating from the smaller to the larger DBH classes.

The palm tree *Syagrus romanzoffiana* occurred in all plots that were in the initial and average regeneration stages. This is a common pioneer species in seasonal semideciduous forests and has also been found in other forest remnants in western São Paulo State, in some cases creating almost pure canopies (MMA et al., 2007). The *S. romanzoffiana* fruit is much appreciated by the local fauna, which disperse it widely (Lorenzi, 1992). The diametric distribution of this differed from those of others by following the pattern of an almost normal curve, with the presence of 91% of the sampled individuals in the intermediate diameter classes, which indicated a certain degree of homogeneity and development of this species within the forests. Moreover, palm trees present different growth patterns when compared to the other species: the production of the stem axis occurs from a single apical meristem, with regular production of leaves, very constant crown structure and the absence of typical secondary growth; the diameter can be decreased through death or destruction of the external stem (stip) tissues, which allows these plants to reach higher heights relative to the diameter (Tomlinson, 1990).

The Shannon-Weaver index computed for the studied forest remnant was lower when compared to those of other areas of seasonal semideciduous forest in the São Paulo state, as mentioned by Durigan et al. (2002), who reported diversity values above 3.50, indicating different dynamics in these forest types in the different locations. For the *Ponte Branca* Forest remnant, Ditt. (2002) found a diversity value of 2.29. The difference may be linked to the dynamics that occurred in the forest between the dates of the two studies (approximately 13 years of difference), in which the author showed a low abundance of pioneer trees by quadrant sampling. However, currently, there is an abundance of pioneer trees in the *Ponte Branca* Forest remnant that have relevant ecological dominance, which was confirmed by the Pielou evenness, with a value of J' = 0.50; some species had the most tree individuals (Table 1) in comparison with the low densities of other species (Fonseca et al., 2013).The *Ponte*

*Branca* Forest remnant suffered from several anthropogenic disturbances over time that significantly changed forest coverage, including the advance of agriculture (sugarcane) and pastures, the application of agricultural chemicals in the cultivated areas and forest fires that caused edge effects. Therefore, it was difficult for the forest to regenerate in many areas. The selective logging of species of high economic value that presented high DBH values, such as *Aspidosperma polyneuron, Cariniana estrellensis, Copaifera langsdorffii, Hymenaea courbaril, Pterodon pubescens* and *Tabebuia heptaphylla*, has also intensified the deforestation process (Berveglieri et al., 2016; Durigan et al., 2002). Furthermore, deforestation had led to an increase in the groundwater level in the northern region of *Ponte Branca*, where the altitude is higher, such that the greater flow of water into the ground has led to the rise of groundwater. As a result, the regions at lower altitudes have begun to present an increase in the humidity near the surface, causing changes in the forests, as seen in Plot 1, where a riparian zone was found with the species characteristics of that environment (Berveglieri et al., 2016; MMA et al., 2007).Using canopy height models obtained from historical and current images, Berveglieri et al. (2021) studied the cover change of vegetation in the *Ponte Branca* Forest remnant based on structural information on tree heights relative variance between tree heights and density of higher trees in th

e upper canopy. These conceptual models showed that between 1978 and 2010 a high variance for tree height and density was found, confirming the degradation that occurred until the late 1970s in the area, mainly due to the removal of climax species present in the canopy with wood potentials like *Aspidosperma polyneuron, Cariniana estrellensis and Hymenaea courbaril.* In the second analyzed period (2010 to 2017) a smaller variation was observed, but with a tendency for canopy growth. This is related to the fact that since 2002 the *Ponte Branca* Forest remnant has become a conservation unit protected by federal laws, and it is possible to notice that the previously degraded areas are being re-established.

Forest fragmentation has occurred in western São Paulo State, mainly during the second half of the 20th century. Most of the trees that currently form the canopy layer were established before fragmentation. In the long term, however, the ability of these forests to survive the impacts of fragmentation is unknown. The conservation of species with small populations in these forest remnants, especially those under selective logging, can be seriously threatened, and for other species, the maintenance of the structure and genetic diversity of the population in the fragments may already be seriously affected (Durigan et al., 2002).

## 4. Conclusion

This study showed the structure, diversity, and floristic composition of a remnant of inland Atlantic Forest, in the western region of the state of São Paulo. Comparing the same forest type in other parts of the state, less diversity was found in our study area. The anthropic intervention had a decisive influence on succession stages since there are stages of primary and initial regeneration in *Ponte Branca* Forest remnant. However, some areas have remained intact, which have not suffered from deforestation and have been protected since the area became a federal protected reserve, with the presence of secondary species and climax with varying heights and diameters at breast height. Despite pressure from the neighborhood (e.g. agriculture), there is a recovery, although the fragment's territorial limitations, is still noticeable. For future studies, the use of digital image processing and photogrammetry techniques and LiDAR data processing can be of great value for tropical forests, mainly due to the difficulty of obtaining field and historical data from these areas. Therefore, to facilitate the measurement and understanding of the forest structure and dynamics, remote sensing data are needed for the estimation of structural attributes and their relationships, mainly for these degraded areas with a lack of field data.

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