# DIAMETER DISTRIBUTION PROJECTIONS IN MIXED OMBROPHYLOUS FOREST IN THE CENTER-SOUTH REGION OF PARANA, BRAZIL

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**Resumo**

*Projeções da distribuição diamétrica em Floresta Ombrófila Mista na região Centro-Sul do Paraná.* Técnicas de projeções da estrutura diamétrica, como Matriz de Transição e Razão de Movimento, têm sido usadas com frequência em Floresta com Araucária, mas não se têm informações acerca do potencial do método de Wahlenberg. Além disto, os trabalhos sobre o tema, dificilmente tinham dados suficientes para avaliar as projeções com dados observados. Assim, o objetivo foi avaliar os métodos Matriz de Transição, Razão de Movimento e de Wahlenberg na projeção da estrutura diamétrica em uma Floresta Ombrófila Mista na região Centro-Sul do Paraná, comparando as projeções com dados observados. A pesquisa foi realizada com dados provenientes de 25 parcelas permanentes de um hectare cada, instaladas na Floresta Nacional de Irati. As medições dessas parcelas ocorreram a cada três anos, no período de 2002 a 2017, contemplando 15 anos de monitoramento. A base de dados aplicada aos três métodos utilizou as remedições de dois períodos: três anos (2002-2005) e seis anos (2002-2008). Com isto, as projeções foram realizadas para períodos múltiplos, o que possibilitou a comparação com os dados observados. A acuracidade das projeções geradas foi avaliada pelo teste de Kolmogorov-Smirnov e Índice de Reynolds. Observou-se que nos períodos analisados houve uma tendência de redução na projeção do número total de árvores da floresta para os três métodos testados. Entre os métodos analisados, a Matriz de Transição apresentou maior acuracidade, com intervalo de três anos (até 2011) e seis anos. Cabe ressaltar, no entanto, que o método ainda possui limitações de uso com relação ao período entre projeções.
*Palavras-chave:* Floresta com araucária; matriz de transição; razão de movimento; método de Wahlenberg.

**Abstract**

Projection techniques of the diametric structure, such as Transition Matrix and Movement Ratio, have been frequently used in Araucaria Forest, but there is no information about the potential of the Wahlenberg method. In addition, studies on the subject hardly had enough data to assess projections with observed data. Thus, the objective herein was to evaluate the Transition Matrix, Movement Ratio and Wahlenberg Methods in projecting the diametric structure in a Mixed Ombrophylous Forest in the Center-South region of Paraná, Brazil, and compare the projections with observed data. The study was carried out with data from 25 permanent plots of one hectare each, installed in the National Forest of Irati. The measurements of these plots occurred every three years, from 2002 to 2017, covering 15 years of monitoring. The database applied to the three methods used measurements from two periods: three years (2002-2005) and six years (2002-2008). With this, the projections were made for multiple periods, which enabled comparing them with the observed data. The accuracy of the generated projections was assessed by the Kolmogorov-Smirnov test and the Reynolds Index. It was observed that there was a reduction tendency in the projection of the total number of trees in the forest for the three tested methods in the analyzed periods. Among the analyzed methods, the Transition Matrix was more accurate, with an interval of three years (until 2011) and six years. However, it should be noted that the method still has limitations of use in relation to the time between projections.
*Keywords:* Araucaria forest; transition matrix; movement ratio; Wahlenberg method.

## INTRODUCTION

It is known that the forests in southern Brazil have had their floristic composition altered due to the intense logging that took place in the past, as this fragmentation process caused numerous changes. These transformations have led to limited management of these natural resources, seeking to protect the Mixed Ombrophylous Forest (MOF) remnants from disorderly exploitation. However, it is observed that this restriction can be unfavorable, resulting in the depreciation of the forest and loss of interest of the population in its conservation. In order to guarantee conservation, information on how the forest grows is necessary so that it can be managed, thus enabling the conservation and rational use of these resources, mainly by small producers who could supplement their income.

Some of the mechanisms in forest management which assist in forest planning are growth and production models, which are based on growth data acquired by monitoring the forest in a given period. According to Vanclay

(1994), these growth models can be classified into models of total stand, distribution by diameter class and individual tree models. Of these, the diametric distribution models are the most used, as they make it possible to describe changes in the stand structure over time. In this type of model, the stochastic models of diameter growth stand out for use in native forests, for which the Transition Matrix is available; and the stand tables, for which the Movement Ratio method and the Wahlenberg method can be cited.

Many studies on the prognosis of the diametric structure for the Mixed Ombrophylous Forest have been conducted using the Transition Matrix and Movement Ratio methodology (EBLING *et al*., 2012; EBLING *et al*., 2013; and DALLA LANA *et al*., 2015). Two studies using the methodology proposed by Wahlenberg were found in the region of Minas Gerais, carried out by Pulz (1999) in a Montana Semi-deciduous Forest remnant, and Austregésilo et al. (2004) in a secondary Semi-deciduous Seasonal Forest. Thus, it is observed that the Wahlenberg method has not yet been tested for the Araucaria Forest, for which the most recent studies have focused on the Transition Matrix and Movement Ratio. The Wahlenberg method considers the growth rate variation of individual trees within each diameter class and as a result, Vanclay (1994) stated that this method can generate more accurate production estimates.

Finally, it should be noted that the works on the subject developed so far in Mixed Ombrophylous Forest did not provide a database which would enable comparisons of projections with observed data, which therefore did not allow a more accurate assessment of the projections made.

In view of the above, the objective of the present study was to evaluate the Transition Matrix, Movement Ratio and Wahlenberg methods in diameter distribution projections in a Mixed Ombrophylous Forest in the Center-South region of Paraná, Brazil, by testing periods with different amplitudes (three and six years) and comparing the results with observed data. Due to the applicability of methods based on the Transition Matrix and Movement Ratio, it is questioned whether the Wahlenberg Method, which considers the variation in the increment rate of individual trees within each diameter class, would have better results for the projection of the forest, and whether these methods are consistent for forest projection.

## MATERIAL AND METHODS

### *Description of the study area and data collection*

The study was carried out with data from permanent plots installed in the National Forest (FLONA) of Irati, state of Paraná, Brazil. The FLONA de Irati is located on the second plateau of Paraná at a distance of approximately 150 km west of the capital city of Curitiba, and has a total area of 3,495 hectares, of which 57.6% are occupied by native forests (ICMBIO, 2013). The region's climate is Cfb (Mesothermal Humid Subtropical) according to the Köppen classification, characterized by cool summers, severe and frequent frosts and no dry season (ROIK *et al*., 2019;).

In order to carry out the diametric structure projections, 25 permanent plots (100 mx 100 m) installed by professors from the Forest Management Laboratory of the Forest Engineering Department at UNICENTRO in 2002 were used, composing a total sample area of 25 hectares in an area of Mixed Ombrophylous Forest existing in FLONA de Irati. The remeasurements of these plots took place in 2005, 2008, 2011, 2014 and 2017, covering 15 years of monitoring the forest dynamics. The data on vegetation dynamics (growth, ingress and mortality) used to carry out the projections refer to the period 2002-2005 for the diametric structure projection with an interval every three years, and 2002-2008 for the diametric structure projection every six years. All trees with a diameter of 1.3 m from the ground (DBH) equal to or greater than 10 cm were measured in the inventories, and the dead trees and those which entered the system were also included.

### *Diametric distribution projection methods*

Three projection methods were tested: Transition Matrix (TM), Movement Ratio (MR) and the Wahlenberg Method (WM). The calculations for the diameter distribution projections in the three evaluated methods were carried out for periods equivalent to the available measurements, meaning for periods of three and six years with diameter classes with amplitudes of 10 cm. Therefore, using data from 2002 to 2005, the diametric distribution was projected for the years 2008, 2011, 2014 and 2017. This procedure was also performed with data from 2002 to 2008, projecting the diametric structure for 2014. These steps enabled comparing the projected diameter distribution with the real one obtained in the specific remeasurements.

### *Transition matrix*

The Transition Matrix was composed by determining the migration or permanence probabilities of trees in each diameter class, as well as the number of trees that enter and die in the period (SANQUETTA, 1996; SCOLFORO, 1998). The diameter structure of the forest, calculated (or projected) for a future period, is the result of multiplying the transition probability matrix (G) by the number of trees in the current period, added to the number of trees entered (Eq. 1). It should be noted that the calculated mortality admission values refer to the period 2002-2005 for projection with an interval of every three years, and 2002-2008 for the projection of six years.

$$Y_{t+\Delta t} = GY_{it} + I_{it} \quad (1)$$

In which: $Y_{t+\Delta t}$ = Number of projected trees; G = Transition probability matrix by diameter class; $Y_{it}$ = Number of trees per diameter class in the current period; $I_{it}$ = Number of trees entered or recruited.

**Movement ratio**

In the Movement Ratio, it is assumed that the trees are uniformly distributed within the classes, where each tree grows at an average rate (AUSTREGÉSILO *et al*., 2004). Thus, the annual periodic increment in diameter, in centimeters, per DBH class was initially found. The average increase rate was subsequently identified to calculate the Movement Ratio with data from the period 2002 to 2005 for projection every three years and 2002 to 2008 for projection using a six-year interval. The mean periodic increment (Eq. 2) and the Movement Ratio (Eq. 3) were calculated by the following expressions:

$$\overline{IPD}_j = \frac{\sum_{i=1}^{n}(DBH_{2i}-DBH_{1i})}{N} \quad (2) \qquad MR\ (\%) = \frac{\overline{IPD_J}}{C}\ 100 \quad (3)$$

In which: MR = Movement ratio, in percentage; $\overline{IPD_J}$ = Annual mean periodic increment in diameter of the *j*-th diameter class (cm); C = diameter class range (cm); $DBH_{1i}$ = Diameter at breast height (1.3 m from the ground) of the *i*-th tree in the 1st measurement (cm); $DBH_{2i}$ = Diameter at breast height (1.30 m from the ground) of the *i*-th tree in the 2nd measurement (cm); *i* = measurement periods 1, 2, ..., n; N = total number of trees in each diameter class.

To interpret the movement rate, it is considered that the values obtained in each DBH class indicate the percentage of the total number of trees that will migrate to the next class. If the value is discounted from 100, it indicates the percentage of the total number of trees that will continue in the same DBH class (LONGHI *et al*., 2017).

**Wahlenberg method**

The Wahlenberg Method (WM) is based on recognizing the increment rate variation of individual trees within each diameter class, meaning that a tree can remain in the same diameter class, change to the next diameter class, or even change two classes (HUSCH *et al*., 1982). The following steps described and used by Pulz (1999) were adapted for this method:

Step 1 - Quantification of the periodic increment in diameter (Eq. 4):

$$IPd = DBH_{2i} - DBH_{1i} \quad (4)$$

In which: *IPd* = periodic increment in diameter (cm); $DBH_{1i}$ = Diameter at breast height (1.3 m from the ground) of the *i*-th tree in the 1st measurement (cm); $DBH_{2i}$ = Diameter at breast height (1.30 m from the ground) of the *i*-th tree in the 2nd measurement (cm); i = measurement periods 1, 2, ..., n.

Step 2 - Definition of admission and mortality - these parameters were not estimated using models, but the values observed in the period were used, with 2002-2005 for three years and 2002-2008 for six years.

Step 3 - Projection of the diametric structure – the diametric distribution was obtained by adding the number of trunks/stems after movement to the number of entries, minus the number of dead trunks/stems.

Thus, the evolution of the diametric structure of the forest was performed with the calculation of the movement percentages for each diameter class, similar to the Movement Ratio, described above.

***Evaluation of the projections***

The accuracy of the projections generated by the Transition Matrix, Movement Ratio and Wahlenberg Method was evaluated by the Kolmogorov-Smirnov (K-S) and Reynolds Index (RI) adherence tests. The K-S test tests cumulative distributions, suggesting whether samples come from the same or different populations. A significance level of 0.05 (α) was considered to perform the test to find the critical value ($D_{tab}$). The test considers the following hypotheses: $H_0$: the calculated distribution is similar to the observed one; $H_1$: the calculated distribution is not similar to the observed one. The K-S test was applied to the maximum divergence ($D_n$) values between distributions, with lower $D_n$ values indicating better fits (SCHNEIDER *et al*., 2009). The maximum divergence value ($D_n$) (Eq. 5) and distribution value ($D_{calc}$) (Eq. 6) are defined by the expressions:

$$Dn = max|F_{0(x)} - F_{e(x)}| \quad (5) \qquad D_{calc} = \frac{Dn}{N} \quad (6)$$

In which: Dn = Point of greatest divergence of the distribution; $F_{o(x)}$ = Accumulated observed frequency for each class; $F_{e(x)}$ = Accumulated estimated frequency for each class; N = Total number of trees.

The Reynolds Index enables evaluating the performance of the methods by diameter class, where the lowest value indicates a small difference between the number of observed and estimated trees in the diameter classes (ORELLANA, 2014). In this study, the unweighted Reynolds Index was used according to Orellana (2014) (Eq. 7). This index was calculated for the three projection methods used in the prognosis of the forest in each projection period (2008, 2011, 2014, 2017), resulting in the difference in trunks/stems.ha$^{-1}$ per diameter class between the value observed in the remeasurements and the projection.

$$RI = \sum_{I=1}^{K} |\mathrm{N_i} - \widehat{\mathrm{N}}_\mathrm{i}| \quad (7)$$

In which: $RI$ = Reynolds Index; $N_i$ = number of trees per hectare observed in the class *i*; $\widehat{N}_i$ = number of trees per hectar estimated in the class *i*.

## RESULTS

### *Diametric distribution*

The largest number of trunks/stems in the fragment for the evaluated periods is concentrated in the first two diameter classes, mainly in 2002 (Figure 1). It is observed that the number of trunks decreases significantly in 2002 and 2017 with the increase in the diameter class; however, the frequency of trunks is higher from class 25 onwards in 2017 compared to 2002.

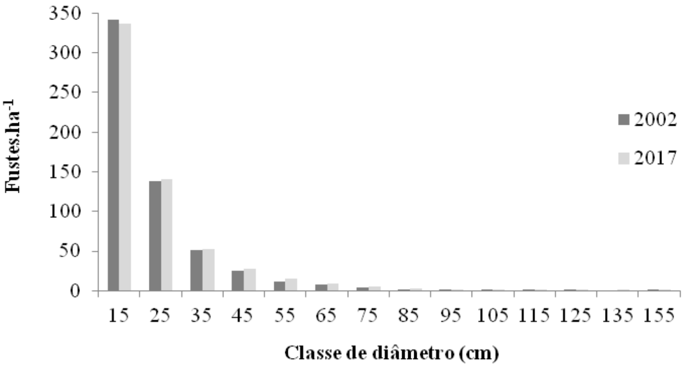


Figure 1. Diametric distribution for all tree species found in the fragment of Mixed Ombrophylous Forest in Irati, Paraná, Brazil.
Figura 1. Distribuição diamétrica para todas as espécies arbóreas encontradas no fragmento de Floresta Ombrófila Mista em Irati, Paraná.

### *Diametric distribution prognosis*

The diameter distribution projections of the forest for the number of trunks/stems was performed through the Transition Matrix (TM), Movement Ratio (MR) and Wahlenberg Method (WM) based on the years 2002-2005 (Table 1). There was a tendency to reduce the total forest density for the three methods in the analyzed projection years. The number of trunks projected for the four occasions (2008, 2011, 2014 and 2017) in the 15 cm diameter class decreased in relation to that observed for any of the methods. There was an increase in the number of trees in relation to what was observed in classes from 25 to 105 cm, with the exception of the year 2017 for TM in classes 25 and 55 cm; and WM in the 25 cm class, which had their values lower than the observed. The observed and projected numbers tend to decrease from the 115 cm class, being identical in some classes. The projections of the three methods were compared with the real data and the statistics used for this are shown in Table 2.

In analyzing the K-S test, it was observed that the null hypothesis was accepted for the 2008 and 2011 projections, meaning that the predicted diametric distribution was statistically similar to the observed diametric distribution. The best estimate of the projections considering the lowest RI value was for TM and WM in the years 2008 and 2011. There was no adherence to the projections for 2014 and 2017, since the $D_{calc}$ was greater than the

$D_{tab}$ (0.06) considering α of 0.05 probability of error. The highest RI and $D_{calc}$ were found for MR in the years 2017 and 2014, respectively. Thus, it can be seen that the RI value increases as projections are made for longer periods for the three methods, generating less consistent projections.

The projection for a six-year interval was performed to compare the methods using information from a longer period. Table 3 shows the number of trees per diameter class projected for the year 2014, comparing the projections using data from 3 years (2002-2005) and 6 years (2002-2008). The projections of the three methods overestimated the number of trunks in the 35 to 65 cm class for the three-year period and for the six-year period for the 25 to 95 cm class. The difference in the total number of trunks.ha$^{-1}$ in relation to the projected data based on the span of six years (2002-2008) was approximately 30 trunks.ha$^{-1}$ for TM (5.1%), 31 trunks.ha$^{-1}$ (5.27%) for MR, and 31 trunks.ha$^{-1}$ (5.27) for WM. This difference in the time span of three years (2002-2005) was 37 trunks.ha$^{-1}$ (6.29%) for TM, 41 trunks.ha$^{-1}$ (6.96%) for MR and 31 trunks.ha$^{-1}$ (5.27%) for WM.

Evaluating Table 4 using the K-S test, it can be seen that only the TM for the 6-year projection was accurate, which is also noted in the RI, which resulted in the smallest variation with 32 trunks.ha$^{-1}$. There was no adherence by the K-S test for MR and TM, and the RI also resulted in greater variations in trunks.ha$^{-1}$. Therefore, the most suitable method using 10 cm diameter classes for the period of 6 years would be the TM, since the projections based on 2002-2008 were better to estimate in the diameter classes and for the total.

Table 1. Frequency of the number of trunks per hectare observed (OBS) and projected based on the period 2002-2005, using the Transition Matrix (TM), Movement Ratio (MR) and Wahlenberg Method (WM) for amplitude of 10 cm diameter class for the Mixed Ombrophylous Forest of the Irati National Forest, PR, Brazil.

Tabela 1. Frequência do número de fustes por hectare observado (OBS) e projetado tendo como base o período 2002-2005, empregando a Matriz de Transição (MT), Razão de Movimento (RM) e Método de Wahlenberg (MW) para amplitude de classe diamétrica de 10 cm para a Floresta Ombrófila Mista da Floresta Nacional de Irati, PR.

| DBH class center (cm) | 2008 | | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| | OBS | TM | MR | WM | OBS | TM | MR | WM |
| 15 | 324.88 | 314.31 | 305.34 | 312.92 | 320.2 | 303.9 | 285.06 | 299.3 |
| 25 | 137.88 | 138.48 | 142.6 | 139.11 | 135.92 | 137.74 | 144.52 | 138.79 |
| 35 | 52.44 | 54.54 | 57.38 | 54.86 | 52.88 | 55.71 | 61.46 | 56.42 |
| 45 | 26.84 | 27.51 | 28.07 | 27.69 | 27.56 | 28.52 | 29.96 | 28.93 |
| 55 | 12.84 | 13.02 | 14.16 | 13.12 | 13.28 | 13.56 | 15.79 | 13.78 |
| 65 | 8.16 | 8.68 | 8.35 | 8.71 | 8.16 | 9.38 | 8.95 | 9.46 |
| 75 | 4.24 | 4.4 | 4.77 | 4.43 | 4.48 | 4.83 | 5.48 | 4.89 |
| 85 | 1.96 | 2.22 | 2.13 | 2.22 | 2.4 | 2.76 | 2.61 | 2.76 |
| 95 | 0.32 | 0.39 | 0.55 | 0.28 | 0.36 | 0.53 | 0.83 | 0.28 |
| 105 | 0.08 | 0.12 | 0.18 | 0.12 | 0.08 | 0.12 | 0.31 | 0.12 |
| 115 | 0.04 | 0.04 | 0.05 | 0.04 | 0.04 | 0.04 | 0.06 | 0.04 |
| 125 | 0.08 | 0.02 | 0.05 | 0.02 | 0.08 | 0.01 | 0.05 | 0.01 |
| 135 | 0.04 | 0.02 | 0.05 | 0.06 | 0.04 | 0.07 | 0.05 | 0.07 |
| 145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 155 | 0.04 | 0.04 | 0.02 | 0.04 | 0.04 | 0.04 | 0.01 | 0.04 |
| **Total** | 570 | 564 | 564 | 564 | 566 | 557 | 555 | 555 |
| **DBH class center (cm)** | **2014** | | | | **2017** | | | |
| | **OBS** | **TM** | **MR** | **WM** | **OBS** | **TM** | **MR** | **WM** |
| 15 | 339.16 | 294.15 | 266.31 | 286.41 | 335.72 | 285.49 | 248.98 | 274.18 |
| 25 | 137.64 | 136.54 | 144.71 | 137.79 | 140.24 | 135 | 143.47 | 136.17 |
| 35 | 52.8 | 56.67 | 65.21 | 57.81 | 52 | 57.41 | 68.5 | 58.99 |
| 45 | 28 | 29.49 | 32.07 | 30.2 | 27.2 | 30.4 | 34.34 | 31.46 |
| 55 | 14.04 | 14.12 | 17.43 | 14.47 | 15.16 | 14.26 | 19.11 | 15.18 |
| 65 | 8.48 | 10.05 | 9.71 | 10.22 | 8.68 | 10.71 | 10.61 | 10.99 |

Continuation...

| DBH class center (cm) | 2014 | | | | 2017 | | | |
|---|---|---|---|---|---|---|---|---|
| | **OBS** | **TM** | **MR** | **WM** | **OBS** | **TM** | **MR** | **WM** |
| 75 | 4.76 | 5.29 | 6.16 | 5.38 | 5.08 | 5.76 | 6.86 | 5.9 |
| 85 | 2.64 | 3.32 | 3.12 | 3.34 | 2.88 | 3.92 | 3.66 | 3.95 |
| 95 | 0.44 | 0.71 | 1.13 | 0.28 | 0.44 | 0.93 | 1.45 | 0.28 |
| 105 | 0.08 | 0.12 | 0.49 | 0.12 | 0.08 | 0.12 | 0.73 | 0.12 |
| 115 | 0.04 | 0.04 | 0.09 | 0.04 | 0.08 | 0.04 | 0.15 | 0.04 |
| 125 | 0.04 | 0.01 | 0.06 | 0.01 | 0.04 | 0 | 0.08 | 0 |
| 135 | 0.08 | 0.08 | 0.06 | 0.08 | 0.08 | 0.08 | 0.07 | 0.08 |
| 145 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 155 | 0.04 | 0.04 | 0.01 | 0.04 | 0.04 | 0.04 | 0 | 0.04 |
| **Total** | 588 | 551 | 547 | 546 | 588 | 545 | 538 | 537 |

Table 2. Kolmogorov-Smirnov test (K-S) and Reynolds Index (RI) calculated for the projections performed with an interval every three years based on the 2002-2005 measurement in a Mixed Ombrophylous Forest fragment in Irati, PR, Brazil.

Tabela 2. Teste de Kolmogorov-Smirnov (K-S) e Índice de Reynolds (IR) calculados para as projeções realizadas com intervalo a cada três anos com base na medição 2002-2005 em um fragmento de Floresta Ombrófila Mista em Irati, PR.

| Projection year | Method | $D_{calc}$ | RI |
|---|---|---|---|
| 2008 | TM | 0.02 | 14.68 |
| | MR | 0.03 | 33.05 |
| | WM | 0.02 | 17.90 |
| 2011 | TM | 0.03 | 24.40 |
| | MR | 0.06 | 60.01 |
| | WM | 0.04 | 31.44 |
| 2014 | TM | 0.08* | 54.65 |
| | MR | 0.12* | 104.13 |
| | WM | 0.09* | 63.80 |
| 2017 | TM | 0.10* | 68.92 |
| | MR | 0.05* | 124.49 |
| | WM | 0.11* | 81.36 |

Legend: TM=Transition Matrix; MR= Movement Ratio; WM= Wahlenberg method; $D_{cal}$ = value calculated in the K-S test for the distributions; * Significant at α = 0.05 (Tabled = 0.06).

Table 3. Frequency of the number of trunks per hectare observed (OBS) and projected based on the period 2002-2005 (3 years) and 2002-2008 (6 years), using the Transition Matrix (TM), Movement Ratio (MR) and Wahlenberg Method (WM) for a Mixed Ombrophylous Forest fragment in Irati, PR, Brazil.

Tabela 3. Frequência do número de fustes por hectare observado (OBS) e projetado tendo como base o período de 2002-2005 (3 anos) e 2002-2008 (6 anos), empregando a Matriz de Transição (MT), Razão de Movimento (RM) e Método de Wahlenberg (MW) para um fragmento de Floresta Ombrófila Mista em Irati, PR.

| DBH class center (cm) | OBS (2014) | Period | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 years | | | 6 years | | |
| | | TM | MR | WM | TM | MR | WM |
| 15 | 339.16 | 294.15 | 266.31 | 294.96 | 309.57 | 292.89 | 304.23 |
| 25 | 137.64 | 136.54 | 144.71 | 139.40 | 136.35 | 143.16 | 138.10 |
| 35 | 52.8 | 56.67 | 65.21 | 63.84 | 53.06 | 58.19 | 53.77 |
| 45 | 28 | 29.49 | 32.07 | 27.90 | 28.02 | 28.81 | 28.53 |
| 55 | 14.04 | 14.12 | 17.43 | 13.50 | 13.71 | 15.33 | 14.06 |
| 65 | 8.48 | 10.05 | 9.71 | 9.02 | 9.08 | 8.86 | 9.14 |
| 75 | 4.76 | 5.29 | 6.16 | 4.66 | 4.89 | 5.40 | 4.97 |
| 85 | 2.64 | 3.32 | 3.12 | 2.49 | 2.73 | 2.67 | 2.73 |
| 95 | 0.44 | 0.71 | 1.13 | 0.41 | 0.51 | 0.73 | 0.53 |
| 105 | 0.08 | 0.12 | 0.49 | 0.08 | 0.05 | 0.18 | 0.05 |
| 115 | 0.04 | 0.04 | 0.09 | 0.04 | 0.03 | 0.04 | 0.03 |
| 125 | 0.04 | 0.01 | 0.06 | 0.04 | 0.08 | 0.09 | 0.08 |
| 135 | 0.08 | 0.08 | 0.06 | 0.08 | 0.04 | 0.06 | 0.04 |
| 145 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 155 | 0.04 | 0.04 | 0.01 | 0.04 | 0.04 | 0.02 | 0.04 |
| Total | 588.24 | 550.62 | 546.57 | 556.45 | 558.16 | 556.42 | 556.31 |

Table 4. Statistics for the projection carried out for the year 2014 based on the measurement 2002-2005 (3 years) and 2002-2008 (6 years) in a Mixed Ombrophylous Forest fragment in Irati, PR, Brazil.

Tabela 4. Estatísticas para a projeção realizada para o ano de 2014 com base na medição 2002-2005 (3 anos) e 2002-2008 (6 anos) em um fragmento de Floresta Ombrófila Mista em Irati, PR.

| Period | Method | Dcalc | RI |
|---|---|---|---|
| 3 | MT | 0.08* | 54.64 |
| | RM | 0.12* | 104.12 |
| | MW | 0.09* | 63.79 |
| 6 | MT | 0.05 | 32.51 |
| | RM | 0.08* | 60.80 |
| | MW | 0.06* | 38.08 |

Legend: TM = Transition Matrix; MR = Movement Ratio; WM = Wahlenberg method; Dcal = value calculated in the K-S test for the distributions; RI = Reynolds Index; * Significant at α = 0.05 (Tabulated = 0.056).

## DISCUSSION

The observed diametric distribution with negative exponential distribution, also called "inverted J" (Figure 1), is characteristic of forests, meaning the frequency of individuals in the DBH classes presents a balanced distribution of individuals, thus ensuring continuity of the forest due to its self-regeneration capacity (LIMA; LEÃO, 2013; SANTOS *et al*., 2016; CYSNEIROS *et al*., 2017). This negative exponential distribution pattern was found by several authors for this same forest typology, such as Ebling *et al*. (2012) and Callegaro *et al*. (2016).

The decrease in the number of trunks (Table 1) in the projections generated in the three methods can be attributed to the mortality that was greater than the recruitment, since the mortality and recruitment used for the projections were calculated based only on the first period (2002-2005). The increase in the number of trunks from class 25 to 105 could denote a superior growth pattern to the mortality that the forest would present for the time horizon of the simulation; however, as the observed values are available, it is noted that the methods may underestimate or overestimate the diameter distribution. The observed and projected numbers tend to decrease from the 115 cm class, being identical in some classes. When analyzing the total number of trunks.ha$^{-1}$, it was observed that the projected values for the three methods in 2014 and 2017 mainly tend to underestimate the number of trunks. However, it is important to emphasize that the estimation of the total number of trunks.ha$^{-1}$ depends on how mortality and recruitment are estimated, since the projection methods estimate how trees migrate within the classes and not the total.

In studies conducted by Dalla Lana *et al*. (2015) in the region of São João do Triunfo, Paraná, the authors found opposite trends for a stretch of Mixed Ombrophylous Forest, with small increases in the first classes and reduction in the largest. These differences between the forest dynamics possibly occur because of the balance between mortality and ingression rates, since the aforementioned authors reported higher recruitment rates than mortality. In comparing diametric structure prognosis methods, Machado *et al*. (2017) showed adherence between the observed real values and the projections in both evaluated class intervals, indicating the efficiency of the Transition Matrix for the evaluation of forest succession, whereas Austregésilo *et al*. (2004) found that the projections for the Transition Matrix differed statistically from the real structures.

In this study, the Transition Matrix (TM), which is a more usual method, presented estimates close to the Movement Ratio (MR) method, both in the diameter classes and in the total, with the projections being similar to the observed values. According to Soares *et al*. (2009), the Transition Matrix helps as decision tools for silvicultural treatments, at least for shorter periods, and if the forest presents slow growth rates. These projections serve as an initial guide to support decisions on cutting intensity and the use of silvicultural techniques, such as refinement, which can use the diametric distribution to systematically reduce the basal area by diameter class, as in the BDq technique (HANSON *et al*., 2012).

In Table 2, it can be seen that there was a divergence between the $D_{calc}$ and RI statistics in the two periods (3 and 6 years) in which the analyzes were performed, corroborating Orellana and Figueiredo Filho (2017), who also found divergence between these statistics. It was also observed (Table 2) that the diametric distribution projection for the last two periods was rejected by the K-S test at the level of 5% error probability for the three methods tested. The Reynolds Index also increased in relation to the two previous projections, indicating that using only observations of a short period (3 years) to make long projections would not be advisable; a fact which is already mentioned in the literature. Another justification for the non-adherence found may be a consequence of the high number of trees in a plot with an area of one hectare. In these cases, Retslaff (2012) reported that when using the number of trees corresponding to one hectare, the estimated distribution is often rejected by the K-S test, because as the number of trees increases, the $D_n$ (α) value becomes smaller ($D_n$ (α) is tabular, being calculated as $1.3581/\sqrt{n}$), making it more difficult to accept the estimated distribution. Retslaff adds that the test assumes that as more data are used for the fit, the quality of the fit should be better, and thus the $D_n$ value is smaller.

Dalla Lana *et al*. (2015) reported that there was an overestimation of the number of trees by the Transition Matrix for the 5 and 10 cm diameter classes and an underestimation by the Movement Ratio in the first diameter class. The authors also stated that differences in prognosis, especially in the first diameter class, are common, due to this being the class with the greatest dynamics within the forest, meaning in which there is greater recruitment and greater mortality. This study partially corroborates the results found in this study, in which there was an overestimation of the number of trunks by TM and MR.

In evaluating the Transition Matrix for a time span of four years (data from 2006-2010) in different diameter classes (5 and 10 cm), Longhi *et al*. (2017) reported that it presented diameter classes with a probability of 100% of permanence, or the so-called absorbing states. For projection purposes, the occurrence of this state makes the use of this method unfeasible in the future prognosis of the forest, since it is not possible to estimate the real probability of transition of a tree to the subsequent class, with a continuous increase of trees occurring in this class as more predictions are made.

In studying the prognosis in a MOF and using a diameter class of 5 and 10 cm in the region of São João do Triunfo, Paraná, Dalla Lana *et al*. (2015) concluded that both the Transition Matrix and the Movement Ratio were close to the real structure of the forest with regard to the total number of trees per hectare. However, the estimate by the Transition Matrix increasingly overestimated the number of trees for the temporal amplitudes of two, three, four and five years. The opposite happened with the Movement Ratio, in which an underestimation occurred. The authors observed that the TM method resulted in a greater proximity of the number of trees observed with an interval of 10 cm; and concluded that this can be considered more accurate than the Movement Ratio method. This information corroborates the result obtained in the present study, in which TM was the only method which presented estimated values close to the observed, and can be used for a long period (6 years). However, it should be noted that the prognosis performed with this method is influenced by absorbing states, which does not make the method invalid, but restricts its use (DALLA LANA *et al*., 2015).

This research does not corroborate the study by Pulz *et al*. (1999), who concluded that the Transition Matrix, Movement Ratio and Wahlenberg Method presented the same degree of accuracy for the purpose of prognosing the total number of trees in the forest. Despite the proximity of the number of trees observed, it is worth noting that the prognosis of the frequency in diameter class may differ in the evaluation periods, showing that this is sensitive to the recruitment and mortality dynamics of the forest structure.

## CONCLUSION

Among the analyzed methods:

- The Transition Matrix was more accurate, with an interval of three years (until 2011) and six years.
- However, it should be noted that the Transition Matrix method has limitations of use in relation to the period between projections.
- Due to the difference in values observed between the years of remeasurement, different diameter classes must be compared in order to seek information on whether the projection of the Forest with these three methods can be accurate in smaller classes, especially for predictions with the Movement Ratio and Wahlenberg Method, which were the ones that differed from the observed measurements.

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## REFERENCES

AUSTREGÉSILO, S. L.; FERREIRA, R. L. C.; SILVA, J. A. A.; SOUZA, A. L.; MEUNIER, I. M. J.; SANTOS, E. S. Comparação de métodos de prognose da estrutura diamétrica de uma floresta estacional semidecidual secundária. **Árvore**, Viçosa-MG, v.28, n. 2, p. 227-232, 2004.

CALLEGARO, R. M.; ANDRZEJEWSKI, C.; LONGHI. S. J., LONGHI, R. V.; BIALI, L. J. Composição das categorias sucessionais na estrutura horizontal, vertical e diamétrica de uma Floresta Ombrófila Mista Montana. **Revista Brasileira de Ciências Agrárias**, Recife-PE, v. 11, n. 4, p. 350–358, maio/novembro. 2016.

CYSNEIROS, V. C.; AMORIM, T. DE A.; MENDONÇA JÚNIOR, J. DE O.; GAUI, T. D.; DE MORAES, J. C. R.; BRAZ, D. M; DO AMARAL, S. M. Distribuição diamétrica de espécies da Floresta Ombrófila Densa no Sul do Estado do Rio de Janeiro. **Pesquisa florestal brasileira,** Colombo, v. 37, n. 89, p. 1-10, jan./mar. 2017.

DALLA LANA, M.; PÉLLICO NETTO, S.; DALLA CORTE, A.P.; SANQUETTA, C.R.; EBLING, A.A. Prognose da Estrutura Diamétrica em Floresta Ombrófila Mista. **Floresta e Ambiente**, Seropédica-RJ, v. 22, n. 1, p. 71-78, janeiro/março. 2015.

EBLING, A.A.; WATZLAWICK, L.F.; RODRIGUES, A.L.; LONGHI, S.J.; LONGHI, R.V.; ABRÃO, S.F. Acuracidade da distribuição diamétrica entre métodos de projeção em Floresta Ombrófila Mista. **Ciência Rural**, Santa Maria-RS, v. 42, n. 6, p. 1020-1026, junho/julho. 2012.

EBLING, A.A.; NETTO, S.P.; WATZLAWICK, L.F.; MIRANDA, R.O.V.; ABRÃO, S.F. Ecologia e projeção diamétrica de três grupos arbóreos em remanescente de Floresta Ombrófila Mista em São Francisco de Paula, RS. **Floresta**, Curitiba, v. 43, n. 2, p. 261-270, abril/junho. 2013.

HANSON, J. J.; LORIMER, C. G; HALPIN, C. R.; PALIK, B. J. Ecological forestry in an uneven-aged, late-successional forest: simulated effects of contrasting treatments on structure and yield. **Forest Ecology and Management**, Amsterdam, v. 270, p. 94-107, 2012. 10.1016/j.foreco.2012.01.017

HUSCH, B.; MILLER, C. I.; BEERS, T. W. **Forest mensuration**. New York: McGRAW-HILL, 397 p. 1982.

ICMBIO, Instituto Chico Mendes de Conservação da Biodiversidade. **Plano de Manejo da Floresta Nacional de Irati**. Fernandes Pinheiro, v. 1, p. 186, 2013.

LIMA, J.P.C.; LEÃO, J.R.A. Dinâmica de Crescimento e Distribuição Diamétrica de Fragmentos de Florestas Nativa e Plantada na Amazônia Sul Ocidental. **Floresta e Ambiente**, Seropédica-RJ, v.20, n.1, p.70-79, janeiro/março 2013.

LONGHI, R. V.; SCHNEIDER, P. R.; LIRA, D. F. S.; LISBOA, G. S. Projeção da distribuição diamétrica em floresta com araucária explorada seletivamente no Sul do Brasil. **Revista Brasileira de Ciências Agrárias**, Recife-PE v. 12, n. 2, p. 210–219, abril/junho. 2017.

MACHADO, S.; CYSNEIROS, V.; NASCIMENTO, R. G.; MARTINS, A.; SCHMIDT, L. Projeção da estrutura diamétrica de grupos ecológicos em uma Floresta Ombrófila Mista. **Floresta e Ambiente**, Seropédica-RJ, v. 24, 2017.

ORELLANA, E.; FIGUEIREDO FILHO, A.; PÉLLICO NETTO, S.; DIAS, A. N. Modelagem da distribuição diamétrica de espécies florestais em um fragmento de floresta ombrófila mista. **Árvore**, Viçosa-MG, v. 38, p. 297-308, abril/junho. 2014.

ORELLANA, E.; FIGUEIREDO FILHO, A. Uso do método da predição de parâmetros para projetar a distribuição diamétrica em florestas nativas com a função Weibull. **Ciência Florestal**, Santa Maria-RS, v. 27, n. 3, p. 981-991, julho/setembro, 2017.

PULZ, F. A.; SCOLFORO, J. R.; OLIVEIRA, A. D.; MELLO, J. M.; OLIVEIRA FILHO, A. T. Acuracidade da predição da distribuição diamétrica de uma floresta inequiânea com a matriz de transição. **Cerne,** Lavras-MG, v.5, n.1, p.01-14, janeiro. 1999.

RETSLAFF, F. A. DE S.; FIGUEIREDO FILHO, A.; DIAS, A. N.; BERNETT, L. G.; FIGURA, M. A. Prognose do crescimento e da produção em classes de diâmetro para povoamentos desbastados de *Eucalyptus grandis* no sul do Brasil. **Árvore** (Impresso), Viçosa-MG, v. 36, p. 719-732, agosto/outubro. 2012.

ROIK, M.; FIGUEIREDO FILHO, A.; GRESPAN, T.; STEPKA, T. F.; DE MIRANDA, R. O. V. Dinâmica da florística e da estrutura horizontal em um fragmento de Floresta Ombrófila Mista Montana. **Nativa**, Sinop-MT, v. 7, n. 6, p. 748-757, novembro/dezembro. 2019.

SANQUETTA, C. R.; ANGELO, H.; BRENA, D. A. MENDES, J. B. Matriz de transição para simulação da dinâmica de florestas naturais sob diferentes intensidades de corte. **Revista Ciência Florestal**, Santa Maria, v. 6, n. 1, p. 65-78, 1996.

DOS SANTOS, R. O.; DE ABREU, J. C.; DE LIMA, R. B.; APARÍCIO, P. DA S.; SOTTA, E. D.; LIMA, R. C. Distribuição diamétrica de uma comunidade arbórea na Floresta Estadual do Amapá, Brasil. **Biota Amazônia (Biote Amazonie, Biota Amazonia, Amazonian Biota)**, Macapá-AP, v. 6, n. 2, p. 24-31, 2016.

SCHNEIDER, P.R.; SCHNEIDER, P.S.P.; SOUZA, C.A.M. **Análise de regressão aplicada à Engenharia Florestal.** 2. Ed. Santa Maria: UFSM, CEPEF, 2009. 236p.

SCOLFORO, J. R. S.; PULZ, F. A.; MELLO, JM. **Modelagem da produção, idade das florestas nativas, distribuição espacial das espécies e a análise estrutural. Manejo Florestal.** Lavras: UFLA/FAEPE, p. 189-246, 1998.

SCOLFORO, J. R. S.; PULZ, F. A.; MELLO, J. M.; OLIVEIRA FILHO, A. T. Modelo de produção para floresta nativa como base para o manejo sustentado. **Cerne**, Lavras-MG, v.2, n.1, p. 112-137, 1996.

SOARES, C. P. B.; DEMOLINARI, R. A.; LEITE, H. G; SOUZA, A. L. Predição do crescimento em povoamentos clonais de eucalipto não desbastados utilizando matrizes de transição não estacionárias. **Árvore**, Viçosa, MG, v. 33, n. 5, p. 831-840, 2009.

VANCLAY, J. K. Modelling forest growth and yield: applications to mixed tropical forests. **Wallingford: CAB International,** 1994. 312p.