# Autoecology and Individual Tree Modeling of *Eugenia involucrata* DC. in an Araucaria Forest

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**ABSTRACT –** Understanding how a particular species grows and factors that affect its growth are relevant in ecological studies, especially when one intends to manage a particular species. Thus, this research aimed to evaluate the spatial distribution, phytosociology dynamics and competition of *E. involucrata*, to characterize floristic composition and phytosociology of the associated community and to observe relationship between species growth and competition in order to propose and validate diameter growth models for the species. This research was developed at Irati National Forest, Parana state in 25ha permanent plots, with inventory data from 2002 to 2017. To characterize the specie, the spatial distribution, phytosociology, and dynamics (increment, mortality and ingress) data were evaluated. Characterization of associated community was carried out in 111 plots of 100m$^2$, evaluating floristic composition, phytosociology, and competition, and later, growth models were proposed at individual trees level. The species showed aggregate spatial distribution, slow growth diameter, and an ingress rate greater than the mortality rate. The species most associated with *E. involucrata* were *Araucaria angustifolia*, *Ilex paraguariensis* and *Ocotea odorifera*. *E. involucrata* trees in smaller DBH classes (10 to 20cm), suffered more competition from associated community. Variables initial DBH and initial cross-sectional area were most correlated with final diameter, and these were variables that had best fit for diameter growth models for individual trees. This research provides relevant information about ecology of this species and its associated communities very useful for future research for the species.

**Keywords:** Cerejeira, competition; growth; dynamics; associated community.

## Autoecologia e Modelagem de Árvore Individual de *Eugenia involucrata* Dc. em Floresta Ombrófila Mista

**RESUMO –** Compreender como uma determinada espécie cresce e os fatores que afetam seu crescimento são relevantes nos estudos ecológicos, especialmente quando se pretende administrar uma determinada espécie. Assim, esta pesquisa visou avaliar a distribuição espacial, fitossociologia, dinâmica e competição de *E. involucrata*, caracterizar a composição florística e a fitossociologia da comunidade associada e observar a relação entre o crescimento da espécie e a competição, a fim de propor e validar modelos de crescimento de diâmetro para a espécie. Esta pesquisa foi desenvolvida na Floresta Nacional do Irati, estado do Paraná, em parcelas permanentes de 25ha, com dados de inventário de 2002 a 2017. Para caracterizar a espécie, foram avaliados os dados de distribuição espacial, fitossociologia e dinâmica (incremento, mortalidade e ingresso). A caracterização da comunidade associada foi realizada em 111 parcelas de 100m$^2$, avaliando-se a composição florística, fitossociologia e competição e, posteriormente, foram propostos modelos de crescimento em nível de árvores individuais. As espécies apresentaram distribuição espacial agregada, diâmetro de crescimento lento, e uma taxa de ingresso maior que a taxa de mortalidade. As espécies mais associadas com *E. involucrata* foram *Araucaria angustifolia*, *Ilex paraguariensis* e *Ocotea odorifera*. As árvores de

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*E. involucrata* em classes de DAP menores (10 a 20cm) sofreram mais competição da comunidade associada. As variáveis DAP iniciais e a área da seção transversal inicial estavam mais correlacionadas com o diâmetro final, e estas foram as variáveis que melhor se adequaram aos modelos de crescimento de diâmetro para árvores individuais. Esta pesquisa fornece informações relevantes sobre a ecologia dessa espécie e suas comunidades associadas, muito úteis para pesquisas futuras para a espécie.

**Palavras-chave:** Cerejeira; competição; crescimento; dinâmica; comunidade associada.

## Autoecología Y Modelado de Árboles Individuales de *Eugenia involucrata* Dc. en Bosque de Araucaria

**RESUMEN –** Entender cómo crece una especie concreta y los factores que afectan a su crecimiento es relevante en los estudios ecológicos, especialmente cuando se pretende gestionar una especie concreta. Así, esta investigación tuvo como objetivo evaluar la distribución espacial, la fitosociología, la dinámica y la competencia de *E. involucrata*, caracterizar la composición florística y la fitosociología de la comunidad asociada y observar la relación entre el crecimiento de la especie y la competencia para proponer y validar modelos de crecimiento diamétrico para la especie. Esta investigación se desarrolló en la Selva Nacional de Irati, Estado de Paraná, en parcelas permanentes de 25ha, con datos de inventario de 2002 a 2017. Para la caracterización de la especie, se evaluaron los datos de distribución espacial, la fitosociología y dinámica (incremento, mortalidad y reclutamiento). La caracterización de la comunidad asociada se realizó en 111 parcelas de 100m², evaluando la composición florística, la fitosociología y la competencia, y posteriormente se propusieron modelos de crecimiento a nivel de árboles individuales. Las especies mostraron una distribución espacial agregada, un diámetro de crecimiento lento y una tasa de reclutamiento mayor que la tasa de mortalidad. Las especies más asociadas a *E. involucrata* fueron *Araucaria angustifolia*, *Ilex paraguariensis* y *Ocotea odorifera*. Los árboles de *E. involucrata* de menor DAP (10 a 20cm), sufrieron más competencia por parte de la comunidad asociada. Las variables DAP inicial y área transversal inicial fueron las que más se correlacionaron con el diámetro final, y fueron las variables que mejor se ajustaron a los modelos de crecimiento diamétrico de los árboles individuales. Esta investigación proporciona información relevante sobre la ecología de esta especie y sus comunidades asociadas muy útil para futuras investigaciones de la especie.

**Palabras clave:** Cerejeira; competencia; crecimiento; dinámica; comunidad asociada.

## Introduction

*Eugenia involucrata*, commonly known as cherry tree, belongs to Myrtaceae family. It is native to South America, and in Brazil occurs from Minas Gerais to Rio Grande do Sul states, in various forest formations (Sobral *et al.*, 2015). The species has potential for logging (Lorenzi *et al.*, 2009), medicinal (Sausen *et al.*, 2009; Santos, 2012) and ecological, attracts bees species for honey production and serves as food for wild animals (De Souza *et al.*, 2015). It has great economic potential, and its fruits can be consumed fresh and in sweets, jellies and liqueurs manufactures, by local population.

Despite its economic and ecological potential, few explored, ecological information about its growth and behavior in native areas is scarce in literature, especially at Araucaria Forest. Thus, the species lacks of ecological studies, which provides important information for its sustainable management and conservation in its *habitat*.

However, research about the species ecology is not always easy, since this requires years of research in order to evaluate its growth, dispersal, mortality, and other factors that are part of these processes (Rode *et al.*, 2010).

According to Virillo (2010), populations ecological studies are from fundamental importance, because they provide relevant information to understand different interactions that influence dynamics and structure of a system or species in particular. Obtaining this information can provide subsidies to understand forests evolution over time and species associations, this information is obtained through phytosociological studies, dynamics and competition (Longhi *et al.*, 2000; Mognon *et al.*, 2012; Oestreich Filho, 2014).

The phytosociology diagnoses quali-quantitative data of vegetation formations, relevant to environmental planning, such as in forest management and recovery of degraded areas (Felfili & Rezende, 2003; Mognon *et al.*, 2012; Oestreich Filho, 2014). Allied to phytosociology, dynamics study brings information about rate ingress, which makes it possible to verify a forest population sustainability, as well as the mortality rate, which informs species natural longevity, as well as the factors that may influence their death such as pathogens, herbivores, environmental conditions and natural senescence (Carvalho, 2008; Mognon *et al.*, 2012).

Together along with information on mortality and ingress, diameter increment is a fundamental prerequisite for sustainable management, because differences in species increment are due to different factors, such as light availability, soil fertility, rainfall regimes, genetic characteristics, and health degree, among others (Carvalho, 2008). It is worth to note that tree growth modeling is always related to diameter (DBH) because it is easy to measure, sensitive to environmental and demographic changes, and is closely related to tree crown, height, and volume (Roik *et al.*, 2018).

Another important evaluation in ecological studies are those related to species spatial distribution and the association with other species. These associations can be intraspecific (relationship between same species individuals) or interspecific (relationship between different species individuals), and can be positive or negative (Virillo, 2010). The positive relationship, or sociability, occurs when two species cohabit without harming growth and establishment of each other (Rode, 2008). Negative relationships, on the other hand, are associated with competition and/or allopathy, and have long been considered determining factors in conceptual models of community structure (Dalmaso *et al.*, 2016).

To understand how this process occurs, several indexes have been developed, to evaluate horizontal space occupied by a target tree, related to its neighbors, influenced by the number of individuals, size, distance, and neighbor trees orientation (Silva *et al.*, 2012). These indexes have also been applied in individual modeling studies to determine the growth of uneven-aged forests species, due to the influence that competition has on species growth (Vanclay, 1994).

Ecologists interested in evaluating forest succession have begun to use mathematical models, to seek a better understanding of dynamics and growth of species in uneven-aged forests. For this research, modeling of growth by individual trees must be used, because here, each species is considered as the basic unit of modeling (Vanclay, 1994). However, in Brazil, studies involving these models are scarce in native forests (Andreassen & Tomter, 2002; González *et al.*, 2006; Zhao *et al.*, 2006; Mattos, 2007; Adame *et al.*, 2008), especially regarding the growth rate of species, thus presenting great potential for study.

Thus, this research aimed to evaluate the spatial distribution, phytosociology dynamics and competition of *E. involucrata*, to characterize floristic composition and phytosociology of the associated community and to observe relationship between species growth and competition in order to propose and validate diameter growth models for the species.

## Material and Methods

### Area description

The study was developed in 25ha permanent plots, at Irati Nacional Forest (Irati FLONA) (Figure 1), with 3.495ha total area, under the geographic coordinates 25°20’24,818” S and 50°33’44,889” W, located between Fernandes Pinheiro and Teixeira Soares municipalities, in Parana state. According to Köppen-Geiger classification, region climate is “Cfb” – Warm temperate climate, minimum temperature of – 3°C and average 18°C, uniformly distributed rainfall, absence of dry season, severe frosts occur in winter (Beck *et al.*, 2018). Average annual pluviosity is 1.442mm, from 1.100 to 2.000mm (IBGE, 2019). Predominant soils are Cambisols, with small patches of dystrophic red Latosols (Figueiredo Filho, 2011).

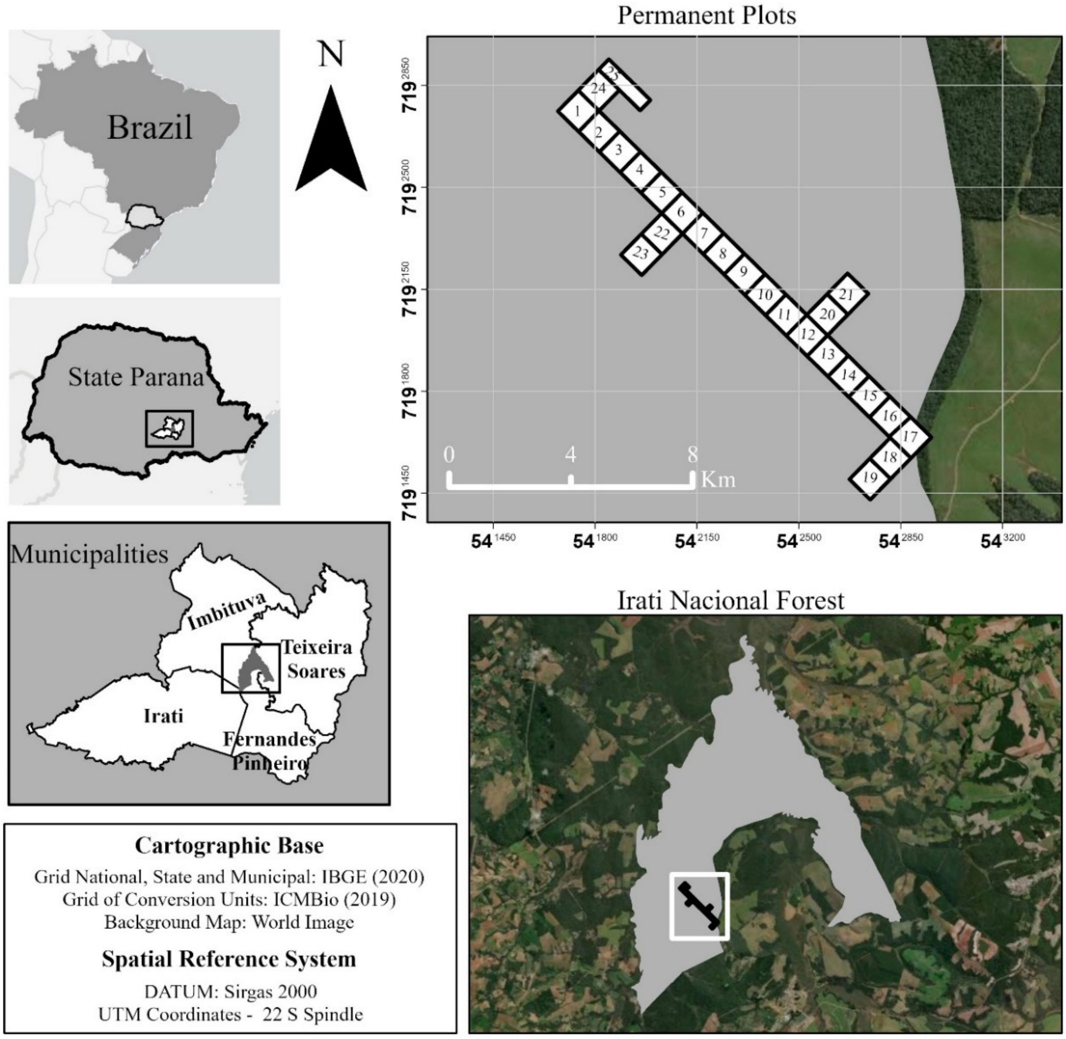

Figure 1 – Irati Nacional Forest (FLONA Irati) and 25ha permanent plots location, between Fernandes Pinheiro and Teixeira Soares municipalities, Parana state.

## Data collection

Data on this research were provided from continuous forestry inventories, led by reseachers from Forest Management laboratory at Unicentro Forest Engineer Department, Irati campus, Paraná State. Permanent plots were installed in 2001 and covers a 25ha area, divided into 25 blocks of 1ha area (100 x 100m) and subdivided in plots 0.25ha (50 x 50m). Measurements were taken every three years, from 2002 through 2017, as a total of six measurements, in 2002, 2005, 2008, 2011, 2014 and 2017. All individuals with diameter breast high (DBH) higher than 10cm were measured; mortality and ingress of individuals were included in all measurements, as well as their cartesian coordinates. Samples of botanical material from species that occurred in the area were collected, identified, and classified following The Angiosperm Phylogeny Group APG IV (Chase *et al.*, 2016), subsequently stored and incorporated into the Unicentro Herbarium (HUCO).

In this research, data from the inventory of 2002 and 2017 were used to evaluate the species dynamics (diameter and basal area increments), associated community phytosociology and competition indexes. For its spatial distribution analysis, only data collected in 2017 was used. For ingress and mortality analysis, data from all measurements for *E. involucrata* were used.

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### Characterization of *E. involucrata* species in study area

The spatial distribution analysis was performed based on 2017 forest inventory, considering species individuals Cartesian coordinates (X and Y) under study. For quantification and spatial patterns analysis, an univariate Ripley K-function was used, in order to determine specie spatial pattern (if aggregate, random or uniform). All living and measured trees from block 1 through 17 were included, totaling 17ha in 2017. Other plots (18 through 25) were not included, due to their plot sample design (Figure 1), which made it impossible.

The analysis was first performed for all individuals and then for two DBH classes (Class 1: 10 to 20cm and Class 2: equal or greater than 20cm), due to the reduced number of individuals in classes above 20cm. In all cases the null model (spatial randomness hypothesis) was tested with 1,000 Monte Carlo simulations, with $\alpha = 0.01$ for confidence limits. The analyses were performed graphically in "R" statistical language (Core Team, 2020), 3.6.3 version, with statistical package "splancs" (Rowlingson & Diggle, 2017).

Phytosociological parameters were evaluated for data collected in 2002 and 2017, to verify these parameters evolution inside study area (25ha). The following parameters were evaluated: absolute density (DA) and relative density (DR); absolute dominance (DoA) and relative dominance (DoR); absolute frequency (FA) and relative frequency (FR); and relative importance value index (IVI) (Souza & Soares, 2013). Phytosociological analysis was run at "R" statistical programme, with FitoCom, v. 1.5 interface support.

Diametrical evolution distribution of the species in 2002 through 2017 was grouped by individuals divided in DBH classes with 10cm range. In dynamical analysis, basal area and DBH increments were evaluated, as well as ingress and mortality for the species at 25ha. Diameter increases were obtained based in tree growth, considering only trees existing since 2002 and still alive in 2017. However, medium increments for grouped data and medium increments for DBH classes ranging 10 cm also were calculated. Diameter periodic increments (PI) and annual periodic (API) were calculated by functions (Function 1) and (Function 2), as (Finger, 1992):

$$PI_d = d_{2017} - d_{2002} \qquad (1)$$

$$API = \frac{PI_d}{P} \qquad (2)$$

As $PI_d$ = diameter periodic increment (cm); $API_d$ = diameter annual periodic increment (cm year$^{-1}$); $d_{2017}$ = DBH at the end of the measurement (2017) (cm); $d_{2002}$ = DBH at the beginning of measurement (2002) (cm); $P$ = measurement gap (15 years).

To get basal area increment, same criteria for DBH was adopted. Collected data species basal area increments between 2002 to 2017, with non-grouped data and in DBH class.

To evaluate ingress (In%) and mortality (M%) rates, all *E. involucrata* individuals that reached DBH equal to higher than 10cm and died, respectively, in each measurement were considered (2002-2005; 2005-2008; 2008-2011; 2011-2014; 2014-2017). Ingress (Function 3) and mortality (Function 4) indexes for 15 years were obtained with weighted average (Figueiredo Filho *et al.*, 2010):

$$In\% = \frac{N_{in}}{N_i} x\, 100 \qquad (3)$$

$$M\% = \frac{N_m}{N_i} x\, 100 \qquad (4)$$

As $In\%$ = ingress rate (%); $N_{in}$ = number of measured ingressing trees in the evaluation period; $N_i$ = number of individuals in the beginning of the evaluation period; $M\%$ = mortality rate (%); $N_m$ = number of dead trees in the evaluation period.

### Characterization of *E. involucrata* associated community

Associated community to *E. involucrata* individuals were considered when within plots established in this study, that is, individuals closest to target species. To characterize the community area and verify competition, 100m$^2$ plots were traced, according to species position, with reference to X and Y Cartesian coordinates from *E. involucrata* individuals through 2002 and 2017 inventories, at the plot central point (Figure 2), i.e., five meters distance in four directions (North, South, East and West).

For plots determination the following criteria were considered: a) be positioned at a minimum distance of 5m from another specie individual, to avoid overlapping; b) selection of one individual at sites where distance between individuals was less than 5m; c) exclude individuals that were close to the edge of the study area (distance less than 5m), because there is no information to evaluate the community around it; d) exclude from plot selection the ingress and mortality during continuous forest inventories. Considering criteria mentioned above, 111 plots were selected (Figure 2).

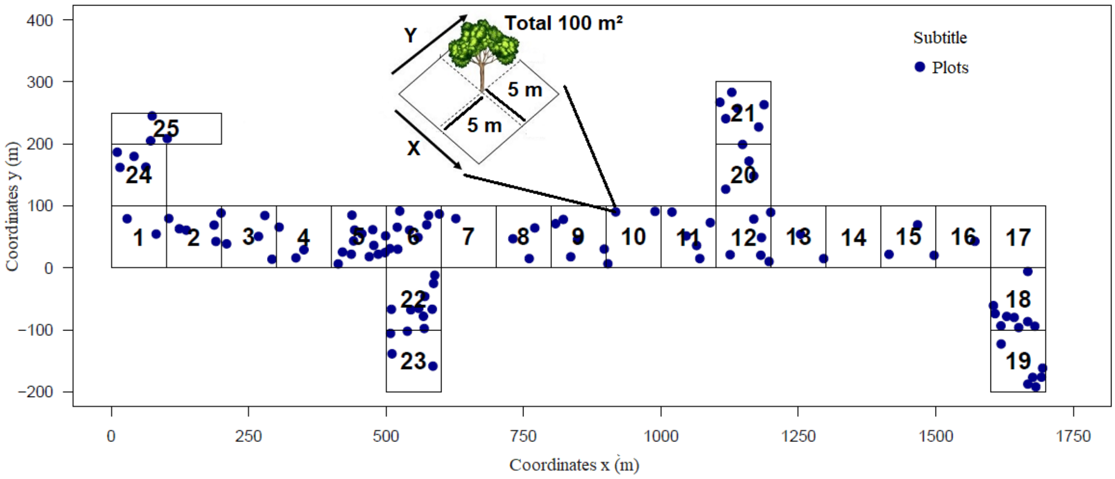

Figure 2 – Diagram of the delimitation and distribution of the sampling areas for associated community study with *Eugenia involucrata* in the permanent plots (25ha) at Araucaria Forest, Irati Nacional Forest, Paraná State. Blue dots represent selected individuals to characterize associated community, and the featured graphic refers to plot limits for the associated community research.

To determine sample sufficiency, the collector's curve technique was adopted, as a graphic representation, from the species-area relationship, specifying as a stability criterion an increase of less than 10% in the number of new species for a 10% increase in the sample area (Schilling & Batista, 2008), being performed in the software R (Core Team, 2020), v. 3.6.3, under "Vegan" package (Oksanen *et al.*, 2019).

For floristic composition analysis, family's number, genera, and species in the sampled area in the years 2002 and 2017, following the classification of *The Angiosperm Phylogeny Group* APG IV (Chase *et al.*, 2016). The analysis of the changes in composition was carried out by means of the presence or absence of the species found in the study area. The associated community horizontal structure was evaluated from 2002 through 2017. The phytosociological parameters used have been described previously.

The competition of the object tree and the trees of its associated community was carried out for the years 2002 and 2017, under three competition indexes: GHI (Glover and Hool Index) (Function 5), BAI (Basal Area Index) (Function 6) and BAL (Basal Area Larger) (Function 7):

$$GHI = \frac{d_i^2}{\overline{D}^2} \qquad (5)$$

$$BAI = \frac{d_i^2}{q^2} \qquad (6)$$

$$BAL = \sum_{i=1}^{n} gi \qquad (7)$$

As $d_i$ = target tree diameter (DBH, cm); $\overline{D}$ = mean diameter (DBH) from sampled unit trees (cm); $q$ = quadratic diameter (cm); $n$ = number of trees with transversal area higher than sampled tree at sampled point; $gi$ = transversal area (m$^2$).

## Individual modeling

A total of 35 plots out of 111 plots were selected for models fitting. The remaining plots (76) were used for validation of the best models. For variables selection for models, a Pearson correlation was performed and variables with moderate to strong significant correlation for 2017 DAP measurement were selected (DBH$_{final}$) (Chassot *et al.*, 2011). According to Brito Neto *et al.* (2018), under 0.20 is negligible; 0.20-0.40 is weak; 0.41-0.60 is moderate; 0.61-0.80 is strong and above 0.80 is a very strong correlation.

The $DBH_{final}$ was modeled depending on $DBH_{initial}$; transversal initial area ($g_{initial}$); $IGH_{initial,}$ $BAI_{initial}$ competition indexes, and initial plot density ($DA_{initial}$). Thus, 12 models were proposed (Table 1), with best models selected to validate, considering following statistical criteria: adjusted determination coefficient ($R^2_{adj.}$%), percentual standard error estimate (Syx%), and graphic residual analysis. In this research only proposed models with significant coefficients at 5% error probability were proposed here (Table 1).

Table 1 – Proposed and tested individual growth estimation models for *Eugenia involucrata* evaluated in an Araucaria Forest, Irati National Forest, Parana state.

| **Model** | **Models** |
|---|---|
| Mod. 1 | $DBH_f = \beta_0 + (\beta_1\,\mathrm{DBHi}) + \varepsilon_i$ |
| Mod. 2 | $DBH_f = \beta_0 + (\beta_1\,\mathrm{DBHi}) + (\beta_2\,\mathrm{gi}) + \varepsilon_i$ |
| Mod. 3 | $DBH_f = \beta_0 + (\beta_1\,\mathrm{gi}) + \varepsilon_i$ |
| Mod. 4 | $DBH_f = \beta_0 + (\beta_1\,\mathrm{BAIi}) + \varepsilon_i$ |
| Mod. 5 | $DBH_f = \beta_0 + (\beta_1\,\mathrm{GHIi}) + \varepsilon_i$ |
| Mod. 6 | $DBH_f = \beta_0 + (GHI\mathrm{i}) + (\beta_2\,\mathrm{ADi}) + \varepsilon_i$ |
| Mod. 7 | $DBH_f = \beta_0 + (\beta_1 \frac{1}{\mathrm{DBH}i}) + \varepsilon_i$ |
| Mod. 8 | $DBH_f = \beta_0 + (\beta_1\,(\mathrm{DBHi})^2) + \varepsilon_i$ |
| Mod. 9 | $DBH_f = \beta_0 + (\beta_1 \frac{1}{\mathrm{DBHi}}) + (\beta_2\,(\mathrm{DBHi})^2) + \varepsilon_i$ |
| Mod. 10 | $DBH_f = \beta_0 + \beta_1\,(\frac{1}{\mathrm{gi}})^2 + \varepsilon_i$ |
| Mod. 11 | $DBH_f = \beta_0 + \beta_1\,(\mathrm{DBHi})^2 + \beta_2\,(\frac{1}{\mathrm{gi}}) + \varepsilon_i$ |
| Mod. 12 | $DBH_f = \beta_0 + (\beta_1 \frac{1}{\mathrm{DBHi}}) + (\beta_2\,(\mathrm{gi})^2) + \varepsilon_i$ |

$DBH_f$ = diameter breast height (1.30 m from ground, cm) in 2017; DBHi = diameter breast height (cm) in 2002; gi = transversal area in 2002; ADi = absolute density in 2002; BAIi = basal area index in 2002; IGH02 = Glover and Hool index in 2002; $\beta$ = parameters to be estimated; $\varepsilon$i= aleatory error.

To validate the best models, 76 remnant plots were tested. Predicted over observed values analysis was done by 1:1 graphic and bias statistics (Function 8), precision (Function 9) and accuracy (Function 10) (Pretzsch, 2009).

$$\bar{e} = \frac{\sum_{(i=1)}^{n} (x_i - X_i)}{n} \qquad \overline{(e\%)} = \frac{\bar{e}}{\bar{X}} * 100 \qquad (8)$$

$$S_e = \sqrt{\frac{\sum_{(i=1)}^{n} (e_i - \bar{e})^2}{n\text{-}1}} \qquad S_e\% = \frac{S_e}{\bar{X}} * 100 \qquad (9)$$

$$m_x = \sqrt{(S_e)^2 + (\bar{e})^2} \qquad m_x\% = \frac{m_x}{\bar{X}} * 100 \qquad (10)$$

As i = plot; $x_i$ = predicted values; $X_i$ =observed values; $n$ = plot number; $\bar{X}$= mean observed values.

# Results

## Species characterization

*E. involucrata* presented an aggregated spatial pattern (Figure 3A), as observed by the K-function line (continuous), near upper confidence limit (upper traced line) until 450m distance, but, at DBH classes, its spatial pattern changed, considered aggregated at 10-20cm class (Figure 3B) and aleatory at above 20cm class (Figure 3C).

The species presented phytosociological parameters alterations, measured from 2002 through 2017, with absolute density (DA) of

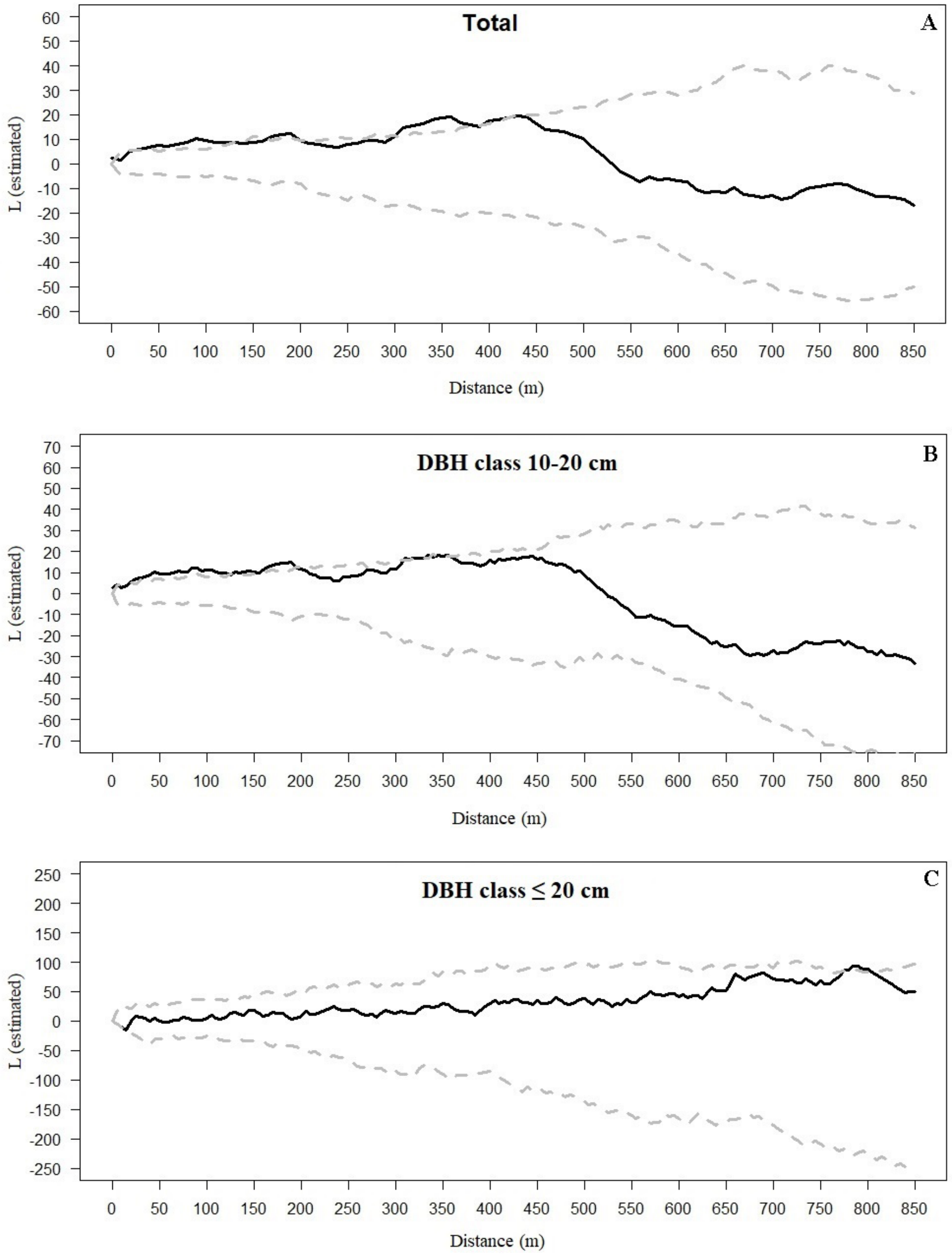

Figure 3 – Ripley's univariate K-function analysis and spatial patterns for *Eugenia involucrata* adult individuals, in 25ha permanent plots in an Araucaria Forest, Irati Nacional Forest, Paraná State. (A): K-function for all individuals measured in 2017; (B): K-function for individuals in 10-20 cm DBH class in 2017; (C): K-function for individuals in above 20cm DBH class in 2017.

5.76 ind. $ha^{-1}$ (2002) and 8.84 ind. $ha^{-1}$(2017); absolute dominance (DoA) of $0.12m^2ha^{-1}$ (2002) and $0.20m^2ha^{-1}$ (2017); absolute frequency (FA%) of 71% (2002) and 79% (2017). Besides that, importance value index changed from 1.22% (2002) to 1.42% (2017).

Related to diametric distribution (Fig. 4), in 2002 maximum DBH was 34.54cm and minimum were 10.03cm, and in 2017, 39.63cm and 10.63cm, respectively. An increase of individuals in DBH classes, especially in first class (10-20cm), from 118 in 2002 to 179 individuals in 2017 was observed.

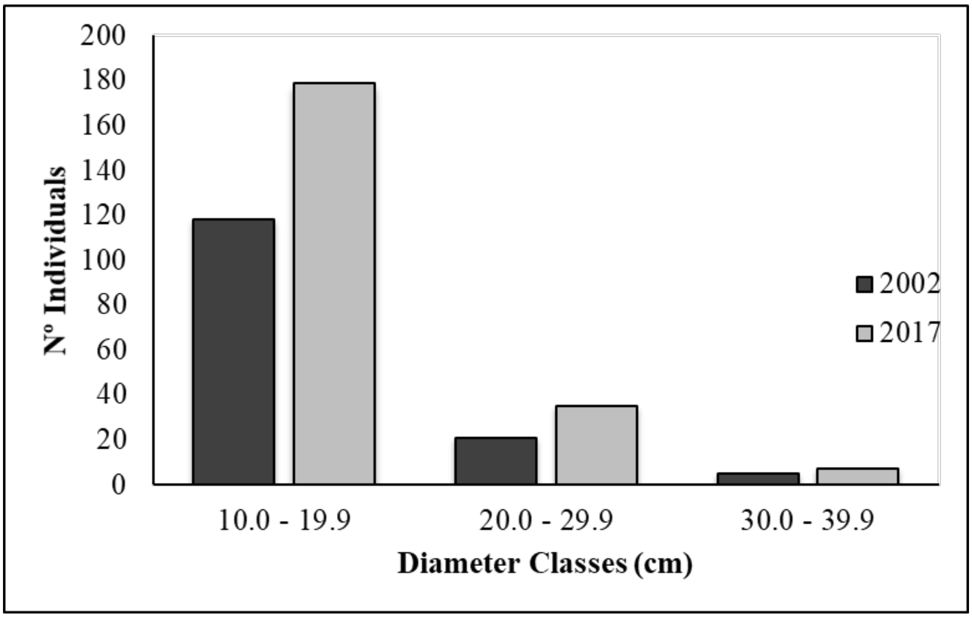

Figure 4 – Diametric distribution of individuals of *Eugenia involucrata* in 25ha permanent plots in 2002 and 2017, in an Araucaria Forest at Irati Nacional Forest, Parana state.

The species annual periodic increment (API) of the species (Table 2) for DBH class diameter mean was 0.20cm year$^{-1}$, and 10 to 20cm class was the one with highest annual diametric increment rate (1.46%), however, maximum diameter increment was observed in 20 to 30cm class (0.61cm year$^{-1}$). The species basal area API (Table 2) was 0.0036 m$^2$ ha$^{-1}$ year$^{-1}$, and the highest annual rate (4.35%) was also observed in 10 to 20cm class.

Table 2 – Annual periodic increment (API) in diameter and basal area by DBH classes of *Eugenia involucrata*, measured from 2002 and 2017, in an Araucaria Forest, in Irati Nacional Forest, Parana state.

| **DBH class (cm)** | **Diameter increment cm year$^{-1}$** | | | | |
|---|---|---|---|---|---|
| | **Minimum** | **Mean** | **Maximum** | **CV %** | **Annual rate %** |
| 10-20 | 0.01 | 0.20 | 0.42 | 47.47 | 1.46 |
| 20-30 | -0.05 | 0.26 | 0.61 | 53.09 | 1.31 |
| 30-40 | 0.02 | 0.05 | 0.10 | 62.66 | 0.13 |
| Mean | -0.01 | 0.21 | 0.45 | 49.67 | 1.36 |
| **DBH class (cm)** | **Basal area increment** | | | | |
| | **2002 (m$^2$ ha$^{-1}$)** | **2017 (m$^2$ ha$^{-1}$)** | **API (m$^2$ ha$^{-1}$ year$^{-1}$)** | **CV %** | **Annual rate %** |
| 10-20 | 0.0463 | 0.0705 | 0.0020 | 49.61 | 4.35 |
| 20-30 | 0.0432 | 0.0615 | 0.0015 | 53.26 | 3.53 |
| 30-40 | 0.0252 | 0.0262 | 0.0001 | 63.03 | 0.34 |
| **General** | **0.1146** | **0.1581** | **0.0036** | **55.30** | **3.16** |

CV = variation coefficient; API = annual periodic increase; DBH = diameter breast high.

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From 2002 to 2017, there were 87 new and 10 dead individuals. Concerning to annual ingress and mortality rates (Table 3), ingress was higher (4.57%) than mortality (0.49%) rates, an increase in basal area (0.0079$m^2ha^{-1}$) was greater than the loss (0.0022$m^2ha^{-1}$).

Table 3 – Annual ingress and mortality rates of *Eugenia involucrata*, from 2002-2005, 2005-2008, 2008-2011, 2011-2014, 2014-2017 in an Araucaria Forest, in Irati Nacional Forest, Parana state.

| **Period** | **Ingress** | | | | **Mortality** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Adding G ($m^2ha^{-1}$)** | **Annual rate (%)** | **N $ha^{-1}$** | **Annual rate (%)** | **Loosing G ($m^2ha^{-1}$)** | **Annual rate (%)** | **N $ha^{-1}$** | **Annual rate (%)** |
| 2002-2005 | 0.0056 | 1.56 | 0.64 | 3.70 | 0 | 0 | 0 | 0 |
| 2005-2008 | 0.0124 | 2.98 | 1.44 | 7.50 | 0.0004 | 0.11 | 0.04 | 0.21 |
| 2008-2011 | 0.0034 | 0.71 | 0.40 | 1.71 | 0.0009 | 0.19 | 0.08 | 0.34 |
| 2011-2014 | 0.0053 | 1.02 | 0.56 | 2.30 | 0.0027 | 0.53 | 0.12 | 0.49 |
| 2014-2017 | 0.0037 | 0.66 | 0.44 | 1.71 | 0.0029 | 0.52 | 0.16 | 0.62 |
| **Means** | **0.0079** | **1.85** | **0.91** | **4.57** | **0.0022** | **0.41** | **0.12** | **0.49** |

N ha = number of individuals per hectare; G = basal area.

### *E. involucrata* associated community characterization

Through constructing collector's curve, plots were enough representing *E. involucrata* associated community in both years, with a curve accentuation from 100 plots. In 2002, 29 families, 48 genera and 62 species were registered, and 18 families were composed by only one species. Most richness families were Myrtaceae (eight), Lauraceae (eight), Salicaceae (six), Sapindaceae (five) and Fabaceae (four). In 2017, data has increased to 32 families, 51 genera and 67 species. Families with highest species richness were: Annonaceae, Celastraceae, Solanaceae and Symplocaceae. Most richness families were: Myrtaceae (nine), Lauraceae (seven), Salicaceae (six), Sapindaceae (five) and Fabaceae (four). In 2017, still, there was a new family registry, Symplocaceae and new species in families Annonaceae, Celastraceae, Fabaceae, Myrtaceae, Rubiaceae and Solanaceae. Besides that, families Aquifoliaceae, Araliaceae, Fabaceae, Lauraceae and Myrtaceae has lost species (Table 4).

Table 4 – Associated community to *Eugenia involucrata*, in an Araucaria Forest, at Irati Nacional Forest, Parana state.

| **Family** | **Scientific name** | **Popular name** | **2002** | **2017** |
|---|---|---|---|---|
| Anacardiaceae | *Lithraea molleoides* (Vell.) Engl. | Aroeira-branca | X | X |
| Annonaceae | *Annona rugulosa* (Schltdl.) H.Rainer | Ariticum-de-porco | | X |
| Aquifoliaceae | *Ilex dumosa* Reissek | Cauninha | X | |
| | *Ilex paraguariensis* A. St.-Hil. | Erva-mate | X | X |
| | *Ilex theezans* Mart. ex Reissek | Caúna | X | X |
| Araliaceae | *Schefflera morototoni* (Aubl.) Maguire *et al.* | Mandiocão | X | |
| Araucariaceae | *Araucaria angustifolia* (Bertol.) Kuntze | Araucária | X | X |
| Arecaceae | *Syagrus romanzoffiana* (Cham.) Glassman | Palmeira | X | X |

| Family | Scientific name | Popular name | 2002 | 2017 |
|---|---|---|---|---|
| Asteraceae | *Piptocarpha angustifolia* Dusén ex Malme | Vassourão-branco | X | X |
| | *Vernonanthura petiolaris* (DC.) H. Rob. | Vassourão | X | X |
| Bignoniaceae | *Jacaranda micrantha* Cham. | Caroba | X | X |
| Canellaceae | *Cinnamodendron dinisii* Schwacke | Pimenteira | X | X |
| Celastraceae | *Maytenus aquifolia* Mart. | Espinheira-Santa-falsa | | X |
| Clethraceae | *Clethra scabra* Pers. | Carne-de-vaca | X | X |
| Elaeocarpaceae | *Sloanea hirsuta* (Schott) Planch. Ex Benth. | Sapopema | X | X |
| Euphorbiaceae | *Sapium glandulosum* (L.) Morong | Leiteiro | X | X |
| | *Sebastiania commersoniana* (Baill.) L.B.Sm. & Downs | Branquilho | X | X |
| Fabaceae | *Cassia leptophylla* Vogel | Canafistula | X | X |
| | *Dalbergia brasiliensis* Vogel | Jacarandá | X | X |
| | *Machaerium stipitatum* (DC.) Vogel | Sapuva | X | X |
| | *Mimosa scabrella* Benth. | Bracatinga | | X |
| | *Ormosia arborea* (Vell.) Harms | Coronheira | X | |
| Lauraceae | *Cinnamomum amoenum* (Nees & Mart.) Kosterm | Canela-alho | X | |
| | *Nectandra grandiflora* Nees | Canela-amarela | X | X |
| | *Nectandra megapotamica* (Spreng.) Mez | Canela-imbuia | X | X |
| | *Ocotea corymbosa* (Meisn.) Mez | Canela-pimenta 2 | X | X |
| | *Ocotea diospyrifolia* (Meisn.) Mez | Canela-pimenta | X | X |
| | *Ocotea odorifera* (Vell.) Rohwer | Sassafrás | X | X |
| | *Ocotea porosa* (Nees & Mart.) Barroso | Imbuia | X | X |
| | *Ocotea puberula* (Rich.) Nees | Canela-guaicá | X | X |
| Lythraceae | *Lafoensia pacari* A.St.-Hill. | Dedaleiro | X | X |
| Malvaceae | *Luehea divaricata* Mart. & Zucc. | Açoita-cavalo | X | X |
| Meliaceae | *Cabralea canjerana* (Vell.) Mart. | Canjerana | X | X |
| | *Cedrela fissilis Vell.* | Cedro-rosa | X | X |
| Myrsinaceae | *Myrsine umbellata* Mart. | Capororocão | X | X |
| Myrtaceae | *Campomanesia xanthocarpa* (Mart.) O.Berg | Guabiroba | X | X |
| | *Curitiba prismatica* (D. Legrand) Salywon&Landrum | Murteira | X | X |
| | *Eugenia involucrata* DC. | Cerejeira | X | X |
| | *Myrcia hebepetala* DC. | Caingá | X | |
| | *Myrcia splendens* (Sw.)DC. | Guamirim-preto | X | X |
| | *Myrciaria delicatula* (DC.) O.Berg | Araçá-do-mato | X | X |
| | *Myrciaria floribunda* (H.West ex Willd.) O.Berg | Cambuí | X | X |
| | *Myrciaria tenella* (DC.) O. Berg | Guamirim-ferro | | X |
| | *Plinia cauliflora* (Mart.) Kausel | Jaboticabeira | X | X |

| Family | Scientific name | Popular name | 2002 | 2017 |
|---|---|---|---|---|
| Proteaceae | *Roupala montana* Aubl. | Carvalho | X | X |
| Rosaceae | *Prunus myrtifolia* (L.) Urb. | Pessegueiro-bravo | X | X |
| Rubiaceae | *Coussarea contracta* (Walp.) Müll.Arg. | Cinzeiro-preto | X | X |
|  | *Psychotria vellosiana* Benth. | Jasmim-verdadeiro | X | X |
|  | *Rudgea jasminoides* (Cham.) Müll.Arg. | Véu-de-noiva |  | X |
| Rutaceae | *Zanthoxylum rhoifolium* Lam. | Mamica-de-cadela | X | X |
| Salicaceae | *Casearia decandra* Jacq. | Guaçatunga-branca | X | X |
|  | *Casearia lasiophylla* Eichler | Guaçatunga-da-graúda | X | X |
|  | *Casearia obliqua* Spreng. | Guaçatunga-vermelha | X | X |
|  | *Casearia sylvestris* Sw. | Guaçatunga-preta | X | X |
|  | *Prockia crucis* P.Browne ex L. | Cambroé | X | X |
|  | *Xylosma pseudosalzmanii* Sleumer | Sucareiro | X | X |
| Sapindaceae | *Allophylus edulis* (A.St.-Hil. *et al.*) Hieron. ex Niederl. | Vacum-de-folha-graúda | X | X |
|  | *Allophylus petiolulatus* Radlk. | Vacum-de-folha-larga | X | X |
|  | *Cupania vernalis* Cambess. | Cuvatã | X | X |
|  | *Diatenopteryx sorbifolia* Radlk. | Maria-preta | X | X |
|  | *Matayba elaeagnoides* Radlk. | Miguel-pintado | X | X |
| Sapotaceae | *Chrysophyllum gonocarpum* (Mart. & Eichler ex Miq.) Engl. | Guatambu | X | X |
|  | *Chrysophyllum marginatum* (Hook. & Arn.) Radlk. | Guatambu-leite | X | X |
| Simaroubaceae | *Picrasma crenata* (Vell.) Engl. | Tenente-José | X | X |
| Solanaceae | *Solanum pseudoquina* A. St.- Hil. | Joá-de-árvore |  | X |
| Styracaceae | *Styrax leprosus* Hook. & Arn. | Canela-raposa | X | X |
| Symplocaceae | *Symplocos tenuifolia* Brand. | Maria-mole |  | X |
|  | *Symplocos uniflora* (Pohl) Benth. | Sete-Sangria |  | X |
| Theaceae | *Laplacea fruticosa* (Schrad.) Kobuski | Santa-Rita | X | X |
| Winteraceae | *Drimys brasiliensis* Miers | Cataia | X | X |

For 2002, the density of the associated community was 595.42ind.ha$^{-1}$, and five species with higher density were *I. paraguariensis*, *C. decandra*, *O. odorifera*, *A. angustifolia* e *M. umbellata*. Community basal area was 28.48m$^{2}$ha$^{-1}$, and five species with higher dominance were *A. angustifolia*, *O. porosa*, *I. paraguariensis*, *N. grandiflora* e *O. odorifera*. As for the community dynamics, annual ingress rate was 1.19%, with basal area gain of 1.64%, while mortality rate was 1.64% and basal area loss was 1.41%.

In 2017, the community density was lower than observed for 2002 (554.62ind.ha$^{-1}$), and the five species with higher densities were *I. paraguariensis*, *O. odorifera*, *A. angustifolia*, *C. decandra* e *C. contracta*. The community basal area, it had increased (33.12m$^{2}$ha$^{-1}$), compared to 2002, and five species most dominant were *A. angustifolia*, *P. crenata*, *O. porosa*, *O. odorifera* e *I. paraguariensis*. The importance value index of 2002 to 2017 were listed in Figure 5, and the associated community three most important species in both years were: *A. angustifolia*, *I. paraguariensis* e *O. odorifera*.

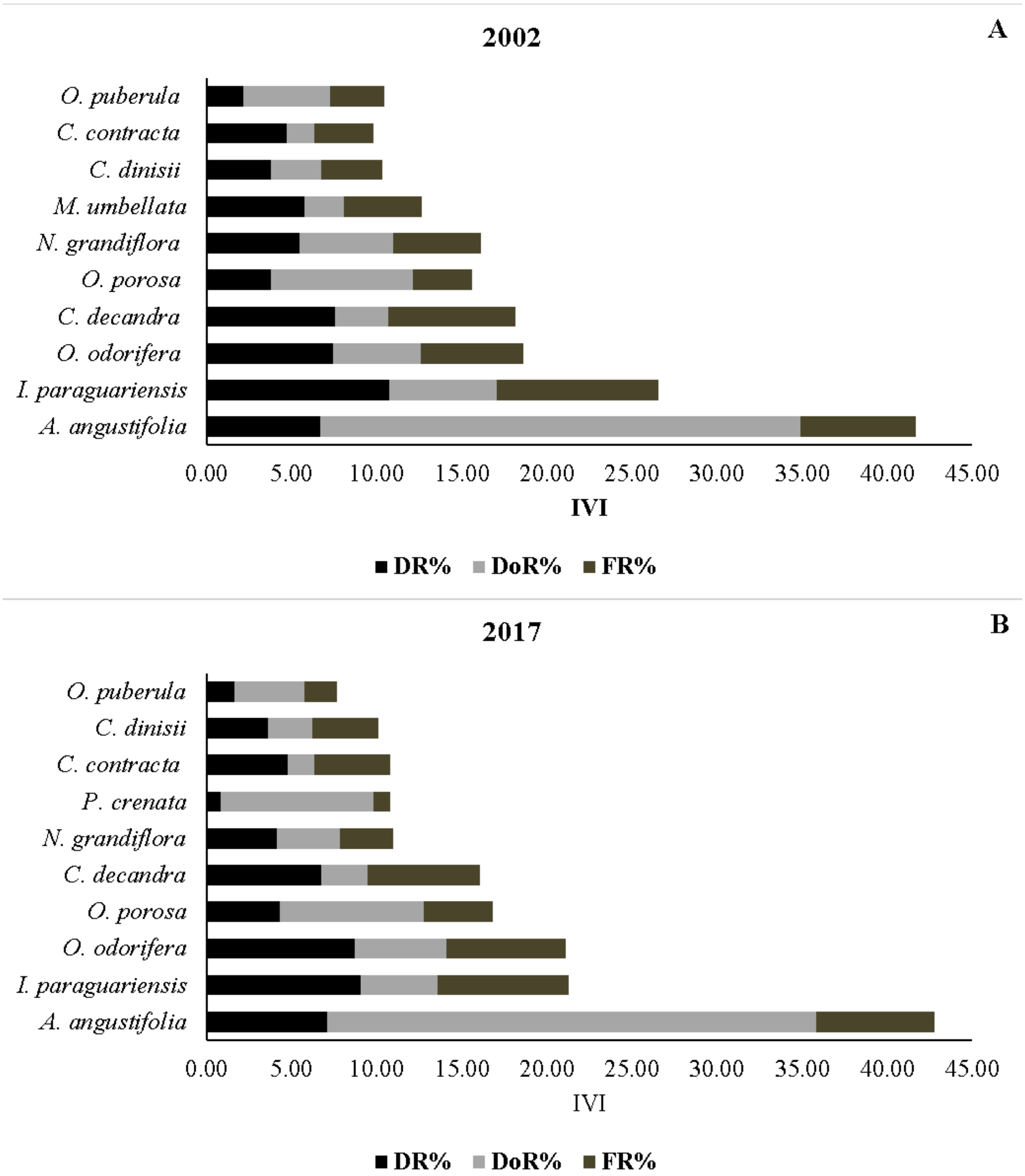

Figure 5 – Importance value index of the associated community of *Eugenia involucrata* from 2002 (A) and 2017 (B) in Araucaria Forest, Irati Nacional Forest, Parana state.
IVI = Importance value index; DR = relative density; DoR = relative dominance; FR = relative frequency.

Individuals in the 10-15cm classes of *E. involucrata* suffered the most from competition (Figure 6). In 2002, most individuals were located in lower classes (up to 20cm DBH), with DBH individuals up to 35cm. In 2017, targeted specie had diameter increase, with widely spaced points, ranging 10 to 40cm DBH. Outliers were also noticed in lower DBH classes (10-20cm), which indicates lower competition in these plots.

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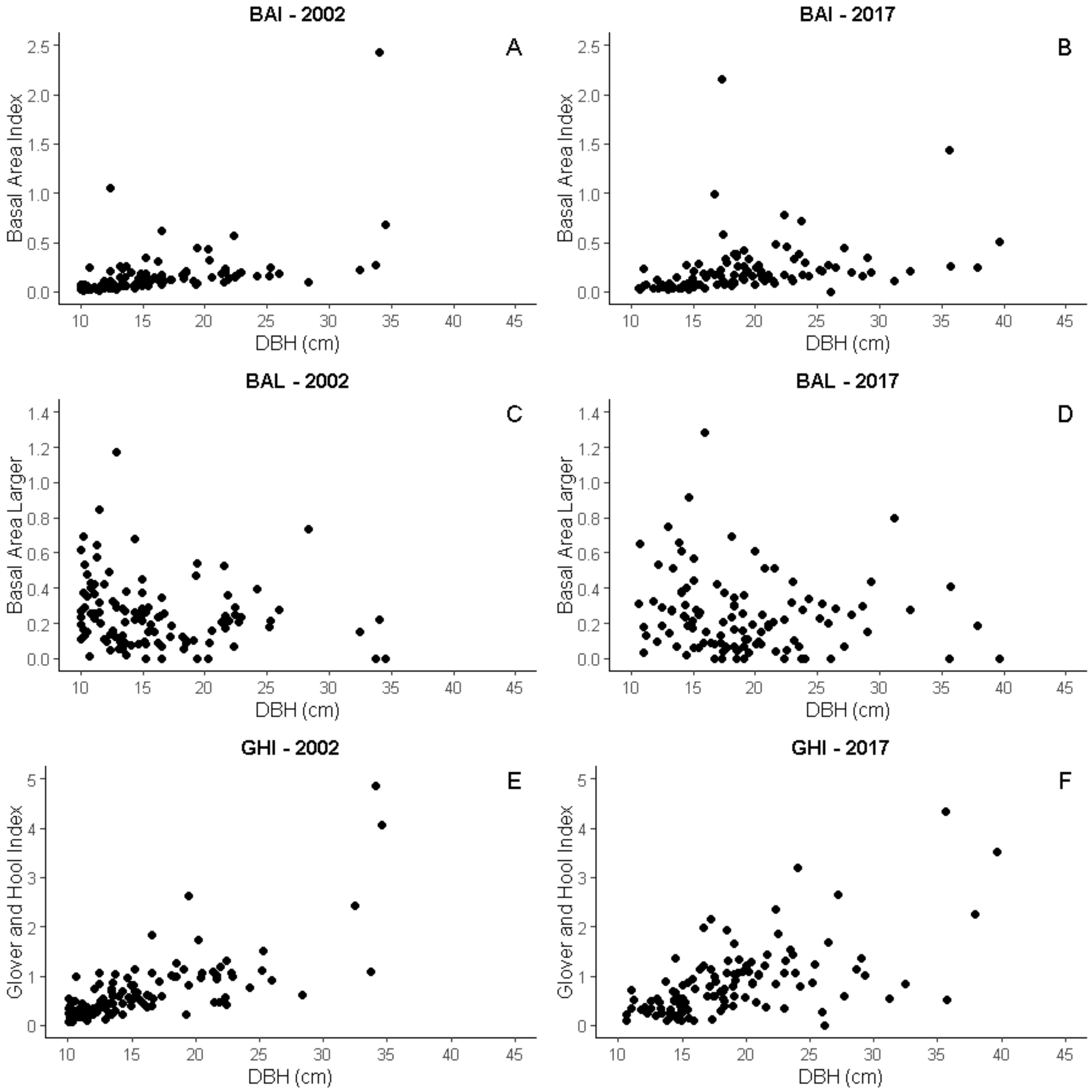

Figure 6 – Competition indexes of BAI (basal area indexes) in 2002 (A) and 2017 (B), of BAL (basal area larger) in 2002 (C) and 2014 (D) and GHI (Glover and Hool indexes) in 2002 (E) and 2017 (F) in relation to the DBH (diameter breast high) of *Eugenia involucrata* in an Araucaria Forest, in Irati Nacional Forest, Parana state.

## Individual modeling

For the 2017 DBH, the most relevant variables were DBH itself, transversal area, GHI competition index and BAI index of 2002 (Table 5). These variables were used to adjust the models already described in Table 1.

Table 5 – Pearson correlation and probability for the dendrometric and phytosociological variables of *Eugenia involucrata*, in an Araucaria Forest, in Irati Nacional Forest, Parana state.

| **r** | **$DBH_{initial}$** | **$g_{initial}$** | **$BAI_{initial}$** | **$BAL_{initial}$** | **$GHI_{initial}$** | **$DA_{initial}$** | **$DoA_{initial}$** |
|---|---|---|---|---|---|---|---|
| **$DBH_{final}$** | 0.95$^{**}$ | 0.93$^{**}$ | 0.47$^{**}$ | -0.21$^{**}$ | 0.68$^{**}$ | -0.18$^{ns}$ | -0.05$^{ns}$ |

$DBH_{final}$ = final diameter breast high (1.30m measured) (cm); $DBH_{initial}$ = initial diameter breast high (cm); $g_{initial}$ = initial transversal area (m$^2$); $BAI_{initial}$ = initial Basal Area Index; $GHI_{initial}$ = initial Glover and Hool index; $BAL_{initial}$= initial Basal Area Larger index; $DA_{initial}$ = initial density the community associated; $DoA_{initial}$ = initial basal area of the community associated; ** significant at 1% probability; ns: not significant.

Model 2 presented higher $R^2_{adj.}$ (0.94), lower $S_{yx}$% (10.22%) and residuals graphic ranging from -10% to 10%, with points near to zero axis and homogeneous distribution, compared to other models (Figure 7).

Table 6 – Parameter estimates of the models proposed for individual modeling of growth in DBH (diameter breast high) of *Eugenia involucrata* in an Araucaria Forest, in Irati Nacional Forest, Parana state.

| **Model** | **Coefficient** | **$R^2_{adj.}$** | **$S_{yx}$(cm)** | **$S_{yx}$%** |
|---|---|---|---|---|
| Model 1 | $\beta_0$: 2.4538$^*$ | 0.92 | 1.79 | 11.15 |
| | $\beta_1$: 1.0486$^*$ | | | |
| Model 2 | $\beta_0$: -3.2923$^*$ | 0.94 | 1.64 | 10.22 |
| | $\beta_1$: 1.6989$^*$ | | | |
| | $\beta_2$: -202.3134$^*$ | | | |
| Model 3 | $\beta_0$: 12.1410$^*$ | 0.85 | 2.56 | 15.96 |
| | $\beta_1$: 308.0505$^*$ | | | |
| Model 4 | $\beta_0$: 17.4060$^*$ | 0.29 | 5.68 | 35.39 |
| | $\beta_1$: 9.2560$^*$ | | | |
| Model 5 | $\beta_0$: 15.6920$^*$ | 0.35 | 5.43 | 33.84 |
| | $\beta_1$: 5.0770$^*$ | | | |
| Model 6 | $\beta_0$: 22.3757$^*$ | 0.45 | 5.01 | 31.21 |
| | $\beta_1$: 4.1402$^*$ | | | |
| | $\beta_2$: -1.1330$^*$ | | | |
| Model 7 | $\beta_0$: 39.2730$^*$ | 0.84 | 2.66 | 16.58 |
| | $\beta_1$: -286.6990$^*$ | | | |
| Model 8 | $\beta_0$: 12.1399$^*$ | 0.85 | 2.56 | 15.95 |
| | $\beta_1$: 0.0241$^*$ | | | |
| Model 9 | $\beta_0$: 25.850$^*$ | 0.92 | 1.8 | 11.21 |
| | $\beta_1$: -151.800$^*$ | | | |
| | $\beta_2$: 0.01359$^*$ | | | |
| Model 10 | $\beta_0$: 30.4821$^*$ | 0.79 | 3.04 | 18.94 |
| | $\beta_1$: -0.1662$^*$ | | | |
| Model 11 | $\beta_0$: 20.3363$^*$ | 0.93 | 1.74 | 10.84 |
| | $\beta_1$: 0.0151$^*$ | | | |
| | $\beta_2$: -0.0822$^*$ | | | |
| Model 12 | $\beta_0$: 33.0530$^*$ | 0.91 | 1.98 | 12.33 |
| | $\beta_1$: -214.5100$^*$ | | | |
| | $\beta_2$: 1247.5200$^*$ | | | |

β = already estimated parameters; $R^2_{adj.}$ = adjusted determination coefficient, $S_{yx}$(cm) = mean standard error (cm) and $S_{yx}$% = estimative standard error (%); * = significant at 5% probability.

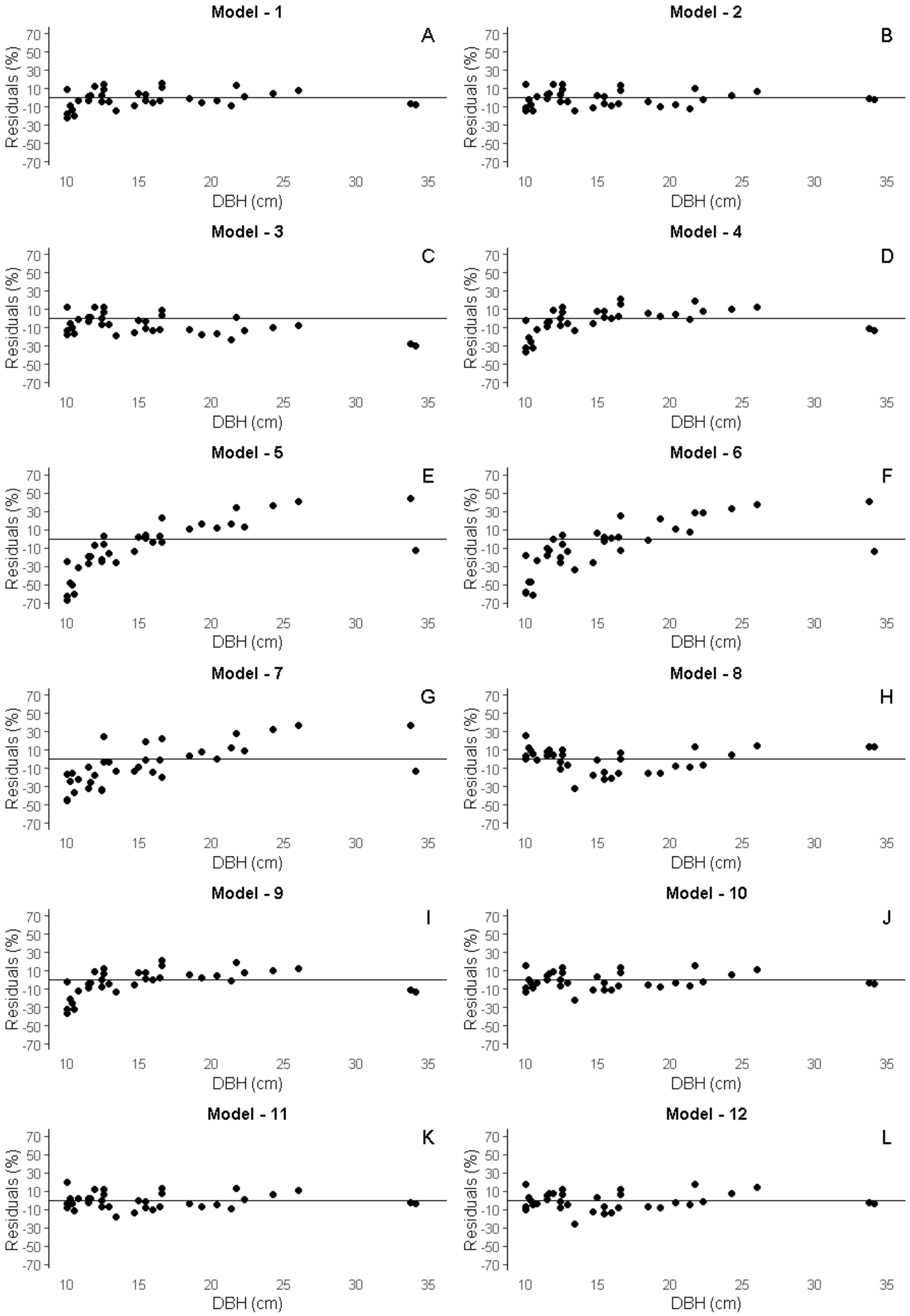

Figure 7 – Graphical representation of the distribution of residuals for the evaluated models (A to L) of *Eugenia involucrata*, in an Araucaria Forest, Irati Nacional Forest, Paraná state.

In all adjusted models, five (1, 2, 9, 11 *e* 12) were selected for validation, considering $R^2_{adj.}$, $S_{yx}\%$ and graphic residuals (Table 6). These models had $R^2_{adj.}$ ranged from 0.92 to 0.94, $S_{yx}\%$ from 10.22% to 12.84% and residuals distribution from -30% to 30%, sometimes near zero axis, unbiased (Figure 7).

For modelling validation, in above 20cm diameters, there were more dispersed points with respect to the central axis; lower diameters showed more grouped points, indicating predicted values are next to observed in this DBH class (Figure 8).

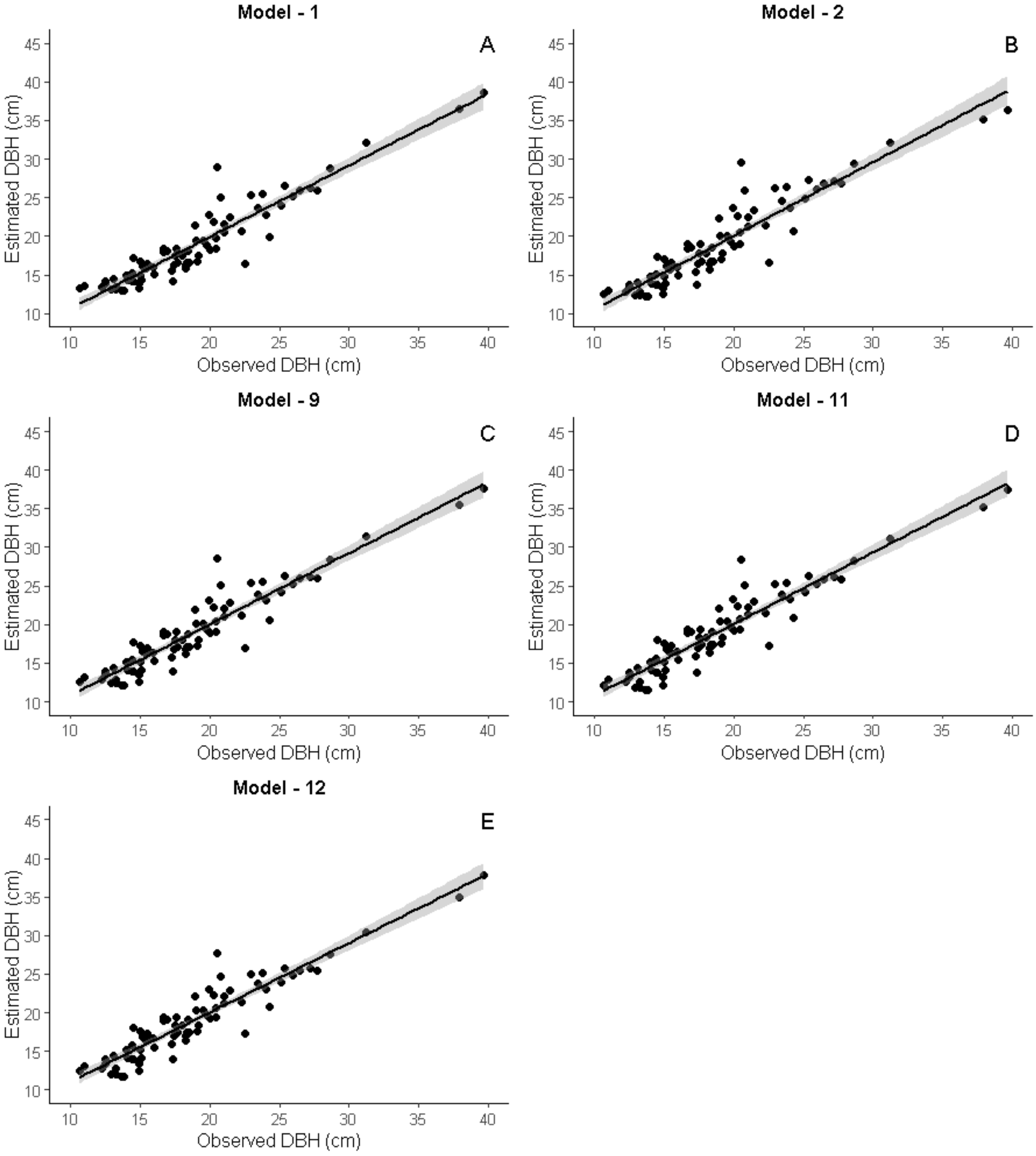

Figure 8 – Observed versus predicted diameter 1:1 graphic representation of the best models (1, 2, 9, 11, 12) of A to E of *Eugenia involucrata*, in Araucaria Forest, in Irati Nacional Forest, Parana state.

When assessing bias, precision and accuracy of selected models for validation, model 2 was considered best for adjustment (Table 7), since it had values above 10%. Model 1 had best bias, while model 12 had best precision and accuracy.

Table 7 – Bias, precision and accuracy calculated for five best selected models to estimate of *Eugenia involucrata* diameter, in an Araucaria Forest, in Irati Nacional Forest, Parana state.

| Statistics | Model 1 | Model 2 | Model 9 | Model 11 | Model 12 |
|---|---|---|---|---|---|
| Bias (%) | 0.004 | 0.688 | 0.584 | 0.779 | 0.745 |
| Precision (%) | 10.30 | 11.21 | 10.24 | 10.43 | 10.18 |
| Accuracy (%) | 10.30 | 11.23 | 10.26 | 10.46 | 10.21 |

# Discussion

## Species characterization

In tropical forests, aggregate spatial pattern of forest species is common, due to niche segregation and seed dispersal limitation (Pannuti, 2009). The species *E. involucrata* in DBH classes lower than 20cm, showed aggregate spatial pattern, but classes higher than 20cm its distribution was random, so it becomes less common to verify species adult individuals occurring in aggregate form. This is because, according to Capretz *et al.* (2012) in forests, competition for space, light and nutrients, can increase species mortality rate throughout its growth, causing random spatial behavior in larger DBH classes. Tonetto et al (2013) at Subtropical Seasonal Forest, verified an aggregate pattern, which was confirmed by low frequency (4.6%), different from this research, which frequency was 79% in 2017, characterizing a random pattern for DBH classes higher than 20cm, same way as observed by Reitz *et al.* (1983).

This pattern is common in native species at Araucaria Forest, as in Homczinski (2017), while evaluating *C. xanthocarpa* spatial distribution, Dalmaso *et al.* (2016) with *O. odorifera*, Silva (2020) with *C. prismatica*. All cited authors verified an aggregate pattern in general, as well as for DBH classes smaller than 20cm and a random pattern for classes larger than 20cm.

Another relevant characteristic is that many tropical forest species fruits and seeds dispersal are done by animals (zoochoric), which influences aggregate or random patterns of distribution of individuals (Budke *et al.*, 2005). An aggregate distribution may be related to spontaneous fall fruits after ripening or anemochoric dispersion (dispersion by wind), with deposited fruits near their mother tree. A random distribution for larger classes, on the other hand, may be associated, besides competition, with zoochoric dispersion, carried out at great distances, randomly, especially in fruiting species (Negrini *et al.*, 2012) as in *E. involucrata*.

In relation to the phytosociological parameters found in the study area, from 2002 through 2017, density and absolute dominance values for *E. involucrata* were similar to those in Rode (2008), at Irati National Forest, but in a 10ha abandoned Araucaria plantation. The author reported, for *E. involucrata*, a 6.60ind.ha$^{-1}$ density and a 0.14m$^2$ha$^{-1}$ dominance. The authors also highlighted association of this species with others, such as *A. angustifolia*, *O. odorifera*, *I. paraguariensis*, *O. puberula* and *M. umbellata*. Santos (2014), at Curitiba, Paraná State, studying an Araucaria Forest remnant, 15.25ha total area, observed only two of *E. involucrata* individuals, resulting in 0.42ind.ha$^{-1}$. Similar result was reported by Topanotti (2016): 1.88ind.ha$^{-1}$, in a 18.70ha fragmented area, at Dois Vizinhos municipality, Parana state.

It is important to note that *E. involucrata* always occur in low frequencies at tropical forest, mostly associated with secondary species (Lorenzi *et al.*, 2009). According to Silva & Higa (2006), one of the most important factors for pollination to happen properly is when the species is well represented in terms of density, offering the necessary resources to keep pollinators in area, and thus, have higher genetic variability, a fact that was not observed for *E. involucrata*, since its density, in this research, was considered low (from 5.76 to 8.84ind.ha$^{-1}$).

At this study, environment favored new individuals' emergence, as well as its growth, because observed low competition from associated community to *E. involucrata* (Figure 6), from 2002 to 2017, density and dominance increased (5.76 to 8.84ind.ha$^{-1}$ and 0.12 to 0.20m$^2$ha$^{-1}$, respectively). Hack *et al.* (2015) e Tonetto *et al.* (2013) at Subtropical Seasonal Forest, verified density (6ind.ha$^{-1}$) and dominance (0.15m$^2$ha$^{-1}$) for *E. involucrata*, very close to that found in this research. For Tonetto *et al.* (2013) understand the structure and dynamics of *E. involucrata* was very relevant to evaluate its potential for seed collection in their research area.

There were no individuals found above 40cm DBH classes for the species, higher DBH registered in literature (Carvalho, 2008; Lorenzi *et al.*, 2009). The diametric distribution was "J-shaped pattern" (Figure 4), with most individuals concentrated at the first DBH class (10-20cm). Native forests, in general, have a decreasing diametric distribution, i.e., most individuals are in smaller classes, and the number of individuals decreases when DBH increases, and this distribution pattern is characteristic of uneven-aged forests (Lima & Leão, 2013).

Regarding the species dynamics, the first DBH class (10-20cm), showed diameter highest increment rate (1.46%) and in basal area (4.35%). It is justified because most individuals (118 in 2002, 179 in 2017) are in this class. However, despite low individuals' number in 20-30cm class (5 in 2002, 7 in 2017), this one expressively contributed to increase diameter (1.31%) and basal area (3.53%) rates, being observed in this class the greatest increment in diameter (0.61cm year$^{-1}$). This species has slow growth for second diameter class, common behavior in native species classified as late secondary (Carvalho, 2008).

The slow growth rate for *E. involucrata* was observed by other authors when evaluating the dynamics of the species, among which one can mention Homczinski (2017) evaluating the dynamics of *C. xanthocarpa*, found an average growth in diameter of 0.2911cm year$^{-1}$, already Beckert *et al.* (2014) analyzing the dynamics and growth of *A. angustifolia*, in an Araucaria Forest fragment of 2.5ha, reported an increase of 0.33cm year$^{-1}$.

Negative diameters were found in the minimum increment of the 20-30cm class (-0.05cm year$^{-1}$). An explanation for this fact is due to many reasons: environmental factors, as higher pluviosity cycles at measuring time, which can cause stem swelling in some individuals; stem cleaning done or not before measuring; or even, due to some species slow growth or few changes while measuring (Roik, 2012).

Individuals identified in major classes (30-40cm) kept their growth rates, showing species is in full expansion. Ingress rate (4.57%) was higher than mortality rate (0.49%), indicating the species is growing in the study area. Higher mortality rates were registered at DBH diameter first classes, due to competition, individuals compete for light, space and nutrients (Homczinski, 2017), which retracts trees diameter growth and raises mortality likelihood (Weiskittel *et al.*, 2011).

### *E. involucrata* associated community characterization

There was predominance of individuals from Lauraceae and Myrtaceae families, as well as verified in other researches at Araucaria Forest fragments (Kozera *et al.*, 2006; Klauberg *et al.*, 2010; Higuchi *et al.*, 2012, 2013; Santos, 2014; Silva *et al.*, 2012). Same floristic pattern was found in forest inventories in Araucaria Forest, which reported Myrtaceae, Lauraceae, Salicaceae, Sapindaceae and Euphorbiaceae as most richness families (Seger *et al.*, 2005). Studies that assess associated community to only one species are scarce in Brazil, being found in literature only Homczinski (2017) for *C. xanthocarpa* and Silva (2020) to *C. prismatica.*

For measured competition indexes in this research, there was bigger competition for target tree in diameter initial classes (up to 25cm). Similar results were found by Homczinski (2017) in *C. xanthocarpa* and Silva (2020) for *C. prismatica*, for BAL and GHI indexes, where lower DBH trees (up to 25cm) had suffered greater competition.

Furthermore, outlier points were verified in the three indexes evaluated, in classes smaller than 25cm and few variation between values found in the indexes evaluated. It can be justified due to plot size for this research is 100m$^2$, presenting in its associated community an average of 5.95ind. in 100m$^2$ for 2002 and 5.50ind. in 100m$^2$ for 2017.

### Individual modeling

For correlation analysis, variables which presented high correlation with 2017 DBH were 2002 DBH (DBH$_{\text{initial}}$) and 2002 transversal area (g$_{\text{initial}}$). Competition indexes had weak to moderate correlation with 2017 DBH (DBH$_{\text{final}}$). BAL index had low and negative correlation (-21%), this indicates that the lower the index values, the higher the DBH. Plot community density and dominance presented weak and non-significant correlation with $DBH_{final}$.

Although competition influences tree growth, in the present research competition had a weak to moderate correlation with $DBH_{final}$ of *E. involucrata*, and variables $DA_{initial}$ and $DoA_{initial}$ of the plots did not correlate with $DBH_{final}$. Chassot *et al.* (2011), when adjusting individual tree diameter growth models for *A. angustifolia*, found a strong positive correlation of interest variable ($DBH_{final}$) with competition indexes, revealing pressure suffered by target trees with other species. However, the authors used only $DBH_{initial}$ and sociological position in the regression model, because only these variables were efficient in predicting $DBH_{final}$.

Chassot *et al.* (2011) also applied other variables, as sociological position, total height, commercial height and crown classes, which did not improved diameter prediction. These results were also found by Mattos (2007) for three Rio Grande do Sul State native species, *Cabralea canjerana*, *Cedrela fissilis e Cordia trichotoma*. Kierman *et al.* (2008) also identified competition indexes for *Acer saccharum*, based in individual tree traits, which had not enhanced final diameter estimative, only population basal area and initial diameter were efficient to estimate $DBH_{final}$.

For adjusting models, $DBH_{initial}$ and $g_{initial}$ variables, connected in different ways, resulted in better adjustment models (models 1, 2, 9, 11 and 12). It is important to highlight that transversal area, when separated from $DBH_{initial}$, presented higher percentage error above 15%, as it also overestimated all diameter classes in model 3, and underestimated all diameter classes in model 9. Other models by applying only competition indexes or other variables had their statistical parameters lower than compared to variables combined with $DBH_{initial}$ and $g_{initial}$. It stands out that some models using competition indexes associated with other variables had not presented significant coefficients, not being selected to $DBH_{final}$ estimative.

As related to statistics to evaluate model validation, seen in 1:1 graph (Figure 9), observed and predicted values for selected models had less variation, indicating predicted values are next to observed values. It is worth to note these graphs are widely used for model validation (Scolforo *et al.*, 2018; Santos *et al.*, 2021). With respect to the statistics to bias, precision, and accuracy, evaluated models showed 10% values for models 1, 9, 11 and 12, which showed reliability in using these to estimate $DBH_{final}$. According to Pretzsch (2009) told bias indicate difference between observed and predicted values; precision is predicted values concentration around the mean; and, finally, accuracy is how much predicted values are next to observed values. In this way, the smaller the percentage value, the better the model, so, model 12, despite not presenting best bias, had better precision and accuracy values when estimating $DBH_{final}$ of *E. involucrata*.

## Conclusion

Species spatial pattern is aggregated, for all diameter classes, and aleatory, when evaluated for DBH classes up to 20cm. Phytosociological parameters presented variation through evaluated years, showing the species had an increase in individuals' number, as well as basal area and frequency inside study area. Species had slow annual growth, with 0.21cm year-$^{1}$ mean diameter and $0.0036m^{2}ha^{-1}$ $year^{1}$ basal area increments, as annual ingress higher than mortality rate (4.57% and 0.49%, respectively);

*A. angustifolia*, *I. paraguariensis* and *O. odorifera* were species most related to *E. involucrata*, these species have the highest importance value for evaluated years (2002 and 2017). Competition indexes revealed major competition for target trees in DBH classes from 10-20cm. Models proposed in this research, using $DBH_{initial}$ and $g_{initial}$ as independent variables, connected in different ways, were considered better models to estimate the final diameter of *E. involucrata*.

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