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DIAMETRIC SITE INDEX: AN ALTERNATIVE METHOD TO ESTIMATE SITE QUALITY IN *Nothofagus obliqua* AND *N. alpina* FORESTS

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ABSTRACT: The first step for constructing models of tree growth and yield is site quality assessment. To estimate this attribute, several methodologies are available in which site index (SI) is a standard one. However, this approach, that uses height at a reference age of trees, can be simplified if age is replaced by another reference variable easier to measure. In this case, the diametric site index (DSI) represents the mean height of dominant trees at a reference mean diameter at breast height. The aim of this work was to develop DSI in pure and mixed *Nothofagus alpina* and *N. obliqua* forests, and compare these models with the classical proposals based on height-age variables, within the temperate forest of northwestern Patagonia from Argentina, South America. Data originated from temporary plots and stem analyses were used. Tree age and diameter at breast height were obtained from each plot and used for establishing DSI family functions, following the guide-curve methodology. Site classes were proportionally represented among DSI curves of 17.0, 21.5, 26.0, 30.5 and 35.0 m of dominant tree height. Reference diameter instead of reference age can be cautiously used in order to fit site index models.

ÍNDICE DE SÍTIO DIAMÉTRICO: UM MÉTODO ALTERNATIVO PARA ESTIMAR A QUALIDADE DO SÍTIO EM FLORESTAS DE *Nothofagus obliqua* E *N. alpina*

RESUMO: primeiro passo para a construção de modelos de crescimento e produção de árvores e a avaliação da qualidade do sítio. Para estimar este atributo, várias metodologias estão disponíveis, na qual o índice de sítio (IS) é padrão. No entanto, esta abordagem, que utiliza uma altura na idade de referência, pode ser simplificada se a idade é substituída por outra variável de referência mais fácil de medir. Neste caso, o índice de índice de sítio diamétrico (ISD) representa a altura média das árvores dominantes de um diâmetro à altura do peito referência. O objetivo deste trabalho foi desenvolver ISD para florestas puras e mistas de *Nothofagus alpina* e *N. obliqua*, e comparar esses modelos com as propostas clássicas baseadas nas variáveis altura-idade, para a floresta temperada do noroeste da Patagônia da Argentina, América do Sul. Dados provenientes de parcelas temporárias e análises de tronco foram utilizados. Foram obtidos idade e diâmetro à altura do peito de cada parcela e utilizados para o estabelecimento das funções da família DSI, seguindo a metodologia da curva-guia. Classes de sítio foram proporcionalmente representados entre curvas DSI de 17,0; 21,5; 26,0; 30,5 e 35,0 m de altura da árvore dominante. O diâmetro de referência em vez da idade de referência pode ser usado com cautela para ajustar modelos de índice de sítio.

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INTRODUCTION

Forest stand productivity is largely defined as site quality which expresses the growth potential of the species, and it is influenced mainly by forest soils (SKOVSGAARD and VANCLAY, 2008; AVERY and BURKHART, 2015). It is not possible to make reliable decisions without silvicultural references, as site quality and other stand conditions and variables which directly influences tree growth (DANIEL et al., 1982). For this, the study of site quality is the first necessary step for the construction of growth and yield models (ARIAS-RODIL et al., 2015), which are essential in forest management and planning to determine the productive goals (RETSLAFF et al., 2015).

Biometric variables that influence tree growth are innumerable, thus forest models must be abstractions of reality (HARI, 1996) to simplify the complexity of the system for the modeling purposes and the subsequent practical uses (GARCÍA, 1988; BLANCO et al., 2015). Different methodologies exist to determine site quality according to employed biometric variables, and one of the most used methods for regular stands are based on indirect parameters using the average dominant height of the stand (BINOTI et al., 2012). Dominant height (h_{dom}) growth is considered one of the best indicators, it is possible to relate it with the productivity of each site (MONSERUD, 1984), and in addition be correlated with growth in volume (DONOSO, 1981) with scarce influence of tree density within a wide range of conditions (DANIEL et al., 1982; AVERY and BURKHART, 2015).

However, in uneven-aged stands, the use of the dominant tree height as an indicator of site quality is complicated by the structural variability of the stands. In these stands, trees have periods of oppression and liberation at younger ages, impossible to determine in individual trees at mature ages, generating irregular or polymorphs growth patterns along the years. Also, there is difficulty to identifying tree ages at field, a costly task (ARIAS-RODIL et al., 2015), making it advisable to try other options than the classic growth equation proposals (ZEIDE, 1993; ARIAS-RODIL et al., 2015). The use of classical site index (SI) methods requires the measuring of h_{dom} at a reference age, and this can be facilitated if age can be replaced with another reference variable. If we consider other volume increase components, the diameter at breast height (DBH) is the second variable in importance. The growth pattern of this variable was considered as more sensible than h_{dom} growth to changes in environmental factors (CORNELIUS, 1994), such as tree density.

However, it is possible to propose the hypothesis that within the lifespan of trees under natural dynamics in uneven-aged stands, the DBH growth of dominant trees are not strongly affected, then it can be proposed the use the H-DBH instead h_{dom} -age variables (BAKUZIS, 1969; HUANG; TITUS, 1993). Thus, site index can be defined as the average height of dominant trees with an average reference DBH, rather than employing tree age, resulting in a diametric site index (DSI) that expresses the potential productivity of a stand, just as the classic proposal of SI.

Several authors propose different models for *Nothofagus* forests in Patagonia region of Argentina and Chile, always using SI based on h_{dom} -age variables. Polymorphic models were proposed for *N. pumilio* (Poepp. et Endl.) Krasser (MARTÍNEZ PASTUR et al., 1997), *N. antarctica* (Forster F.) Oersted (LENCINAS et al., 2002; IVANCICH et al., 2011) and *N. dombeyi* (Mirb.) Oerst (ESSE et al., 2007; 2014) to estimate SI, and many of them were incorporated into different biometric models (e.g. MARTÍNEZ PASTUR et al., 2002; 2008; ATTIS BELTRÁN et al., 2013; IVANCICH et al., 2014). Other studies developed anamorphic models for *N. alpina* Poepp. et Endl. = *N. nervosa* Phill (Dim. et Mil.) (raulí) and *N. obliqua* (Mirb.) Oerst, and proposed a mixed model for both species based on the similarity of their growth patterns (ATTIS BELTRÁN et al., 2015). All these studies highlight the inconvenience of age estimation in the field, where some of them propose to estimate this variable using the tree bark as indicator of the growth stage or age class (e.g. MARTÍNEZ PASTUR, 2006; IVANCICH, 2013). However, the use of DBH instead of bark can be a valid alternative for more accurate and practical uses in the forest management and planning. For this, the aim of this work was to develop DSI in pure and mixed, *Nothofagus alpina* and *N. obliqua* forests, and compare these models with the classical proposals based on h_{dom} -age variables developed by Attis Beltrán et al. (2015).

METHODS

Study area

The natural area of distribution of *Nothofagus obliqua* is located between 33.0° and 41.5° SL, while *N. alpina* covers a slightly narrower latitudinal range between 35.0° and 40.5° SL (DONOSO et al., 1993; SALAS; GARCÍA, 2006). The sampling was performed within the watershed of Lácar and Nonthué lakes (40°07' SL and 71°27' WL to 40°07' SL and 71°39' WL) covering an area of 1,500 ha, where forest management

of the National Reserve of Lanin National Park was conducted (Neuquén Province, Argentina). The forests were dominated by pure or mixed *Nothofagus* forest types located between 600 and 1,100 m.a.s.l. (CHAUCHARD; SBRANCIA, 2003). Climate is humid with annual temperatures of 9°C and rainfall close to 1,800 mm.year⁻¹. The region was shaped by glaciers and later during the Holocene covered by volcanic ash (MERCER, 1976), generating the dominant soils belonging to Andisol order. Soils presented a sequence of O-A-Bw-C horizons or sequences of these horizons due to successive ash deposits which resulted in buried soils (FERRER et al., 1991; FRUGONI et al., 2005).

Data taking

Samples were taken from pure and/or mixed even-aged mature (>150 years old) *N. alpina* and *N. obliqua* stands, with complete overstory cover (>90% without recent human intervention and without presence of large gaps) and with one dominant stratum (a stratum of upper crown and uniform with a normal and narrow diameter distribution). Two samplings were conducted:

(1) Data from temporary plots: We selected stands (n=60) covering the dominant height (10 to 40 m) and rainfall (1,500 to 2,500 mm.year⁻¹) gradients in the study area. We established plots of 500 m², measuring the DBH, H, species and social stratum of each tree. The plots should have a dominant tree generation. In each plot, we measured one to five dominant trees, which represent 20 to 100 dominant trees per hectare. We use these trees to evaluate the dominant height variation, increasing the number of trees if the variation was greater than ±1.5 m.

(2) Data from stem analysis: A total of 17 individuals of *N. alpina* and 21 of *N. obliqua* were cut for destructive sampling. Prior to cuts, dominance of each tree was evaluated by the relative size of indicative variables comparing them with the neighbor trees. The following indicative variables were used: (i) H with laser hypsometer (VL5360 model, Haglöf, Sweden), (ii) DBH (average of two measurements at 90°) with forest caliper, and (iii) crown characteristics, where individual crown must be balanced in size and shape, and lateral growth must represent 25-40% of H as an indicator of competition with the neighbor trees. Trees with greater values and lateral branch presence were considered as free growth trees and were avoided from the sampling. Only trees originated by seed were selected for the samplings, avoiding coppice strain trees, identified as individuals with great buttresses at the base of the trunk.

Wood slices were extracted from the harvested trees at 0.30 m, 1.30 m, 3.30 m, and every 3.00 m to the tree apex following the main stem. Northern aspect of each slice was identified for the measurements at laboratory. Prior to counting and measurement of growth tree-rings, we proceeded to sanding the slices, starting with coarse-grained (80) and gradually reach to fine-grained (360) sandpapers. With ages and diameters at different heights, we built tree profiles for five-year periods. For the last period of growth, at the apex area, profiles were completed by the graphical method, following the profile trend (CHAUCHARD, 2001).

Modelling

First, a graph of average dominant DBH (obtained from 55 permanent plots) based on the stand density index (SDI) (CHAUCHARD et al., 1999) was made to assess the impact of stand density in each species diameters. And then, we examined the number of trees that can be measured per plot to obtain reliable field-work data. The differences between dominant height of 100 trees per hectare (5 per plot of 500 m²), dominant height of 80 trees per hectare (4 per plot of 500 m²), dominant height of 60 trees per hectare (3 per plot of 500 m²), dominant height of 40 trees per hectare (2 per plot of 500 m²), and dominant height of 20 trees per hectare (1 per plot of 500 m²), were examined in a graphic of dominant height vs. number of trees per plot.

Data pairs of h_{dom} -DBH were obtained from each plot (sampling 1) and from tree profiles (sampling 2), and were used for setting the family of DSI functions. For construction of a family of dominant height curves based on the average DBH, we proceeded according to the guide curve methodology (CLUTTER et al., 1983; BINOTI et al., 2012; RETSLAFF et al., 2015). For this purpose, the nonlinear function usually known as Chapman-Richards was used [1], which belongs to the so called biological functions, for their demonstrated flexibility for studies related to growth phenomenon (RICHARDS, 1959; OSUMI, 1983; VANCLAY, 1994; MARTÍNEZ PASTUR et al., 1997; CHAUCHARD, 2001; CARRERO et al., 2008; IVANCICH et al., 2011; ATTIS BELTRÁN et al., 2015; DO AMARAL MACHADO et al., 2015; OLIVEIRA et al., 2015). Where h_{dom} : dominant height; a: parameter related to the asymptote of the function; b: parameter related to the rate of change; c: parameter linked to the inflection point; Da: average DBH.

$$h_{dom} = a(1 - \exp(-b \cdot Da)) \quad [1]$$

$$DSI = a(1 - \exp(-b \cdot Dr))^c \quad [2]$$

With the database, we defined two data groups, one for *N. alpina* and another for *N. obliqua*, and Equation 1 was fitted to the data pairs of each species (h_{dom} -DBH), constituting two guide curves.

In the present proposal, the DBH will be the reference, so h_{dom} of Equation 1 will be replaced by the diametric site index (DSI) (Equation 2), therefore: where DSI: diametric site index; *Dr*: reference average DBH; a, b and c: parameters.

For the generation of the family proportional curves or anamorphic curves, we applied a mathematical conversion between Equations (1) and (2) to obtain an invariant single equation between (Equation 3) the dominant height and DSI (Equation 4).

$$\frac{H_{dom}}{DSI} = \frac{a(1 - \exp(-b \cdot Da))^c}{a(1 - \exp(-b \cdot Dr))^c} \quad [3]$$

Solving for DSI as,

$$DSI = \frac{H_{dom}}{(1 - \exp(-b \cdot Da))^c} \cdot (1 - \exp(-b \cdot Dr))^c \quad [4]$$

To evaluate the goodness of fit we used: (i) standard error of the estimation (SEE), (ii) mean absolute error (MAE), (iii) residual distribution, and (iv) graphical goodness of the guide curve which represent the trend of the point cloud and the biological significance of the parameters.

With the outputs of Equation (4) it is possible to define site quality classes based on DSI constant ranges. We compare the models of each tree species, analyzing the goodness of fit parameters and graphical behaviors. This allowed us to analyze the chance to develop a single model for both species. We established the DSI and SI as proposed by Attis Beltrán et al. (2015) for trees that we performed stem analysis, and compared the correspondence to classify the site class of each dominant tree. Equations were fitted to explain the variation of the DSI as a function of SI, which they were evaluated by the coefficient of determination (r^2), SEE and MAE. Finally, the behavior of the variable SI was studied as a function of fixed diameters (20, 25, 30 and 35 cm) and age according to stem analysis data.

RESULTS

Data base characterization

A constant trend of *Da* (Average DBH) through different stand densities (using SDI index) was found

(Figure 1), which was obtained using the criteria of the proposed methodology.

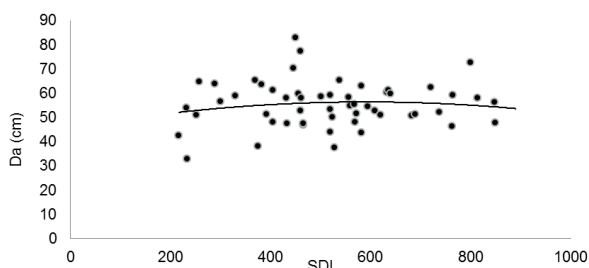


FIGURE 1 Relations between average DBH (*Da*) and Stand density index (SDI).

We defined that 3 trees can be measured per plot to obtain reliable field-work data. Average h_{dom} slightly decrease when increasing the number of dominant trees for each plot, however, the decrease in the average between three and five dominant trees was considered acceptable, in the range of $\pm 3.5\%$ (Figure 2). In order to have a consistent average h_{dom} and DBH values, dominant trees of the same cohort or same age class must be selected, and the closer the measured trees are to mature phases, the more reliable will be the site class estimation. The differences between dominant height of 100 trees per hectare (5 per plots of 500 ha) and dominant height of 60 trees per hectare (3 plots of 500 ha) are within the range mentioned (Table 1).

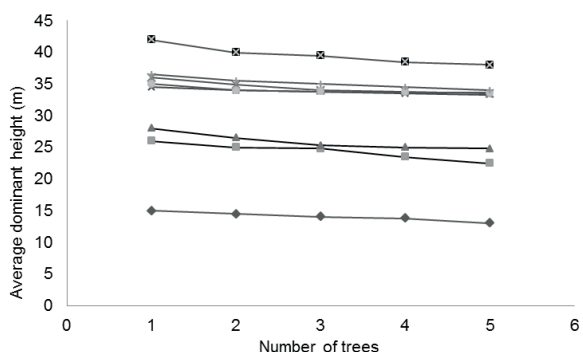


FIGURE 2 Changes in the dominant height value according to the number of measured trees considered in each temporary plot.

TABLE I Comparison between the average of 100 and 60 dominant heights per hectare (h_{dom}), and the absolute differences, resulting in an average underestimation of 3.5%.

h_{dom} 60	h_{dom} 100	Difference
[m]	[m]	[m]
15.0	14.5	0.5
20.0	19.3	0.7
25.0	24.1	0.9
30.0	29.0	1.1
35.0	33.8	1.2
40.0	38.6	1.4

The plots database was composed of 237 h_{dom} -DBH points of both species (*N. alpina* 90; *N. obliqua* 147). The average DBH of *N. alpina* was 48.2 cm (min: 9.5 cm; max 129.0 cm), and the average DBH of *N. obliqua* was 52.5 cm (min: 8.7 cm; max 162.0 cm). The average h_{dom} of *N. alpina* was 24.1 cm (min: 8.3 cm; max 41.0 cm), and the average h_{dom} of *N. obliqua* was 25.4 cm (min: 8.4 cm; max 44.5 cm). These data present a similar distribution in a two-dimensional graph (Figure 3a). Stem analysis database was composed of 131 height-DBH points of 17 *N. alpina* (62 data points) and 21 *N. obliqua* (69 data points). The average h_{dom} of *N. alpina* was 17.6 cm (min: 13.0 cm; max 23.7 cm), and the average h_{dom} of *N. obliqua* was 18.8 cm (min: 10.7 cm; max 30.2 cm). The average age of *N. alpina* was 58.5 years (min: 39 years; max 87 years), and the average age of *N. obliqua* was 62.7 years (min: 37 years; max 115 years) (Figure 3b). The data of the stem analyses allowed to incorporate not only h_{dom} -DBH data pairs, but also allowed to incorporate h_{dom} -age data pairs. The data for each tree were defined for different DBH baseline: 20, 25, 30 and 35 cm DBH, and also to obtain h_{dom} -age when dominant trees had these DBH.

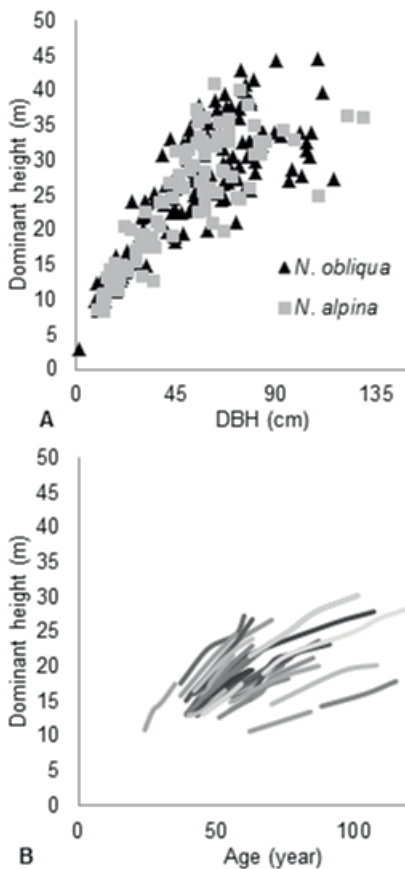


FIGURE 3 A: Representation of h_{dom} -DBH pair plots obtained from temporary plots. B: Representation of the h_{dom} -age data obtained from stem analysis. Both graphs included the two studied species: *Nothofagus obliqua* and *N. alpina*.

Evaluation and performance of the fitted models

The three models obtained with the Chapman-Richards equation (*N. alpina*, *N. obliqua* and mixed) presented acceptable and comparable metrics (Table 2) with no evident differences among the estimated parameters. Graphical representation of the three models denotes good biological behavior, being very similar between species and this behavior was well represented in the mixed species model (Figure 4). In the residual analyses, similar trends among the three models were observed (Figure 5).

According to the obtained results, we decided to employ the model of both species (mixed model), which allowed the use of one equation for both species (*N. obliqua* and *N. alpina*), simplifying application for managers and decision makers.

TABLE 2 Parameters (a, b and c) and adjustment goodness of fit metrics for the three models: coefficient of determination (r^2), standard error of estimation (SEE) and mean absolute error (MAE).

Model	a	b	c	r^2 (%)	SEE	MAE
<i>N. alpina</i>	39.17	0.02730	1.200	73.71	4.04	3.16
<i>N. obliqua</i>	38.03	0.03060	1.280	68.88	4.50	3.79
mixed	39.28	0.02710	1.190	70.99	4.21	3.49

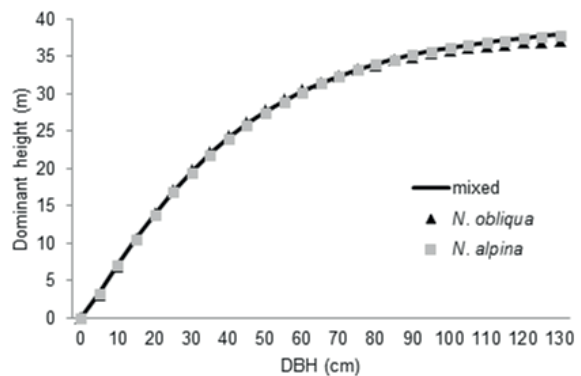


FIGURE 4 Chapman-Richards models fitted for *Nothofagus alpina*, *N. obliqua* and for both species (mixed model).

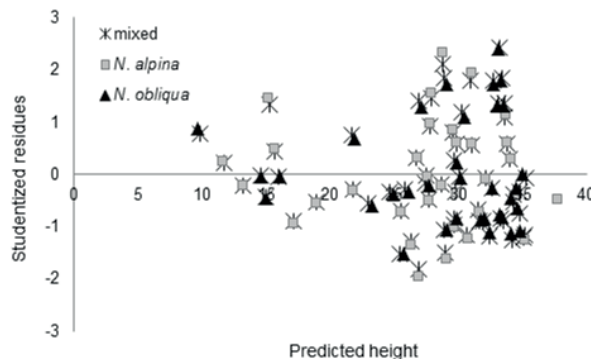


FIGURE 5 Residuals of the adjusted fitted models: *Nothofagus alpina*, *N. obliqua* and for both species (mixed model).

As reference diameter, Da 45 cm was chosen, compatible with the development phase and the average diameter expected for the rotation term of the proposed management (CHAUCHARD et al., 2012). For this, when Da reached 45 cm, the dominant height in function [6] represent the DSI. Where: DSI: diametric site index.

$$DSI = 39.28(1 - \exp(-0.02711 \cdot 45))^{1.187} \quad [5]$$

After that, we obtain the ratio between expressions [5] and [6]:

$$\frac{H_{dom}}{DSI} = \frac{39.28(1 - \exp(-0.02711 \cdot Da))^{1.187}}{39.28(1 - \exp(-0.02711 \cdot 45))^{1.187}} \quad [6]$$

And the resolution of this ratio can be expressed as equation [7]:

$$DSI = \frac{H}{(1 - \exp(-0.02711 \cdot Da))^{1.187}}(1 - \exp(-0.02711 \cdot 45))^{1.187} \quad [7]$$

Based on the constant proportionality principle (PRODAN et al., 1997) and assigning the reference diameter (45 cm), average DSI was conceived at approximately 26 meters. Then, a 4.5 m range of heights was designated for the different site qualities. Thus, site classes will be represented proportionally between the DSI curves 17.0, 21.5, 26.0, 30.5 and 35.0 m of dominant height (Figure 6). The curves family obtained with the DSI model [7] data covering the entire range of class sites.

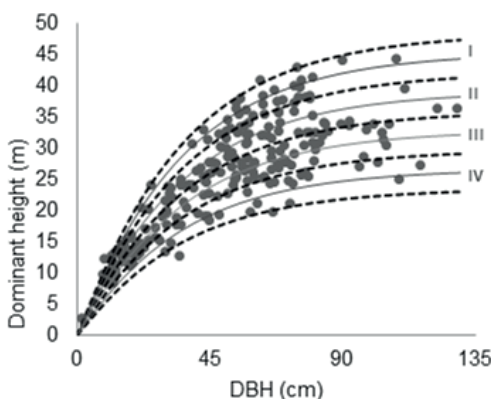


FIGURE 6 DSI family curves for the mixed model (*Nothofagus alpina* and *N. obliqua*) and hdom-DBH data. The curves belong to the 17.0 m, 21.5 m, 26.0 m, 30.5 m and 35.0 m DSI defining the different classes (I = 30.5-35.0 m, II = 26.0-30.5 m, III = 21.5-26.0 m, IV = 17.0-21.5 m).

Comparisons and relationships between DSI and SI

When data of stem analysis were classified according DSI and SI, 85% of them, matched (n =

119) the proposed site classes. The remaining 15% site classes determined by both methods were contiguous with the exception of two data pairs of *N. obliqua*. The fitted model [8] relate the DSI and SI, and indicated a significant relationship between the two indices (Figure 7). The obtained function has the following equation [8]:

$$SI = 0.60 \cdot DSI - 0.52 \quad [8]$$

r²: 57.39%, SEE: 1.67, MAE: 1.34 (p < 0.0001)

We also found a clear relationship between the diameter of the dominant trees and SI and age variables (Figure 8). The trend between SI and age remains constant through the different diameter classes previously established (20, 25, 30 and 35 cm), indicating that upper limit of diameter growth of dominant trees is related to height growth, so higher diameters will be found at higher site qualities.

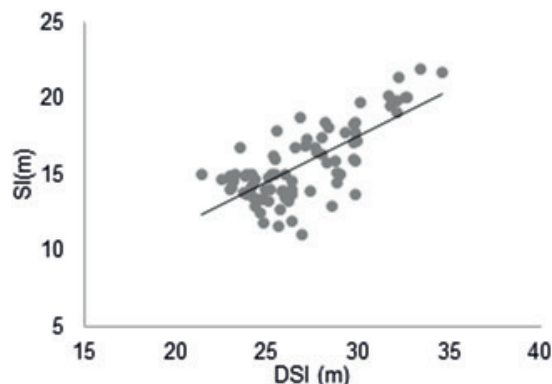


FIGURE 7 Relationship between DSI and SI.

DISCUSSION

Reference diameter was tested for use instead of the reference age in the construction of a site index model. A constant trend of Da (obtained according to the described methodology) through different densities (using SDI index) allowed to use the reference diameter to develop the DSI, supporting the hypothesis that diameter growth of dominant trees was not greatly affected (Figure 1) in a wide range of densities in forests growing under a natural dynamic (BAKUZIS, 1969; HUANG; TITUS, 1993). We tested the number of trees needed to measure to determine the reference value of the stand, as the dominant height was used in the traditional models. The costs of forest inventories are directly related to the amount of data to be taken at field and the difficulty of the methodologies to obtain those variables (LENCINAS et al., 2002). Usually, site index is related to dominant height, and dominant height is defined as the average of 100 tallest trees per hectare.

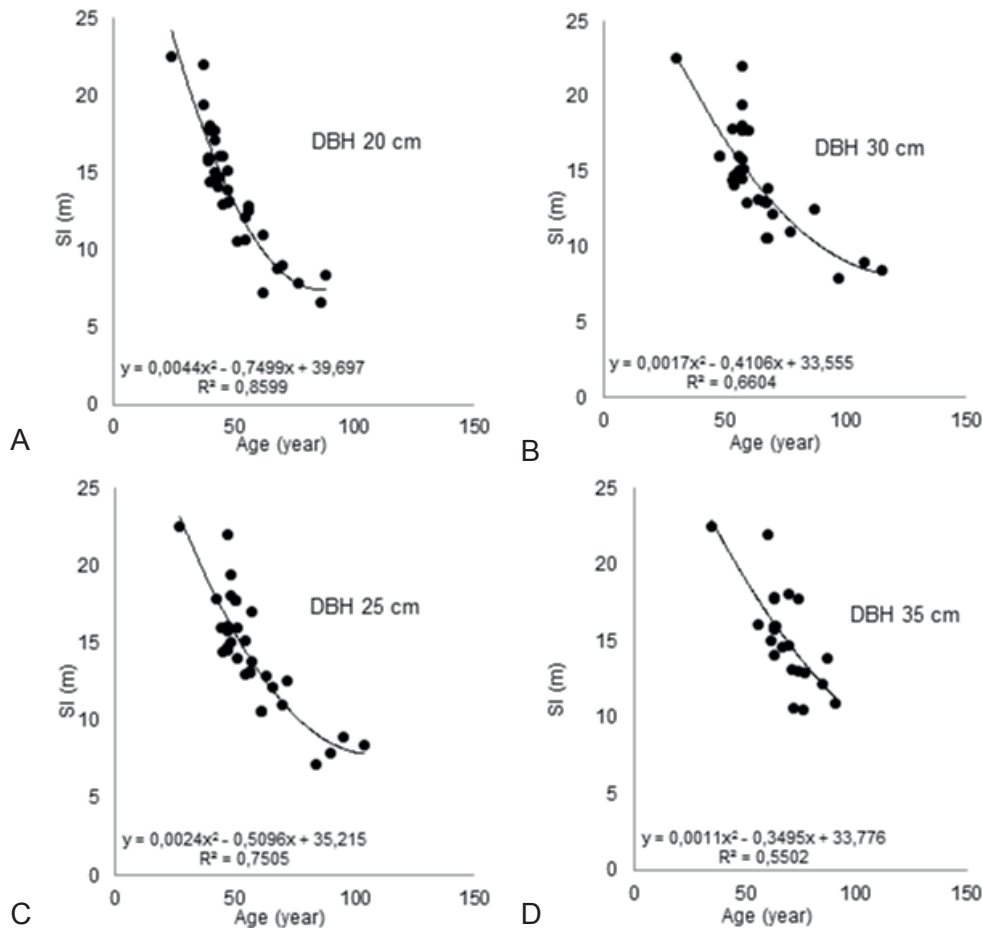


FIGURE 8 Relations between SI, DBH and age.

If we know how many trees below this number can be measured without significantly changing the final output, we can decrease the cost of dominant height estimation (Table 1). The correct quantification of tree height is essential, especially used to calculate volume of timber stands and classify productivity (MOREIRA et al., 2015). Beside this, if we can use the diameter instead the dominant height, we can further decrease the costs of estimating site quality using DSI.

Trees chosen for height and diameter indexes must belong to the dominant generation of the forest structure of the studied stand, which usually belong to mature phase (CHAUCHARD et al., 1999). Measurement in an overripe phase should be avoided, over-mature trees can significantly positively weigh on diameter relationships resulting in an underestimation of the site quality; also over-mature trees generally have reduced total height by breaking the apex or due to self-decay process of age. Although it is not common to find trees with large buttresses, indication of an asexual origin, in this study these trees were avoided because it

is unknown if there are differences in growth patterns between trees originated by seed and agamic origins (HAWLEY; SMITH, 1972). The methodology employed here to determine the origin of trees, as differences or similarities in the growth pattern of natural trees, should be better studied and tested for future studies, including recent studies in tree architecture and growth-unit structure (e.g. PUNTIERI; GHIRARDI 2010; PUNTIERI et al., 2013).

A close similarity was observed between the outputs of our model fitted for each species and mixed species model, and those presented by Attis Beltran et al. (2015) in the fitting of SI curves for *N. alpina* and *N. obliqua*. The residual graph showed that estimation errors for each observation through the mixed species model compared to models of each species are randomly distributed, which indicated that there is not a marked overestimation or underestimation. Due to the mixed species model having showed good statistics and biological behavior for *N. alpina* and *N. obliqua*, as was cited before by Attis Beltran et al. (2015), we decide to

continue working with the mixed species model without considering the individual species models.

Usually, for models such as Chapman-Richards, the biological behavior is equally important to the goodness of fit metrics (IVANCICH et al., 2011). Dominant height growth of *N. alpina* and *N. obliqua* above 70-80 cm of DBH should be very small, since at least 1% of the dominant generation can overcome the DBH of 80 cm, so all height growth curves should have a plateau relative to this diameter (CHAUCHARD, 1991; CHAUCHARD; SBRANCIA, 2003). Although the statistical and biological setting is very good, the plateau of our function appear later than expected (DBH 90-100 cm), however an indicator of fitting was the estimation of parameter “a” which represents the asymptote function of the value. If we compare our model with those presented before, in the range of heights of these forests (15 to 50 m), the average value of 36 m determines the logic behavior of the function (SALAS; GARCÍA, 2006; ATTIS BELTRÁN et al., 2015). The differences among the site classes obtained through IS and DSI can be explained thorough the employed methodology in each case, and may be due to the fact that DSI classes were not obtained from the diameter averages and were obtained from the individual DBH of the stem tree analyses. In fact, this could affect those points that had not coincided in the site classifications.

The fitted model [8] (Figure 7) showed the correlation between the two developed indices, where DSI and SI presented a strong relationship. It is well known that DBH is more affected than h_{dom} by density (DANIEL et al., 1982). In these forests, diameter growth of dominant trees were not greatly affected by density, and suppressed trees mainly reduce their diameter growth due to competition or other biotic factors (e.g. diseases) (Attis Beltrán et al., 2013). This assumption about the growth of dominant trees support the use of the average reference diameter for these *Nothofagus* species, and must be tested for other forest types.

Relations among SI, DBH and age were presented in Figure 8, which support the proposal of use of average reference diameter instead of a reference age. In this graph it is possible to see that trees growing in better SI achieve early the same reference DBH, e.g. both small (30 cm) and large trees (45 cm) close to the reference diameter. Based on the mentioned relationships between h_{dom} , DBH and age, Huang and Titus (1993) developed relations of SI using diameter-height ratios for *Picea glauca* (Moench) Voss, *Pinus contorta* Dougl., *Populus tremuloides* Michx. and *Picea mariana* (Mill.) B.S.P., and using the average indices for each species they obtained one index for the mixed forests. In our study, through

the fitting of both species and the similar growth patterns between *N. alpina* and *N. obliqua*, a DSI for mixed forests was developed without mixing the average values of both pure forests.

Using the DSI (reference diameter) has remarkable advantages over the use of traditional SI (reference age) because age is a very expensive and highly difficult data to measure in natural forests. The disadvantage of DSI versus traditional SI is that the first method requires a proper choice of trees for measurements, with much subjectivity which can result in undesirable structural variability of field data. Beyond the advantages and disadvantages of the method, DSI consistently determines the relationship between average diameter and height of dominant trees along the site quality gradient.

DSI is a method designed to facilitate the work of managers, due to the fast site class classification of stands in the field. It is an indispensable management tool for future forest planning in the Lanin National Park. DSI methodology should be considered to categorize site quality of forest where age is difficult and costly to obtain, or for those forests which required an agile method of classification in the field (WATT et al., 2008). This tool, associated with satellite imagery and forest inventory tools, allows the generation of site quality maps and hence productivity, an indispensable tool for management and conservation plans (ESSE, 2015).

CONCLUSIONS

It is possible to use a reference diameter instead of age reference to fit site index models, within certain limits and precautions that the method required. In this sense, a unique system of diametric site index curves for pure and mixed stands of *N. alpina* and *N. obliqua* was built. Thus, an average reference diameter was used instead of the reference age, commonly used in traditional indices to classify site quality. Using these models, we can define four site quality classes with a regular range among DSI curves: 17.0, 21.5, 26.0, 30.5, and 35.0 m.

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