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Brazilian pine diameter at breast height and growth in mixed Ombrophilous forest in Southern Brazil

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Abstract

Information on the diameter at the breast height (DBH) growth of trees can be useful to understand their productivity and temporal dynamics in natural forests. This study presents the first results of increments in DBH of *Araucaria angustifolia* trees since their logging prohibition in southern Brazil, in late 1970s. We used dendrochronology techniques in 210 individuals in three different sites, which allowed a retrospective analysis of the DBH increment from 60 to 150 years. We adjusted temporal dimensional models whose results may help to support a sustainable forest management of *A. angustifolia* in southern Brazil. The results showed that the width of annual growth rings varied from 0.04 to 4.8 cm year^{-1} along the last 60 to 150 years, and the mean annual increment ranged from 0.3 to 0.9 cm year^{-1}. The DBH increment accumulated in the last ten years showed a decreasing pattern, indicating that most of the sampled trees had already reached maturity. This result denotes a proportional loss in DBH increment with increasing DBH and age. Decreasing DBH growth rates became even more evident in the last ten years (i.e. ~0.15 cm year^{-1}), indicating a need of silvicultural intervention in some sites to reduce competition among trees for soil nutrients and light. Regarding the average DBH increment growth, the time the trees need to reach the optimal DBH harvesting diameter of 40 cm ranged from 25 to 112 years, according to the local site index characteristics. The curve inflection point that represents the DBH increment occurred between 35 and 45 years for this specific DBH. These results confirm the viability and need of forest management practices of *A. angustifolia* trees due to the saturation of the trees DBH growth and increment capacity that reached its inflection. Therefore, since their logging prohibition, most *A. angustifolia* trees reached their optimal DBH harvesting size. Forest management is necessary for conservation of the forest structure. It would favor the growth of young *A. angustifolia*, seedling productions, the natural regeneration of this species and genetic diversity; and stimulate the increase of timber production.

Keywords: DBH growth model; diametric growth; *Araucaria angustifolia*; Atlantic Rain Forest; technical rotation.
Abbreviations: DBH_diameter at breast height; MOF_Mixed Ombrophilous Forest; *id*_annual increment in diameter; MCD_ minimum cutting diameter.

Introduction

The Atlantic Rain Forest is one of the largest humid tropical forests of the Americas. The Mixed Ombrophilous Forest (MOF), located in the southern part of the Atlantic Forest biome, is characterized by the presence of *Araucaria angustifolia* (Bertol.) Kuntze trees. It is also known as Brazilian pine. Natural areas of *A. angustifolia* occupied originally 200,807 sq. km in southern Brazil, 40,807 sq. km in the State of Santa Catarina (Klein, 1978). It is one of the most important tree species in southern Brazil because it generates high-value wood prodicts and has a cultural significance (Silveira, 2005).

The MOF occupies approximately 12% of its original area (Ribeiro et al., 2009). Several other tree arboreous species are usually predominant below its canopy strata, especially Myrtaceae and Lauraceae, and a high density of arborescent pteridophytes (*Dicksonia sellowiana* and *Alsophylla* sp.) and bamboos (*Merostachys* spp.) (Nascimento et al., 2001).

In the early 1900s, large areas of Brazilian pine forests were intensively exploited due to the commercial value of the Brazilian pine timber, and for extraction of its edible seeds (Oliveira et al., 2009, Mattos et al., 2011). The Brazilian federal government prohibited timber exploitation and any forest management practice on this species in the late 1970s (Hess et al., 2009; Diez, 2012). Thus, the lack of information on the growth of forests with Brazilian pine and the resilience of this species also contributed to the reduction, stagnation, and low diversity of the natural remnants of these forests (Hess et al., 2010; Beckert et al., 2014).

The current state and federal legislations require landowners in southern Brazil to maintain at least 20% of their rural properties area covered with natural forests, and places severe restrictions on their use. Although this restriction aims to prevent further deforestation, it creates an antagonism between forest protection and the landowner production, so that the regeneration of young *Araucaria angustifolia* (Brazilian pine) trees and other related species are preferable removed (Diez, 2012). Several landowners use the areas under the forest remnants for livestock grazing or remove seedlings and young trees to avoid their growth. The diversity, stability, and structure of the MOF remnants may be affected by the absence of a reasonable number of seedlings and young trees.

However, absence of intervention does not ensure the conservation of forests, since the tree growth tend to stagnate in its final cycles. It results in a lower natural regeneration index and, according to Sullivan and Sullivan (2016), it does not result in the establishment of structural attributes of primary forests.

Forest interventions are sometimes important and contribute to accelerate the forest succession (Bauhus et al., 2009). Unmanaged natural forests show stable production and growth, decreased diameter at the breast height (DBH) growth over time, low or nonexistent recruitment, competition, limited availability of resources, and high mortality rates, which may indicate a trend of extinction of this species (Beckert et al., 2014).

Therefore, the perpetuity of natural Brazilian pine forests depends on sustainable forest management mechanisms that require better information on their growth rates in different locations. Most of the growth data of commercial tree species used for growth and yield modeling in the tropics are obtained from permanent plots, especially when the forest species have no visible growth rings (Brienen and Zudeima, 2006). The main drawback of these modeling studies is the assumption of a deterministic growth, excluding the natural variability among individual trees, failing to estimate auto correlated growth rates (Brienen and Zudeima, 2006; Skovsgaard and Vanclay, 2008).

Brienen (2005) point out that assumptions and simplifications for growth and yield modeling can lead to unrealistic growth projections, underestimating the actual long-term growth of trees. The use of dendrochronology is an alternative to obtain individual growth rates and evaluate management practices. This is especially used for some tropical species in which the growth rings are visible (Mattos et al., 2011; Speer, 2010).

Information on the growth on the DBH rates is key for a sustainable forest management, allowing the review of historical increments and forecast DBH increments. It also allows the estimation of wood production and calculation of the harvesting time accurately (Skovsgaard and Vanclay, 2008; Braz et al., 2012). Moreover, this information also describes forest competition effects (Curto, 2015), which assists in establish better periods for silvicultural interventions (Santos et al., 2015), periods required for the restoration of the removed forest volume (Braz et al., 2014), forest relationships with the climate, and site index (Mattos et al., 2015), using simple models. These models assume that the forest production and dynamics is an effect of its age, site index and competition.

The objectives of this research were to measure the individual variability of DBH increment of Brazilian pine trees occurring naturally in three different sites in southern Brazil; fit the mean annual increment in DBH as a function of age and diameter; and evaluate the need of silvicultural intervention based on the accumulated DBH growth curves and current DBH increment rates, to predict the future diametric structure of Brazilian pine forests.

Results and discussions

Relationships of DBH increment with age and diameter

The analysis of covariance for the annual increment in diameter (*id*) as a function of the diameter (*DBH*) and age (*t*) showed a difference between levels (Φ_0 coefficient) and inclination (slope) of regression lines for *id* (Prob. <0.0001) for each study area (test site), and an interaction between *DBH**site and *t**site.

The results of the covariate analysis showed a linear effect, suggesting that the growth rates vary according to age (*t*) and diameter (*DBH*), with negative correlation between these variables (Table 1). According to the analysis of covariance, generating regressions was required for the DBH ratio increment-diameter and DBH increment-age in separate groups to explain the annual increment in DBH for each site (Table 1; Fig. 1).

The covariance showed that the DBH growth of Brazilian pine has high variability. This variability can be expressed by different equations for each study site (Fig. 1), indicating that there are differences in the accumulated DBH increment and in their respective slopes. Such differences are probably related to the site index, which combines the most important determinants of tree growth, such as topography, soil characteristics and regional climate (Skovsgaard and Vanclay, 2008). It also showed different forest growth (level) and productive capacity (slope) for each site.

In the equations, the coefficient $\Phi_0>0$ showed a less proportional increase of increment with increasing diameter (*DBH*) and age (*t*) (Fig. 1). The linear model prediction for the selected individuals indicated that growth was higher in DBH for young trees and slower for trees reaching maturity. A strong ontogenetic growth pattern was found, with decreasing growth rates with increasing diameter (*DBH*) and age (*t*). According to Preztsch and Dieler (2011), this decrease in the growth pattern in larger DBH is a consequence of competition among individuals, featuring a partial symmetry of growth-diameter relationship. According to these authors, this competition limits the use of underground resources such as water and soil nutrients. It also confirms the need of silvicultural interventions for a sustainable forest management of Brazilian pine in southern Brazil. Thus, this species has differences in DBH growth patterns and productive capacity according to the environmental resources available at each site.

The regression models showed decreasing growth rates (growth stagnation) in the last ten years, suggesting a need of silvicultural interventions to maintain the structure of the

Table 1. Model coefficients and statistical criteria for fit annual DBH increment (*id*) as a function of *DBH* and age (*t*) for the *Araucaria angustifolia* trees in three selected study areas in Santa Catarina, Brazil.

Site	Coefficients *id* (*d*)		Statistical criteria	
	Φ_0	Φ_1	S_{yx}	R^2adj.
SJQ	0.55406	-0.00369**DBH*		
URU	1.44149	-0.01295**DBH*	0.36	0.40
PNL	1.35450	-0.01440**DBH*		
Site	Coefficients *id* (*t*)		Statistical criteria	
	Φ_0	Φ_1	S_{yx}	R^2adj.
SJQ	0.52180	-0.00325**t*		
URU	1.42687	-0.02376**t*	0.31	0.53
PNL	1.21306	-0.01818**t*		

id = annual increase in diameter in cm; Φ_0 = intercept; Φ_1 = angular coefficient; Syx = standard error of the estimate; R^2adj. = Coefficient of determination adjusted; *DBH* = diameter at breast height; *t* = age. SJQ = São Joaquim; URU = Urupema; PNL = Painel.

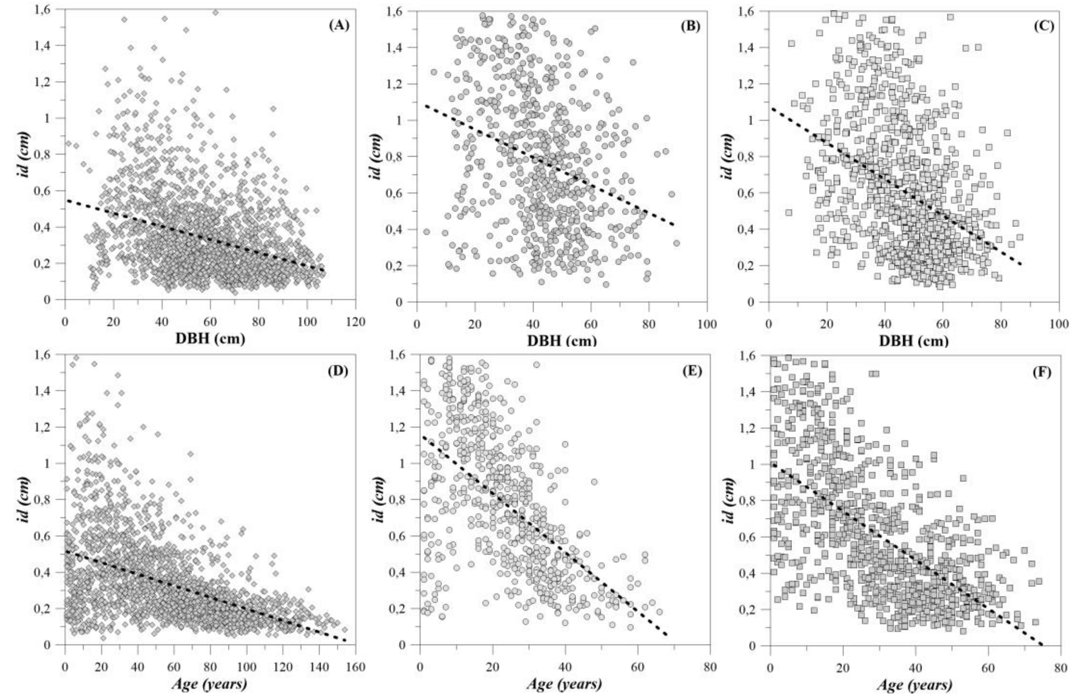


Fig 1. Linear adjustments of increment in diameter with size (*DBH*) (A, B and C) and age (*t*) (D, E and F) for *Araucaria angustifolia* environments in Santa Catarina, Brazil. *id* = annual increment in diameter; *DBH* = diameter at the breast height, *t* = age. Dotted lines indicate the regression lines. Each symbol indicates the increment at a given year. São Joaquim (A and D), Urupema (B and E), and Painel (C and E).

Table 2. Increment intervals and average DBH increment of 210 Brazilian pine trees in three selected study areas in Santa Catarina, Brazil.

DBH annual growth rates	Study Area		
	SJQ	PNL	URU
Minimum (cm.year^{-1})	0.036	0.068	0.069
Maximum (cm.year^{-1})	2.39	3.66	4.79
Average (cm.year^{-1})	0.34	0.68	0.90
Retrospective analysis (Years)	60 to 153	34 to 68	24 to 62

SJQ: São Joaquim; URU: Urupema; PNL: Painel.

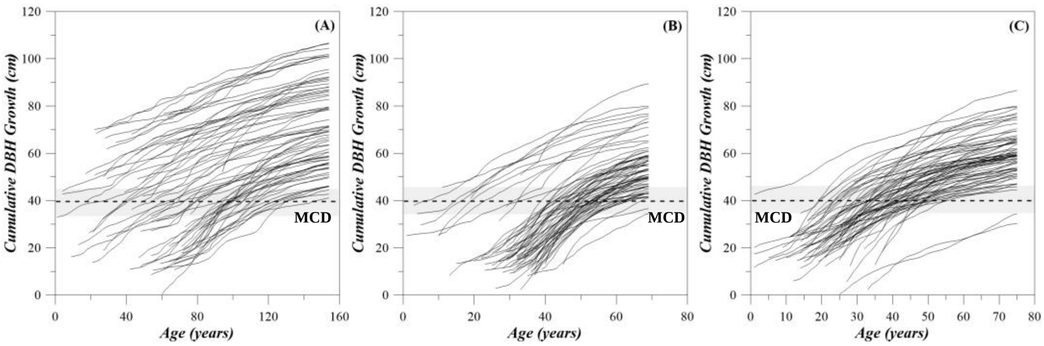
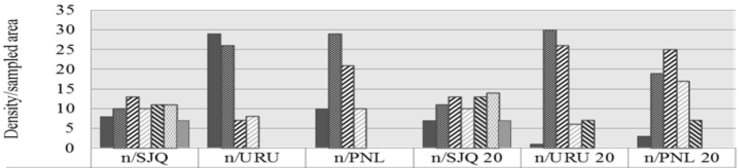


Fig 2. Accumulated diametric growth of *Araucaria angustifolia* trees in three selected study areas. São Joaquim (A), Urupema (B), Painel (C). Dotted lines indicate the minimum cutting diameter (MCD).

Table 3. Biometric measurements of 210 *Araucaria angustifolia* (Bertol.) Kuntze trees.

Biometric measurements	Study Area		
	SJQ	PNL	URU
Minimum tree height (m)	12.3	12.3	11.5
Maximum tree height (m)	25.1	22.6	22.8
Average tree height (m)	18.9	18.4	16.9
Minimum DBH (cm)	41.1	30.2	34.4
Maximum DBH (cm)	106.6	86.6	89.4
Average DBH (cm)	71.5	60.2	54.8
Sample area (ha)	4.1	4.3	2.2

DBH = diameter at the breast height. SJQ = São Joaquim; URU = Urupema; PNL = Painel



	n/SJQ	n/URU	n/PNL	n/SJQ 20	n/URU 20	n/PNL 20
40-49.9	8	29	10	7	1	3
50-59.9	10	26	29	11	30	19
60-69.9	13	7	21	13	26	25
70-79.9	10	8	10	10	6	17
80-89.9	11			13	7	7
90-99.9	11			14		
>100	7			7		

Fig 3. Estimates of the number of *Araucaria angustifolia* trees by diameter classes based on current rates of diameter at the breast height increment in three study areas in Santa Catarina, Brazil. n_1 = number of trees of a given diameter class; SJQ = São Joaquim; URU = Urupema; PNL = Painel; n_2 = number of trees with the diameter class after 20 years.

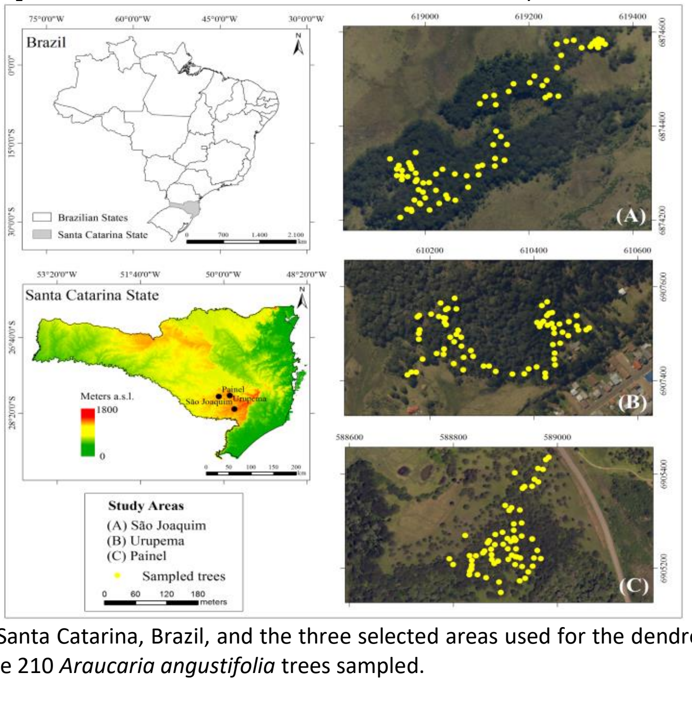


Fig 4. Location of the state of Santa Catarina, Brazil, and the three selected areas used for the dendrochronological studies. Yellow dots indicate the location of the 210 *Araucaria angustifolia* trees sampled.

native forests. Brienen and Zudeima (2006) and Rozendaal et al. (2010) pointed out that a forest management allows some trees to be harvested maintaining the natural dynamics of the forest, thus allowing the perpetuation of selected species. Methodologies considering silvicultural interventions have strong application for the Brazilian southern region, in which the Brazilian pine naturally occurs. Moreover, it would encourage landowners to grow Brazilian pine seedlings in their forest remnants, increasing their forest areas, which is currently occupied by pasture and *Pinus* spp. plantations. This increase in area would allow functional connectivity between isolated forest remnants from different small-scale rural properties.

The lack of silvicultural intervention in the last four decades caused young and intermediate diametrical classes of Brazilian pine trees to compete, reducing their growth potential and prevent them to reach their upper canopy stages, which may compromise the perpetuity of this species and the future of the forest structure. The competition and lack of silvicultural control of tree density may affect the natural dynamics of forests, causing changes in the structure and morphometry of plants, affecting the growth rates and development of new individuals. Medina-Macedo et al. (2016) pointed out that alternatives for conservation of this species must focus on forest remnants located on private properties rather than large conservation units. These authors reported that small forest fragments in southern Brazil that have Brazilian pine can maintain high levels of genetic diversity.

The forest age (*t*) and the diameter of its trees (*DBH*) affect the DBH increment. According to Pretzsch (1999), this effect can be described by the growth pattern of an individual tree. This pattern changes from a rapid growth, when the limitation by competition is null, to gradual decreases of vitality due to long-term depositions (Elling 1993), and then to great growth loss (Utschig 1989) or even dieback (Röhle 1987). In other words, the high growth decrease pattern when DBH increment is close to zero may compromise horizontal forest structures, since the trees may have not reached the minimum cutting diameter (MCD). However, low growth rate patterns are site-dependent and subject to considerable variations between sites (Pretzsch 2009).

The diameter-age increase in native forests is usually nonlinear, and affected by several local environmental factors (Pretzsch, 1999). Fig. 1 shows the dependence of the DBH increment on diameter (*DBH*) and age (*t*) when all other environmental variables are constant (Preztsch and Dieler, 2011). The distribution of the relative growth of different diameter (*DBH*) and age (*t*) is shown in the slope of the regression lines in Fig. 1. According to this figure, the DBH increment shows a partial symmetry with increasing diameter (*DBH*) and age (*t*), in which a stabilization or a stagnant growth pattern is noticed. Therefore, the analyzed bored trees showed that these trees had already reached their growth capacity in DBH (Pretzsch 1999).

Dendrochronology, growth curves, and technical rotation

The results of the dendrochronological analysis showed a high variability in DBH annual growth rates over time (Table 2). These increments confirm the results found by Mattos et al. (2007) and Hess et al. (2009). The results also present potential for a sustainable forest management of Brazilian pine trees, since this species can achieve relatively rapid large DBH, even with annual variations in increment, and lack of silvicultural interventions in the last 40 years in these three test sites due to the prohibitive legislation. The overall average increase was smaller in SJQ, since this site had a reasonable number of mature trees prior to the prohibitive legislation in the late 1970s.

The extracted increment rolls showed that the growth rings located near the bark were usually narrower than those closer to the trunk core. Considering the deep limitation of our thread increment borer (30 cm), some of the sampled trees were most probably over 200 years old. Trees in SJQ showed greater age and large DBH than those in URU and PNL. The individual DBH growth (40 to 100 cm) is shown in Fig. 2.

The age inflection and growth stagnation of the sampled Brazilian pine trees occurred when they were 35 to 45 years old. This time interval is usually related to the age of biological rotation in DBH (Hess et al., 2009). Generally, all DBH classes were stabilized, since reduced growth rates are noticed when trees reached their maximum support capacity, also known as law of diminishing returns. The expected DBH increment was smaller over time even with all available environmental resources (Rodriguez, 1991). According to Pretzsch (2009), the variation in growth inflection represents the different conditions in which each tree has grown, since intraspecific and interspecific competition, space, and availability of resources affect their development.

According to the analysis of the rings closer to the trunk core, the DBH increment was greater in the first years, despite ecological variations regarding site and climate differences. The large increments were found close and prior to the period of logging prohibition established in the late 1970s (Goulart Filho, 2002, Silveira 2005). The Brazilian pine increased more than 1.0 cm year^{-1} at early stages, despite the negative correlation in DBH increment (negative coefficient Φ_1). This increment allowed the trees to reach favorable growing conditions, reaching a MCD in 40 years. The monitoring of the growth rings of Brazilian pine trees showed the variation over their life cycle (Lopez et al., 2013), and proper DBH rates for adequate silvicultural interventions. The analysis of growth rings of trees is important to assess the increment history, which is expected to be similar to their future growth. The stability of the population size and distribution over the time, and regeneration is expected to be continuous and not erratic (Brienen and Zudeima, 2006).

The DBH increasing rates shown in Fig. 2 indicate that the Brazilian pine trees had an optimum harvesting diameter, with MCD of 40 cm. The time interval in which these trees can achieve this MCD is between 25 to 112 years, varying according to the study area, competition, and due to non-intervention in the forest. This range of age shows the growth rate variability of the Brazilian pine. However, suitable management mechanisms in selected sites with good site index may result in a fast achievement of this MCD. Therefore, a proper historical characterization of the DBH increment of each site must be considered when proposing a sustainable forest management protocol.

The average DBH increment in SJQ within the inflection period of the growth curve (45 years) was 0.51 cm year^{-1}, and 0.15 cm year^{-1} for the last 10 years (stagnation of the inflection curve). This result shows a decrease of 71% in the DBH increment rate. The DBH growth in the inflection period (35 years) in URU was 0.96 cm year^{-1}, and in PNL was 0.89 cm year^{-1}; and for the last 10 years, it was 0.49 cm year^{-1} (URU) and 0.34 cm year^{-1} (PNL), representing a reduction of 49% (URU) and 62% (PNL). The DBH increment rate, including all sites and the entire period evaluated, was 0.78 cm year^{-1}, and 0.33 cm year^{-1} for the last 10 years, representing a reduction of 58%. Thus, a single tree with an average DBH growth rate of 0.78 cm year^{-1} would need 51 years to achieve the MCD of 40cm.

The dendrochronological growth curve in Fig. 2 shows that trees with larger DBH require more time to reach upper diametric class intervals. Therefore, forest management is needed for individuals of lower and intermediate DBH classes to achieve more rapidly their maximum growth potential. Considering proper forest management practices and a minimum DBH increment rate of 1.0 cm year^{-1}, a tree would require 40 years to reach a MCD of 40 cm.

According to Brienen and Zudeima (2006), monitoring native forests with frequent measurements of DBH is needed. These measurements allow a better information on DBH increments, however, the exact time that a given forest will reach maturity cannot be forecasted due to the lack of recruitment and mortality rates of Brazilian pine trees. The forecast of DBH of the different diameter class intervals, considering the average rates of the DBH increment of each study area, for the last ten years are shown in Fig. 3.

Even with the low DBH growth rates found in the last 20 years, some trees migrated to upper diametric class intervals. However, this increase is smaller than the potential that this species must reach half of the MCD, since the increase in DBH reduces the growth rates. Therefore, silvicultural interventions in selected Brazilian pine trees may provide some profitability for local communities, and help the conservation of this endangered species. Porter-Bolland et al. (2012) analyzed 40 protected areas and 33 forest communities in 16 countries -11 in Latin America, three in Africa and two in Asia - and found that protected areas lost about 1.47% of vegetation cover per year, while forests that are managed by communities had a loss of about 0.24% per year.

Based on DBH increment estimates in the three selected study areas (0.78 to >1.00 cm year^{-1}), the period between two silvicultural interventions will be 20 to 26 years, considering that the remaining trees with diameter of ±20 cm can reach the MCD of 40 cm in the next cutting cycle. The results showed that most of the trees reached the MCD, showing inflection in the accumulated growth curve. Lacerda (2016) suggested that such characteristics are very similar to old-growth forests, which show very low DBH growth rates and do not have the diversity levels expected, indicating that young trees may not reach upper DBH classes anymore. The extraction of selected *A. angustifolia* trees through sustainable forest management would reduce the basal area and canopy coverage of forest remnants. Contrastingly, this reduction would lead to less competition between trees and allow young Brazilian pine trees to reach the MCD. The current state and federal legislations, from the local landowners' point of view, hinders the regeneration and development of young trees, which may compromise the future of these forest structures.

Materials and Methods

Study design

The study was conducted in three natural forest areas of Brazilian pine in southern Brazil, São Joaquim (SJQ), Urupema (URU) and Painel (PNL) (Fig. 4). The typology of these forests is Mixed Ombrophilous Forest, with Brazilian pine as predominant species in the dominant canopy strata. The region has climate Cfb, according to the Köppen classification, constantly humid temperate, with summer without dry season; annual average temperature of 13.8 to 15.8°C; total annual rainfall of 1,360 to 1,600 mm, evenly distributed throughout the year; and relative humidity of 80% to 83% (Epagri, 2002).

Seventy Brazilian pine trees were selected in each area, totaling 210 trees (Table 3), and a total of 14,151 chronological series of DBH increment were evaluated. The trees were selected according to a minimum cutting diameter (MCD) of 40 cm. The location of the trees was assessed by a handheld GPS (Garmin II). Each tree had its diameter at breast height (DBH) and total height measured. Two increment rolls from each tree were extracted perpendicularly to the diameter breast height (DBH) with a thread increment borer of 30 cm (Pressler Sounder) (Assmann, 1970). The increment cores were carefully sanded and their rings were marked. The ages were assessed by counting the rings. The width of the rings was measured, and the annual increment in DBH was assessed using a digital measuring device (Lintab-6) which has accuracy of 0.0001 mm and is supported by a software for time series analysis and presentation (TSAP-Win) (Schöngart et al., 2005).

Statistical analysis

Data analysis was performed using the Time Series Analysis Program (TSAP-Win) with cross-dating procedure (Rinn Tech, 2010). The increment data were subjected to analysis of covariance to test whether the slopes and levels differ significantly between the study areas (Kaps and Lamberson, 2004), i.e., the differences in growth patterns and productive capacity.

The increment in DBH and its variability was considered a dependent variable that explains aspects of the site index (Schneider et al., 2009). Contrastingly, the DBH and age were considered continuous independent variables. The applied model proposed by Kaps and Lamberson (2004), including the group effect and simple linear regression is shown in Eq. 1.

$$y_{ij} = \beta_0 + \tau_i + \beta_1 x_{ij} + \sum_i \beta_{2i} (\tau * x)_{ij} + \varepsilon_{ij,}\ i = 1, \dots, a;\ j = 1, \dots, n; \qquad \text{Eq. 1}$$

Wherein; y_{ij} is the observation j in the group i; τ_i is the effect of the group i; β_0, β_1 and β_{2i} is the regression parameters; x_{ij} is the value of the continuous independent variable for observation j in the group i; (τ*x)ij is the interaction group-covariate; and ε_{ij} is the random error.

The average annual increment in DBH (id) for each tree was fitted to the diameter (DBH) and age (t) according to the equations 2 and 3.

$id = \Phi_0 + \Phi_1 * DBH$

Eq. 2

$id = \Phi_0 + \Phi_1 * t$

Eq. 3

All data analysis was performed using the SAS 9.3 software (*Statistic Analysis System*) (SAS Institute Inc., 2012). The model residuals did not show any violation of the regression conditions (normality, and homogeneity of variance). The growth curves were developed after the cross-dating analysis, and the age of biological rotation in DBH for forest management was obtained. Differences in cumulative diameter growth rate were assessed by calculating the DBH average, minimum and maximum of selected intervals. The cumulative diameter growth curves were developed using the measured values acquired with the thread increment borer.

The diameter forecasting for 20 years was carried out by adding the average increment in DBH from the last ten years (imd10). The weighted average was added for the selected DBH class intervals for each site. The number of trees with a certain DBH class interval after 20 years (ncd_{i20}) was calculated by adding the number of remaining trees in the class (ncd_{ir}) and the number of trees that had migrated from the previous class interval (ncd_{im}) (equation 4);

$\mathrm{ncd_{i20}} = \mathrm{ncd_{ir}} + \mathrm{ncd_{im}}$

Eq. 4

While, the number of trees of the former class comprised trees that did not migrate to next classes.

Conclusion

The results found in the study (variability analysis of the annual increment in DBH, fit functions of the increment in time, growth form and increment rate) show a clear need of silvicultural interventions. Under current conditions, without applying any forest management practice, there is a risk in maintaining and forming the future diametric structure of the Araucaria Forests. The results also confirmed that the restrictive legislation is not sufficient to ensure the conservation of this endangered species. This is due to the decrease and stagnation of the growth rates in DBH noticed in all selected study areas. The accumulated growth curves in DBH can be used to assess the biological rotation point of this species. Planned interventions in natural forest remnants can result in better growth rates, natural regeneration, and conservation of species.

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