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Article

Influencia de la competencia en el crecimiento diamétrico de *Pinus durangensis* Martínez en Durango, México

Influence of competition on the diametric growth of *Pinus durangensis* Martínez in Durango, Mexico

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Resumen:

En esta investigación se analizó la influencia de la competencia sobre el crecimiento en diámetro normal en árboles de *Pinus durangensis* en bosques mixtos e irregulares del estado de Durango. Se utilizaron datos de dos inventarios realizados en 2009 y 2014, en 16 Sitios Permanentes de Investigación Forestal y de Suelos (SPIFyS) de 2 500 m², dentro de los cuales, *Pinus durangensis* fue la especie dominante del estrato arbóreo, con 39.44 % del valor de importancia, y crece de manera mezclada con otras 18 especies arbóreas. El efecto de la competencia fue analizado mediante 14 índices de competencia independientes de la distancia y 11 dependientes de la distancia; para ello, se evaluaron 11 criterios de selección de árboles competidores. Los índices independientes de la distancia explicaron ligeramente mejor que los índices dependientes de la distancia el crecimiento en diámetro normal de la especie estudiada. El índice de competencia independiente de la distancia que se deriva de la razón entre el área basal del árbol objetivo y el área basal por hectárea describió mejor el efecto deseado, por lo que se recomienda para su posible inclusión en futuros modelos de crecimiento en diámetro normal desarrollados para *P. durangensis*.

Palabras Clave: Crecimiento en diámetro, criterio de selección de competidores, ecuación exponencial, ecuación lineal, ecuación de potencia, índices de competencia dependiente e independiente de la distancia.

Abstract:

In this paper the effect of competition on individual tree diameter growth of *Pinus durangensis* was analyzed. Trees were growing in mixed and uneven-aged stands in Durango, Mexico. The data used in the study were obtained from two forest inventories performed in 2009 and 2014 in 16 permanent sampling plots for forest and soil research (SPIFyS) of 2 500 m² in size. *Pinus durangensis* was the dominant species within the sites, covering 39.44 % of the importance value, and it is growing with other 18 tree species. 14 distance-independent and 11 distance-dependent competition indices were used to evaluate the effect of competition. 11 competitor selection methods were tested in combination with the selected distance-dependent indices. Distance-independent competition indices showed slightly better results than distance-dependent indices for predicting diameter at breast height growth for the studied tree species. The distance-independent competition index derived from the ratio between of the basal area of the reference tree and the basal area per hectare best described the effect of the competition, and therefore, it is recommended for its possible addition within further models to predict the breast height diameter growth for the tree species analyzed in this study.

Key words: Diameter growth, competitor selection method, exponential equation, linear equation, power equation, distance-independent and distance-dependent competition index.

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Introduction

In forest ecology, competition can be defined as the negative effect that a tree exerts on another due to consumption or control over the access to a specific resource (light, water or nutrients) of limited availability (Burkhardt and Tomé, 2012). The effect of this force can lead to a reduction in the survival, growth or reproduction of the affected individual, as it is one of the fundamental factors in the evolution and functioning of ecosystems (Pretzsch, 2009).

Competition has been studied through the use of indices by a large number of researchers for more than half a century (Clark and Evans, 1954; Arney, 1973, Alemdag, 1978; Lorimer, 1983; Tomé and Burkhardt, 1989; Biging and Dobbertin, 1995; Corral *et al.*, 2005). An index of this type is an indicator that estimates the total competition to which a tree is subjected and that manifests itself in its growth (Burkhardt and Tomé, 2012).

Munro (1974) classifies these indices into two groups: distance-independent, which do not consider the spatial distribution of the trees and do not require obtaining the coordinates of it, and distance-dependent indices, which do include the spatial distribution with respect to the target tree.

According to Biging and Dobbertin (1995), Bachmann (1998) and Corral *et al.* (2005), the impact of the competition exerted by one or more individuals on the growth of a tree can be approached with similar results through the use of independent or distance-dependent indices, using for the latter an adequate method for the selection of the competing trees of a target tree. This aspect is one of the indispensable factors for the construction of an individual tree growth model, especially if it is a species in mixed and irregular forests (Schröder and Gadow, 1999). However, these studies have been carried out mainly in plantations of only one species, so those related to irregular forests and with more than one species are still very scarce (Moravie *et al.*, 1999; Coates *et al.*, 2009; Seydack *et al.*, 2011).

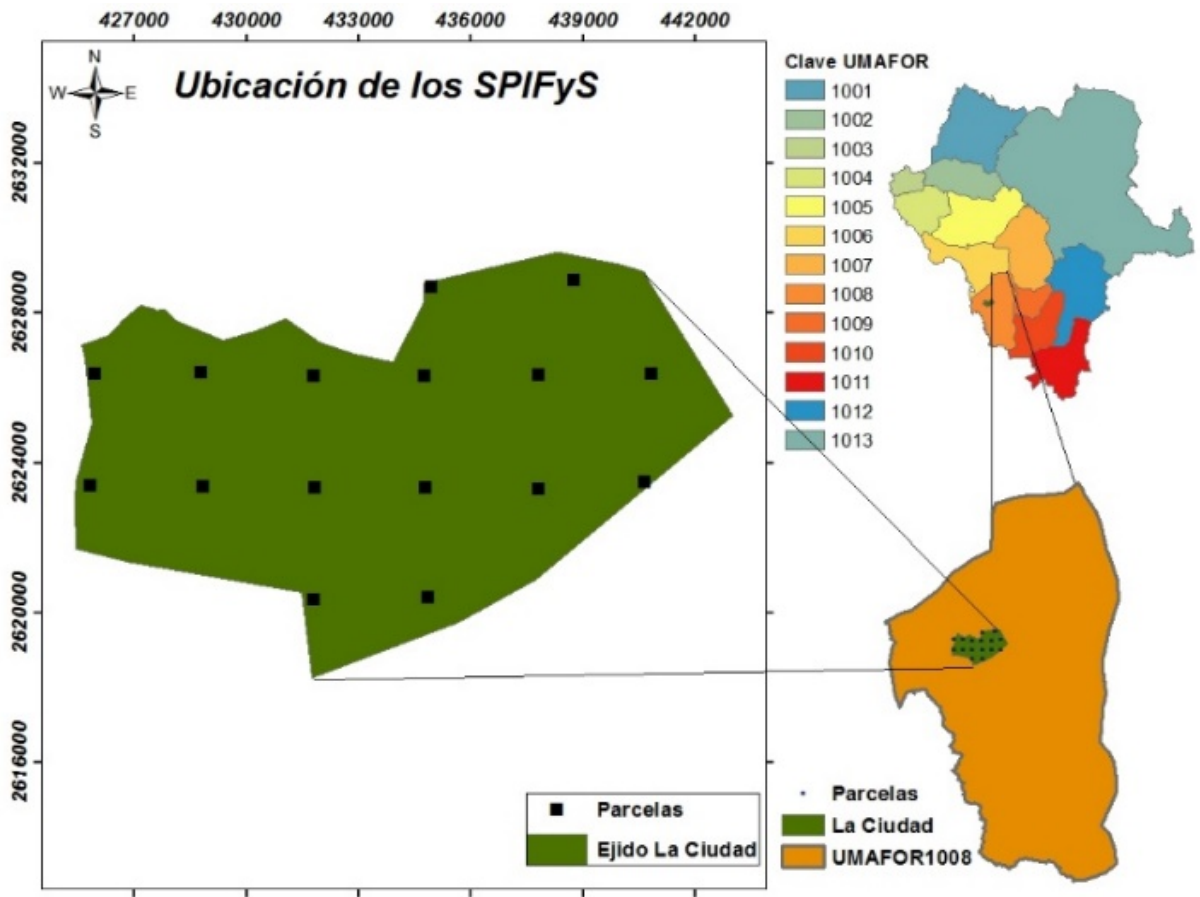
Thus, the following targets were proposed: a) to estimate the significance of the effect of competition on the growth in normal diameter of *Pinus durangensis* Martínez trees in mixed and irregular stands in the state of *Durango*; b) compare the ability to describe the competence of independent and distance-dependent indices with different criteria for the selection of competitors, and c) identify the best competitive index or the best combination of a competitive index with a selection criteria of competitors to be incorporated in a future growth model in normal diameter of this species.

Materials and Methods

Study area

The data come from 16 Permanent Forest and Soil Research Sites (SPIFyS) established in the *La Ciudad ejido, Pueblo Nuevo* municipality, *Durango*, which is located within the Regional Forest Management Unit (UMAFOR) 1008. Forest communities most important of the UMAFOR 1008 are composed of forests mixed with species of *Pinus* and *Quercus*, *Juniperus*, *Arbutus* and *Alnus*; they are stands of second growth that have been subject to forest exploitation for more than 100 years (Luján *et al.*, 2015). The size of the plots was 50 × 50 m (0.25 ha), and they were systematically located within the boundaries of the *ejido* (Figure 1).





Ubicación de los SPIFYs = Location of the SPIFYs; Clave UMAFOR = UMAFOR code; Parcelas = Plots

Figure 1. Location of the Permanent Sites for Forest and Soil Investigation used in the study.

Data collection

The data were taken in two dates; the first one when the SPIFYs were installed and the original inventory was made in 2009, and the second one when the second inventory was made in 2014, five years after; in such a period, the sites were not subjected to any forestry treatment.

For each measurable tree (normal diameter ≥ 7.5 cm) within each site, the following variables were taken: species, dominance, normal diameter (d , cm), with a using a Hagl f Mantax Blue caliper with millimeter graduation and following the directions of the sides of the plot; total height

(h, m), clean stem height (m), distance from the tree to the center of the site (m) and crown diameter (m), with a Vertex IV graded hypsometer (cm), and the azimuth of the tree with respect to the center of the site, with a Suunto Tandem Global Compass / Clinometer instrument.

Pinus durangensis Martínez was the dominant species within the study area since it records 39.44 % of importance value (Campo and Duval, 2014), but it is mixed with the following species, which follow a decreasing sequence according to their importance value (numbers in parentheses): *Pinus cooperi* Blanco (11.51 %), *Quercus sideroxylla* Bonpl. (7.14 %), *Juniperus deppeana* Steud. (5.92 %), *Alnus firmifolia* Fernald (3.47 %), *P. strobiformis* Engelm. (3.42 %), *Q. crassifolia* Humb. et Bonpl. (3.23 %), *P. leiophylla* Schiede ex Schltdl. & Cham. (3.03 %), *Q. rugosa* Neé (2.92 %), *Arbutus arizonica* (A. Gray) Sarg (2.64 %), *P. herrerae* Martínez (2.32 %) *A. madrensis* M. González (2.23 %), *A. bicolor* S. González, M. González et P. D. Sørensen (2.08 %), *P. teocote* Schltdl. & Cham. (1.96 %), *A. tessellata* P. D. Sørensen (1.80%), *A. xalapensis* Kunth (1.72 %), *Q. conzattii* Trel. (1.65 %), *Q. durifolia* Seemen (1.69 %) and *Populus tremuloides* Michx. (1.60 %). In Table 1 are shown the descriptive statistics of the mensuration variables of the two inventories carried out in the SPIFyS until now.

Table 1. Main mensuration variables of the Permanent Sites for Forest and Soil Investigation in the actual study.

Variable	Mean ± SD (2009)	Mean± SD (2014=
N	666 ± 354	612 ± 326
G	23.09 ± 7.77	26.55 ± 8.58
Dg	23.78 ± 6.67	25.83 ± 6.57
V	224.11 ± 83.17	274.03 ± 103.79
H0	20.14 ± 3.9	21.69 ± 4.07

N = Number of trees per ha; G = Basimetric area inn m² per ha; Dg = Squared mean diameter in cm; V = Volume per ha in m³; H0 = Dominant height in m.

Analyzed competition indexes

In tables 2 and 3 are shown the competition indexes that were analyzed: 14 of them belong to the distance-independence group ($IC_1 - IC_{14}$), and 11 to the distance-dependent ($ICd_1 - ICd_{11}$) (Munro, 1974), which were selected from previous experiences (Martínez and Madrigal, 1982; Pukkala and Kolström, 1987; Holmes and Reed, 1991; Biging and Dobbertin, 1992; Mäkinen, 1997; Schröder and Gadow, 1999; Álvarez *et al.*, 2003; Corral *et al.*, 2005; Crecente *et al.*, 2007).



Table 2. Mathematical expression of the distance-independent competition indexes used in this study.

Index	Name of the index and source	Mathematical expression
IC_1	Number of trees per hectare (N)	$(n/100)/S$
IC_2	Basimetric area per hectare (G)	$\pi/4 \sum_{i=1}^{i=n} d_i^2 10000/S$
IC_3	Reineke (1933)	$10^{(\log N + 1.605 \log Dg - 1.605)}$
IC_4	Crown Competition Factor	$\pi/4 \sum_{i=1}^{i=n} dc_i^2 100/S$
IC_5	Hart index (IH)	$100/(H_0 \sqrt{N})$
IC_6	Krajicek <i>et al.</i> (1961) (CCF)	$\pi/4 \sum_{i=1}^{i=n} dcm_i^2 100/S$
IC_7	Ritchie and Hann (1982) (CCFL)	$\pi/4 \sum dcm_{mayori}^2 100/S$
IC_8	Wykoff <i>et al.</i> (1982) (Basal Area in Larger Trees (BAL))	$\pi/4 \sum d_{mayori}^2 10000/S$
IC_9	Vanclay (1991) (BAL)	BAL/G
IC_{10}	Schröder and Gadow (1999) (BALMOD)	$(1 - [1 - (BAL/G)]) / IH$
IC_{11}	Diameter-squared mean diameter ratio	d_i / D_G
IC_{12}	Normal section-basimetric area ratio	g_i / G
IC_{13}	Basimetric area-diameter ratio	$(g_i / G)^{d_i / D_g}$
IC_{14}	Crown diameter-diameter ratio	dc_i / d_i

n = Number of trees per site; S = Surface area of the site (m²); d_i = Normal diameter of the target tree (cm); log = Logarithm base 10; d_g = Quadratic diameter (cm); dc_i = Crown diameter in horizontal projection of the target tree (m); dcm_i = Maximum crown diameter (in free growth) of the target tree (m) estimated by equation (3); dcm_{mayori} = Crown diameter in horizontal projection of the larger trees than the target tree (m); d_{mayori} = Normal diameter of the larger trees than the target tree (cm); g_i = Normal section of the target tree (m²) ; G = Basimetric area (m² ha⁻¹); BAL = BAL index; IH = Hart index.

Table 3. Mathematical expression of the distance- dependent competition indexes used in this study.

Index	Name of the index and source	Mathematical expression
ICd_1	Staebler (1951)	$\sum_{i \neq j} L_{ij}$
ICd_2	Gerrard (1969)	$\sum_{i \neq j} \{O_{ij}/Z_i\}$
ICd_3	Bella (1971)	$\sum_{i \neq j} \{O_{ij} d_j / Z_{ij} d_i\}$
ICd_4	Hegyí (1974)	$\sum_{i \neq j} \{d_j / (Dist_{ij} d_i)\}$
ICd_5	Alemdag (1978)	$\sum_{i \neq j} \left\{ \pi \left[(Dist_{ij} d_i) / (d_i + d_j) \right]^2 (d_j / Dist_{ij}) / \sum (d_j / Dist_{ij}) \right\}$
ICd_6	Martin and Ek (1984)	$\sum_{i \neq j} \left\{ (d_j / d_i) \exp \left((16 Dist_{ij}) / (d_i + d_j) \right) \right\}$
ICd_7	Daniels <i>et al.</i> (1986)	$d_i^2 nc / \sum_{i \neq j} d_j^2$
ICd_8	Braathe (1980)	$\sum_{i \neq j} \left\{ h_i / (h_j Dist_{ij}) \right\}$
ICd_9	Biging and Dobbertin (1992) (CCSp)	$\sum_{i \neq j} \left\{ CC_j / \left(CC_i (Dist_{ij} + 1) \right) \right\}$
ICd_{10}	Biging and Dobbertin (1992) (CVSp)	$\sum_{i \neq j} \left\{ CV_j / \left(CV_i (Dist_{ij} + 1) \right) \right\}$
ICd_{11}	Biging and Dobbertin (1992) (CVU)	$\sum_{i \neq j} \{ CV_{\alpha j} / CV_j \}$

L_{ij} = Length (m) of the segment that links the center of the target tree and its competitor, included the overlay area of its influence zones; O_{ij} = Overlay area (m^2) between the influence zones of the target tree and the competitor tree; Z_i = Influence zone of the target tree (m^2); d_j = Normal diameter of the competitor tree (cm); $Dist_{ij}$ = Distance in horizontal projection between the target tree and the competitor tree (m); nc = Number of competitor trees ; h_i = Total target tree height (m); h_j = Total competitor tree height (m); CC_i = Crown surface in horizontal projection of the target tree (m^2) at a certain p percentage of its height; CC_j = Crown surface in horizontal projection of the competitor tree (m^2) at a certain p percentage of its height; CV_i = Crown volume of the target tree (m^3 over a certain p percentage of its height); CV_j = Crown volume of the competitor tree (m^3) over a certain p percentage of its height; $CV_{\alpha j}$ = Crown volume of the competitor j tree over the α point.

Selection criterion for the competitors

Eleven *Pinus durangensis* competitor tree selection criteria were analyzed (C_1 to C_{11} codes). Through this C_1 criterion, all of the individuals included in this moving Bitterlich plot with center in the target tree and a basimetric area factor (BAF) equal to $4 \text{ m}^2 \text{ ha}^{-1}$ were selected as the competitor trees of this species. According to this criterion, in order to consider a tree as a competitor of the target tree, the distance between them cannot be higher than 25 times its own normal diameter (Crecente *et al.*, 2007).

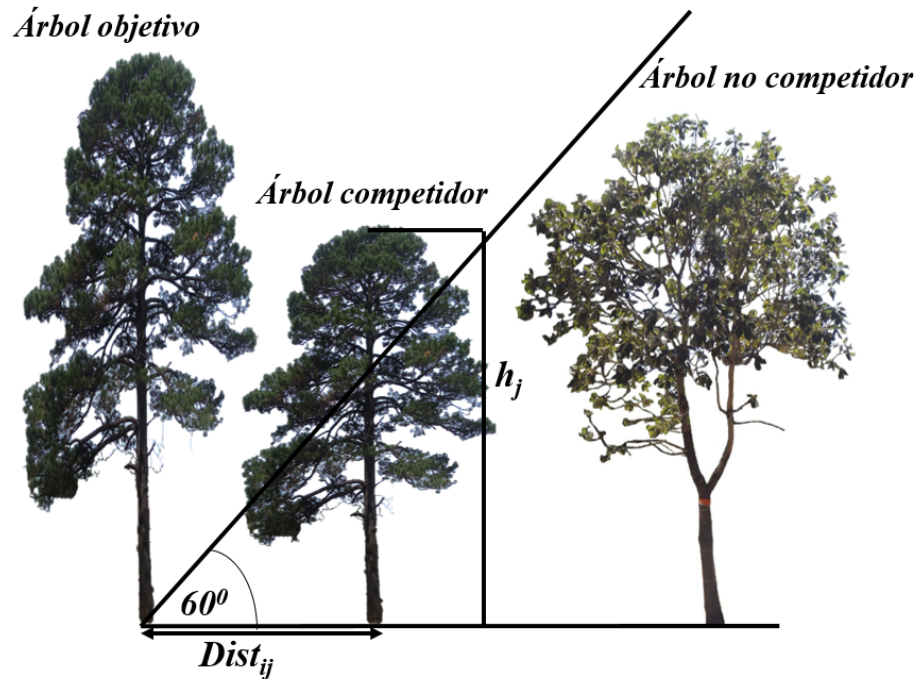
In criterion C_2 , all those selected with criterion C_1 were considered to be competing trees, as well as the closest tree that is located within each of the quadrants defined by the four cardinal points (Crecente *et al.*, 2007). With criterion C_3 , the four trees closest to the target tree were selected (Crecente *et al.*, 2007). Criterion C_4 , proposed by Biging and Dobbertin (1992), was based on considering active competitors those trees whose total height (h_j) exceeds an imaginary line drawn from the base of the objective tree with an inclination of 60° with respect to the horizontal (Figure 2). This line marks a point (at its intersection with the axis of the competitor tree) from which the volume of the cup was considered to calculate the ICd_{11} competition index. The relationship between distance and height that determined whether a tree was selected as an active competitor was:

$$\tan 60^\circ = \frac{h_j}{Dist_{ij}} = 1.73 \Rightarrow Dist_{ij} \leq \frac{h_j}{1.73} \quad (1)$$

Where:

h_j = Total height of the competing tree (m)

$Dist_{ij}$ = Distance from the target tree to the competing tree (m)



Árbol objetivo = Target tree; *Árbol competidor* = Competitor tree; *Árbol no competidor* = No competitor tree

Figure 2. Scheme of C_4 competitor selection criterion.

The C_5 criterion differs from the former in that the inclined line originates at the basis of the target tree crown (Figure 3). The relation between the distance and height that determines if a tree is selected as an active competitor was:

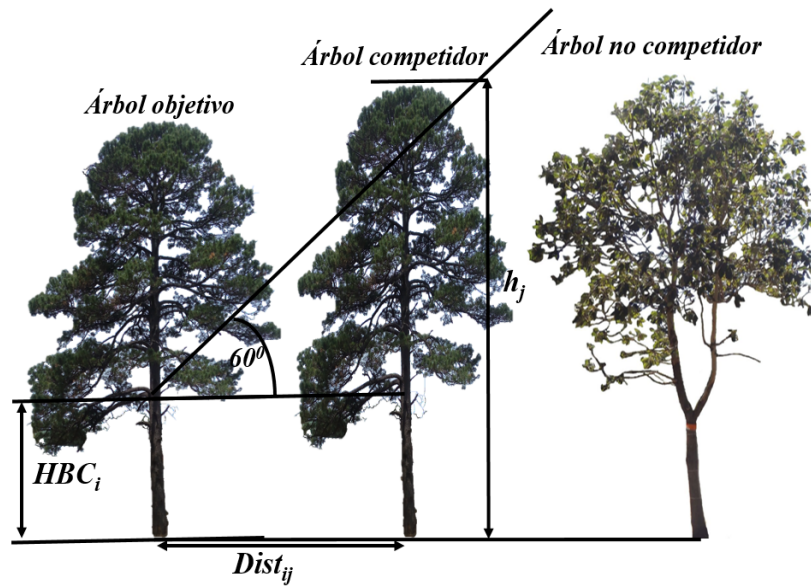
$$\tan 60^\circ = \frac{h_j - HBC_i}{Dist_{ij}} = 1.73 \Rightarrow Dist_{ij} \leq \frac{h_j - HBC_i}{1.73} \quad (2)$$

Where:

h_j = Total height of the competing tree (m)

$Dist_{ij}$ = Distance from the target tree to the competing tree (m)

HBC_i = Height at the crown base of the target tree (m)



Árbol objetivo = Target tree; *Árbol competidor* = Competitor tree; *Árbol no competidor* = No competitor tree

Figure 3. Scheme of C_5 competitor selection criterion.

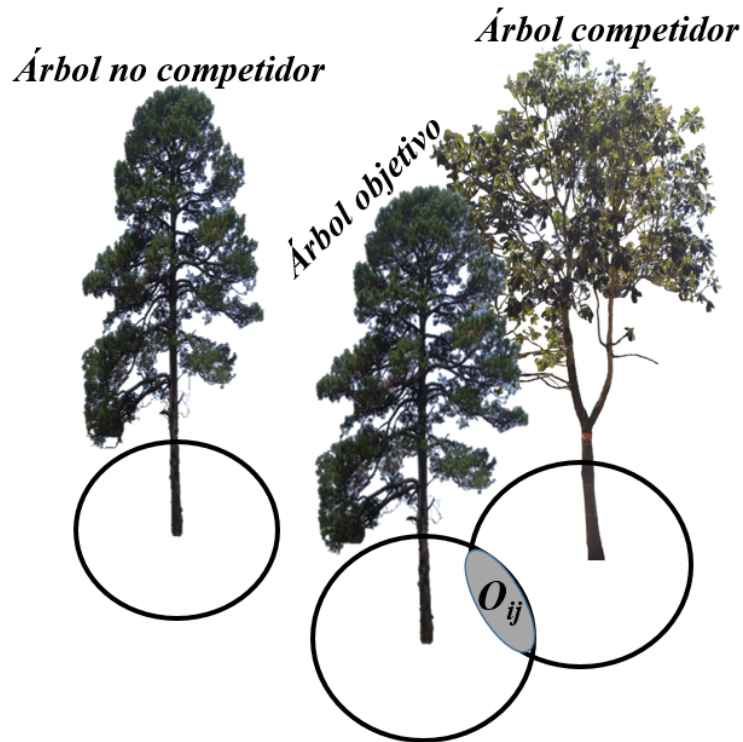
Criterion C_6 was based on the concept of the area of influence (Staebler, 1951). For this case, all the trees whose area of influence overlapped that of the target tree were considered active competitors (Figure 4). In this work, the maximum value that was taken was the radius of the tree crown it could reach if it were growing free of competition, which was estimated by the equation proposed by Cruz and Castañeda (1999):

$$mcw_i = 0.1503d_i + 2.0241 \quad (3)$$

Where:

mcw_i = Maximum crown growth (m)

d_i = Normal diameter (cm) of the selected tree



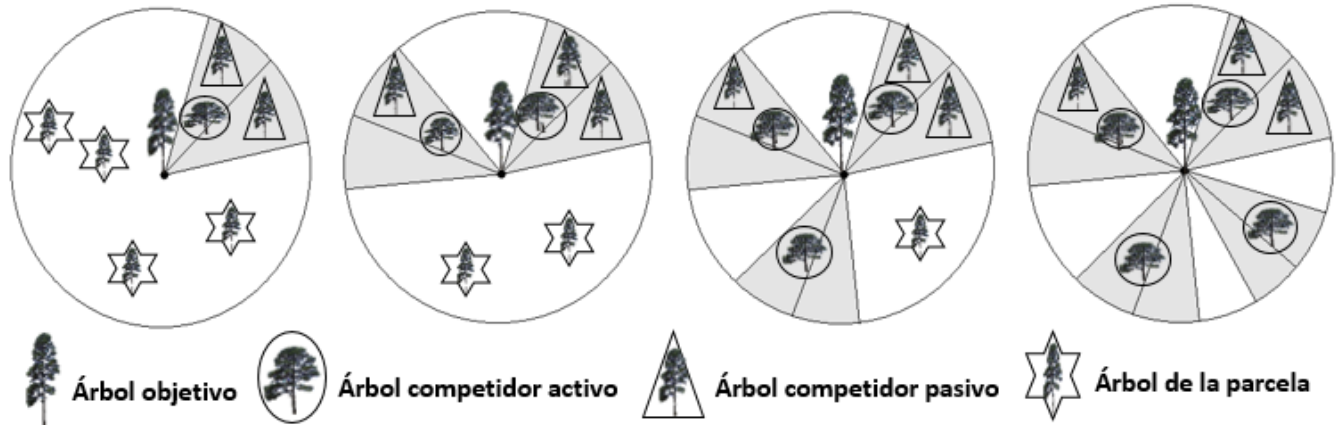
Árbol objetivo = Target tree; *Árbol competidor* = Competitor tree; *Árbol no competidor* = No competitor tree

Figure 4. Scheme of C_6 competitor selection criterion.

The criterion C_6 is the only one that may be used with the competition indexes based upon the concept of the zone of influence (ICd_1 , ICd_2 and ICd_3).

The criteria C_7 to C_{11} include the concept of angle for the elimination of competition (Lee and Gadow, 1997), according to which it is chosen as the first active competitor the closest tree to the target tree; afterwards, a circular section is marked with a particular angle and whose bisectrix is the line that joins both of them. All the trees in this circle that stand behind the first competitor, are discarded as possible active competitors. The process continues with the selection of the next closer tree to the target and located outside of the first circle, and it goes on and on until all the active competitors are found (Figure 5), with a 60° elimination angle (C_9).

The number of active competitors decreases as the elimination angle of competition increases. In other investigations, they have used competition elimination angles of 90, 75, 60, 45 and 30 degrees, which define criteria C_7 to C_{11} , respectively (Corral *et al.*, 2005; Crecente *et al.*, 2007).



Árbol objetivo = Target tree; *Árbol competidor activo* = Active competitor tree; *Árbol competidor pasivo* = Passive competitor tree; *Árbol de la parcela* = Plot tree.

Figure 5. Scheme of the process to select active competing trees from a reference tree, taking into account an elimination 60° angle (criterion C_9).

Analyzed models

Three models were used, one of simple lineal type, one exponential and another potential (equations 4 to 6) to analyze the influence that competition exerts on the growth in normal diameter of *Pinus durangensis* trees within the studied sites. The models were tested for all possible combinations between the indexes and the criteria for selecting competitors:

$$\Delta\gamma = \alpha + \beta \cdot C_i \quad (4)$$

$$\Delta\gamma = \alpha \cdot e(\beta \cdot C_i) \quad (5)$$

$$\Delta\gamma = \alpha \cdot C_i^\beta \quad (6)$$

Where:

$\Delta\gamma$ = Variable to be modeled (normal diameter growth during a 5 year period)

C_i = Distance-independent index of competition or the combination of a distance-dependent competition index with a criterion of competitors' selection

α y β = Parameters to be estimated in the model fit

The estimation of the parameters of the linear model was performed by least squares using the REG procedure of the SAS / STAT[®] program (SAS, 2004). In the case of non-linear models, the NLIN procedure implemented in the same program was used.

The goodness of fit of the models (*i.e.* significance of the effect of competition on the growth in normal diameter) was evaluated through the significance of the adjustments of the models and with the statistical coefficient of determination (R^2) and root mean square error (REMC). For the exponential and potential models, the estimated coefficient of determination corresponded to that proposed by Ryan (1997) for non-linear regression, which is equivalent to the square of the correlation coefficient of the observed values and the values estimated by the models.

Results and Discussion

Table 4 lists the ten competition or combinations of competition index with a criterion of selection of competitors that showed the greatest levels of explanation of the observed variability in normal diameter growth of *Pinus durangensis* trees, taking as predictive variable the competition in the three studied models. These indexes also recorded the least mean errors, and in all cases, fit was very significant ($p < 0.0001$), which means that the use of competition as a predictive variable vigorously helps to explain growth in normal diameter of the studied species.

Table 4. Competition indexes which showed the best statistics of fit of diameter growth models of linear, exponential and potential type.

Lineal				Exponential				Potential			
Cr	IC	R ²	REMC	Cr	IC	R ²	REMC	Cr	IC	R ²	REMC
	IC ₆	0.33	0.76	C11	ICd ₄	0.29	0.78		IC ₁₂	0.35	0.74
	IC ₈	0.28	0.79	C10	ICd ₄	0.28	0.78	C11	ICd ₄	0.28	0.78
	IC ₁₀	0.27	0.79	C2	ICd ₄	0.28	0.78	C10	ICd ₄	0.28	0.78
	IC ₁₁	0.26	0.79	C9	ICd ₄	0.27	0.79		IC ₁₁	0.27	0.79
	IC ₁₂	0.25	0.80		IC ₁₀	0.26	0.79	C3	ICd ₄	0.27	0.79
	IC ₉	0.23	0.81	C8	ICd ₄	0.26	0.79	C9	ICd ₄	0.27	0.79
C11	ICd ₅	0.22	0.82	C7	ICd ₄	0.25	0.80	C3	ICd ₅	0.26	0.79
C7	ICd ₅	0.21	0.82	C3	ICd ₄	0.25	0.80	C2	ICd ₄	0.26	0.79
C3	ICd ₅	0.20	0.82		IC ₁₁	0.22	0.81	C7	ICd ₄	0.25	0.80
C10	ICd ₅	0.20	0.83		IC ₉	0.22	0.82	C8	ICd ₄	0.25	0.80

Cr = Competitor selection criteria; IC = Competence index; R² = Coefficient of determination; REMC = Root of the mean square error.

The best values of the statistics of fit R^2 and REMC were obtained with the independent indexes of the distance and the use of the potential and linear models. The IC_{12} index (which is based on the calculation of the ratio of the basal area of the target tree and the basal area per hectare), was the one that presented the best fit by using the potential model, explaining 35 % of the variability observed in the growth in diameter of the species studied, with a CTM value of 0.74 cm; followed by the IC_6 that represents the crown competition factor (CCF), defined as the percentage of the growth area occupied by the projection of the crowns, assuming that each tree grows freely (without competition), explaining through the linear model, 33 % of the variability observed in the growth in diameter during the observation period, with a CTMR of 0.76 cm.

The independent- distance indexes IC_8 and IC_{10} also showed good results in the explanation of the variance observed in the growth in diameter. The results of this work are consistent with those by Crecente *et al.* (2007) in plantations of *Pinus radiata* D. Don in Galicia, Spain, where the independent indexes of distance presented slightly better results than those distance -dependent in the study of the effect of competition.

Valles and Valadez (2006) also found better fits with the use of a distance-independent competition index based on the density-weighted canopy width in mixed forests in *San Dimas, Durango*. In the same way, Tíscar and Tíscar (2010) reported in a population of *Pinus nigra* Arnold from the *Sierra de Cazorla* (southeast of Spain), a distance -independent index that includes the variable crown area as the most suitable to be included in models for the prediction of growth in normal diameter. However, the R^2 values of this work are lower to those of Álvarez *et al.* (2004), who reported values of 0.66 for the distance -independent indexes of the BAL and BALMOD, in an exponential model fitted in growth data in section of individual trees of *Pinus radiata* in *El Bierzo (León, Spain)*.

Other researchers such as Álvarez *et al.* (2003), Biging and Dobbertin (1995), Corral *et al.* (2005) and Schröder and Gadow (1999) reported that independent-

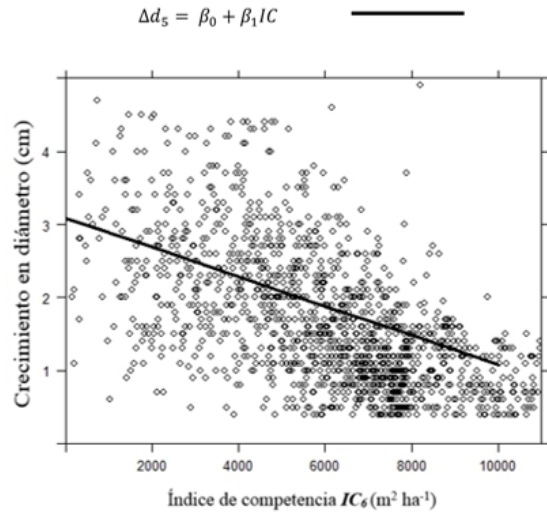
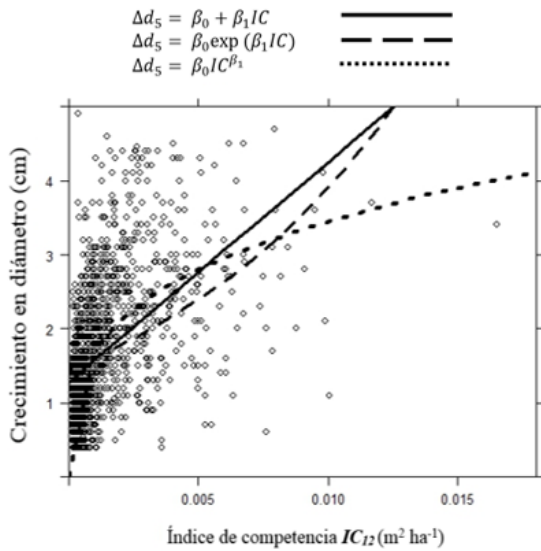
distance indexes based on the use of the basal area (BAL and BALMOD) produced significant improvements in the estimates of diameter growth models of species studied in even-aged stands.

On the other hand, the indexes based on stand density (number of trees per hectare, basal area per hectare, Reineke, crown competition factor, and Hart index) were not adequate to evaluate the effect of competition, since they did not explain even 15 % variation in the growth data, so its use is not recommended as competition indices. These results are common with previous studies conducted on *Quercus robur* L. (Maseda, 1998) and on *Pinus radiata* (Álvarez, 1998, Álvarez *et al.*, 2003).

Within the group of distance- dependent competition indexes, the ICd_4 combined with C_{10} and C_{11} had the best results with the exponential model, as it explained 29 % of the variability observed in diameter growth with REMC values of 0.78 cm. This competitor selection criteria (C_{10} and C_{11}) use 45° y 30° angles for competing elimination and are rather simple to apply since they limit the number of competitors, which might make them useful in field work (Álvarez *et al.*, 2003).

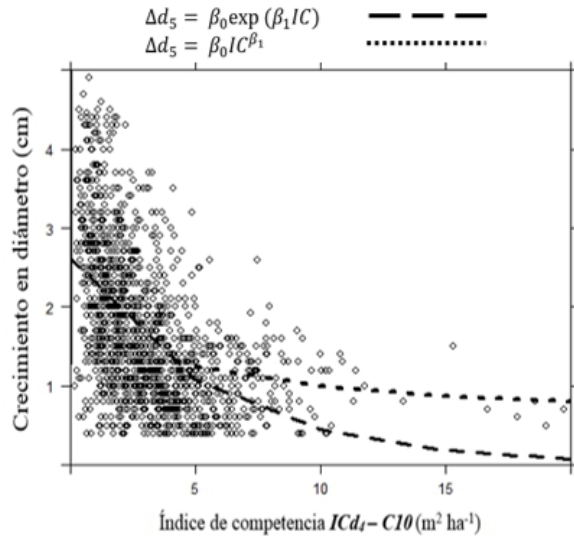
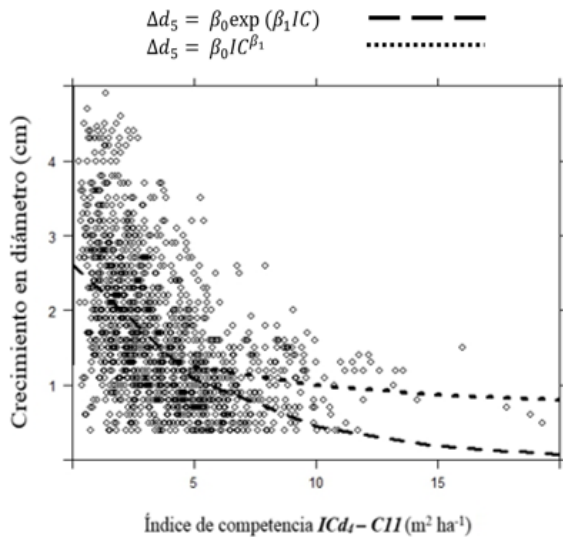
ICd_5 stands in second place, which also provided good results when combined with criterion C_3 . These indices are strongly related to each other, since they are based on ratios of sizes (normal diameter) weighted by distances, and consider that the competition that exerts on a tree around them increases when their size increases and the distance that separates them (Crecente *et al.*, 2007).

Figure 6 shows the relation between the distance independent competition indexes IC_6 and IC_{12} and the distance dependent index ICd_4 with the C_{11} and C_{10} criteria with individual diametric growth of *Pinus durangensis* by the linear, exponential and potential models, or just with the one of the best fit. In most cases, the potential model best describes the tendency of the data when using the competition indexes as predictive variable, a situation that explains itself as values under the squared mean error are obtained, compared to the linear and exponential equations.



Relation between the diameter individual growth and the competition index IC_{12} with the linear, exponential and potential models.

Relation between the diameter individual growth and the competition index IC_6 with the linear model.



Relation between the diameter individual growth and the competition index ICd_4 and the C_{11} criterion, with the exponential and potential models.

Relation between the diameter individual growth and the competition index ICd_4 and the C_{10} criterion, with the exponential and potential models.

Linear model = Continuous line; Exponential model = Dot line; Potential model = Discontinuous line, overlapped to the dot cloud.

Figure 6. Competition indexes with better results for the models of diameter growth.

In general, the value of the different selection criteria for the selection of competitors for a same index, does not exhibit great contrasts, and even though there is always one that is slightly more favorable, the others have a value rather close to it.

Although the results suggest that the best independent distance indexes of distance IC_6 and IC_{12} explain between 33 and 35 % of the variance observed in diameter growth, it is evident that when developing the growth model it would be necessary to include others as predictive variables, such as the initial normal diameter, the quality of the season, and other factors that significantly influence the increase in the normal section of trees (López *et al.*, 2013; Quiñonez *et al.*, 2015).

Conclusions

The fit of most of the tested models resulted significant, which means that the use of competition as a predictive model helps vigorously to explain growth of *Pinus durangensis* normal diameter. The distance independent indexes resulted as better predictive variables than the distance dependent to assess the influence of competition of *Pinus durangensis* that grows in mixed and irregular forests in *Durango* state. The IC_{12} index which came from the ratio between the basimetric area of the target tree and the basimetric area per hectare better described the effect of competition; therefore, it is advised to include it in future growth models of normal diameter for the studied species. Its application in the model is an easy task, since during the inventories for forest management that are performed in the study area every 10 years, the necessary variables for the calculation of this index are taken.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

José Guadalupe Colín: field work and writing of the manuscript; Oscar Alberto Aguirre-Calderón: review of the manuscript and coordination of revisions; José Javier Corral Rivas: review of the manuscript and statistical analysis; Eleney Viveros-Guerrero: field work and writing of the manuscript; Sacramento Corral Rivas: review of the manuscript; Felipe Crecente Campo: review of the manuscript and statistical analysis.

Referencias

Alemdag, I. S. 1978. Evaluation of some competition indices for the prediction of diameter increment in planted White spruce. Canadian Forestry Service, Department of the Environment. Forest Management Institute Information Report FMR-X-108. Ottawa, Ontario, Canada. 39 p.

Álvarez T., M. F. 1998. Influencia de la competencia en el crecimiento en sección en *Pinus radiata* D. Don. Proyecto fin de carrera. EPS. Lugo. Universidad de Santiago de Compostela. Santiago de Compostela, Galicia, España. pp. 1-45.

- Álvarez T., M. F., M. Barrio, J. Gorgoso y J. G. Álvarez. 2003. Influencia de la competencia en el crecimiento en sección en *Pinus radiata* D. Don. Investigación Agraria. Sistemas y Recursos Forestales 12(2): 25–35.
- Álvarez T., M. F., R. A. Marqués G., M. Fernández y F. Castedo V. 2004. Influencia de la competencia en el crecimiento en sección de *Pinus radiata* D. Don en el Bierzo (León). Cuadernos de la Sociedad Española de Ciencias Forestales 18: 129-133.
- Arney, J. D. 1973. Tables for quantifying competitive tress on individual trees on individual trees. Canadian Forestry Service. Information Report BCX-78. Victoria, British Columbia, Canada. 45 p.
- Bachmann, M. 1998. Indizes zur Erfassung der Konkurrenz von Einzelbäumen. Methodische Untersuchung in Bergmischwäldern. Forstliche Forschungsberichte München Nr. 171. München, Bayern, Deutschland. 171 p.
- Bella, I. E. 1971. A new competition model for individual trees. Forest Science 17(1): 364–372.
- Biging, G. S. and M. Dobbertin. 1992. A comparison of distance-dependent competition measures for height and basal area growth of individual conifer tress. Forest Science 38(3): 695–720.
- Biging, G. S. and M. Dobbertin. 1995. Evaluation of competition indices in individual tree growth models. Forest Science 41(2): 360–377.
- Braathe, P. 1980. Height increment of young single trees in relation to height and distance of neighbouring trees. Mitteilungen der Forstlichen Bundesversuchsanstalt 130: 43–47.
- Burkhardt, H. E. and M. Tomé. 2012. Modeling Forest Trees and Stands. Springer. Dordrecht, Netherlands. 458 p.

- Campo, A. M. y V. S. Duval. 2014. Diversidad y valor de importancia para la conservación de la vegetación natural. Parque Nacional Lihué Calel (Argentina). *Anales de Geografía* 34(2): 25-42.
- Clark, P. J. and F. C. Evans. 1954. Distance to nearest neighbor as a measure of spatial relationships in population. *Ecology* 35: 445–453.
- Coates, K. D., C. D. Canham and P. T. LePage. 2009. Above- versus below-ground competitive effects and responses of a guild of temperate tree species. *Journal of Ecology* 97: 118–130.
- Corral R., J. J., J. G. Álvarez, O. Aguirre and F. J. Hernández. 2005. The effect of competition on individual tree basal area growth in mature stands of *Pinus cooperi* Blanco in Durango (Mexico). *European Journal of Forest Research* 124: 133–142.
- Crecente C., F., E. Vázquez-Gómez, R. Rodríguez-Soalleiro y U. Diéguez-Aranda. 2007. Influencia de la competencia en el crecimiento individual de *Pinus radiata* D. Don en Galicia. *Cuadernos de la Sociedad Española de Ciencias Forestales* 23: 167–174.
- Cruz, C. F. y A. J. Castañeda. 1999. Guía de densidad para *Pinus cooperi* var. *blanco* del "Ejido La Victoria" Pueblo Nuevo Durango. *In: X Congreso de la Dirección General de Educación Tecnológica Agropecuaria*. 24 al 26 de noviembre. Oaxaca, Oax., México. 5 p.
- Daniels, R. F., H. E. Burkhart and T. R. Clason. 1986. A comparison of competition measures for predicting growth of loblolly pine trees. *Canadian Journal of Forest Research* 16(6): 1230–1237.
- Gerrard, D. I. 1969. Competition quotient: a new measure for the competition affecting individual forest trees. Michigan State University. Agriculture Research Station. Research Bulletin 20. Lansing, MI, USA. 32 p.

- Hegyí, F. 1974. A simulation model for managing jack pine stands. *In*: Fries, J. (ed.). Growth models for tree and stand simulation. Royal College of Forestry, Department of Forest Yield Research. Research Note Num. 30. Stockholm, Sweden. pp. 74–90.
- Holmes, M. J. and D. D. Reed. 1991. Competition indices for mixed species northern hardwoods. *Forest Science* 37(5): 1338–1349.
- Krajicek, J. E., K. A. Brinkman and S. F. Gingrich. 1961. Crown competition: a measure of density. *Forest Science* 7(1): 35–42.
- Lee, D. T. and K. von Gadow. 1997. Iterative Bestimmung der Konkurrenzbaume in *Pinus densiflora* Beständen. *Allgemeine Forst- und Jagdzeitung* 168(3-4): 41–44.
- López, L., R. Villalba and F. Bravo. 2013. Cumulative diameter growth and biological rotation age for seven tree species in the Cerrado biogeographical province of Bolivia. *Forest Ecology and Management* 292: 49-55.
- Lorimer, C. G. 1983. Test of age-independent competition indices for individual tree in natural hardwood stands. *Forest Ecology and Management* 6(4): 343–360.
- Luján S., J. E., J. J. Corral R., O. A. Aguirre C. and K. von Gadow. 2015. Grouping forest tree species on the Sierra Madre Occidental, Mexico. *Allgemeine Forst- und Jagdzeitung* 186(3-4): 63–71.
- Mäkinen, H. 1997. Possibilities of competition indices to describe competitive differences between Scots pine families. *Silva Fennica* 31(1): 43–52.
- Martin, G. L. and A. R. Ek. 1984. A comparison of competition measures and growth models for predicting plantation red pine diameter and height growth. *Forest Science* 30(3):731–733.
- Martínez M., F. J. y A. Madrigal. 1982. Influencia de la competencia en el crecimiento en sección. *Comunicaciones INIA, Serie Recursos Naturales* Núm. 13. Madrid, España. 88 p.

- Maseda V., P. 1998. Influencia de la competencia sobre el crecimiento en sección en *Quercus robur*. Proyecto fin de carrera. EPS. Universidad de Santiago de Compostela. Lugo, España. 42 p.
- Moravie M. A., M. Durand and F. Houllier. 1999. Ecological meaning and predictive ability of social status, vigour and competition in a tropical rain forest (India). *Forest Ecology and Management* 117(3): 221–240.
- Munro, D. D. 1974. Forest growth models: a prognosis. *In: Fries, J. (ed.). Growth models for tree and stand simulation. Royal College of Forestry, Department of Forest Yield Research. Research Note Num. 30. Stockholm, Sweden. pp. 7-21.*
- Pretzsch, H. 2009. *Forest dynamics, growth and yield, from measurement to model.* Springer. Heidelberg, Berlin. 664 p.
- Pukkala, T. and T. Kolström. 1987. Competition indices and the prediction of radial growth in Scots pine. *Silva Fennica* 21(1): 55–67.
- Quiñonez B., G., H. M. De los Santos P. y J. G. Álvarez-González. 2015. Crecimiento en diámetro normal para *Pinus* en Durango. *Revista Mexicana de Ciencias Forestales* 6 (29): 108-125
- Reineke, L. H. 1933. Perfecting a stand density index for even-aged forest. *Journal of Forest Research* 46: 627–638.
- Ritchie, M. W. and D. W. Hann. 1982. Equations for predicting basal area increment in Douglas-fir and grand fir. Forest Research Laboratory, School of Forestry, Oregon State University. Research Bulletin Num. 51. Corvallis, OR, USA. 9 p.
- Ryan, T. P. 1997. *Modern regression methods.* John Wiley & Sons. New York, NY, USA. pp. 285-332.
- Statistical Analysis System (SAS) 2004. *User's Guide. SAS/STAT® 9.1.* SAS Institute Inc. Cary, NC, USA. n/p.

Schröder, J. and K. von Gadow. 1999. Testing a new competition index for maritime pine in northwestern Spain. *Canadian Journal of Forest Research* 29(2): 280–283.

Seydack A., H. W., G. Durrheim and J. H. Louw. 2011. Spatiotemporally interactive growth dynamics in selected South African forests: Edaphoclimatic environment, crowding and climate effects. *Forest Ecology and Management* 261(7): 1152–1169.

Staebler, G. R. 1951. Growth and spacing in an even-aged stand of Douglas-fir. Master of Forestry. University of Michigan. Ann Arbor, MI, USA. 100 p.

Tíscar, P. A. y M. A. Tíscar. 2010. Influencia del tamaño y la competencia sobre el crecimiento en sección de *Pinus nigra* subsp. *salzmannii* y su relación con la selvicultura próxima a la naturaleza. *Spanish Journal of Rural Development* 1(3): 39–50.

Tomé, J. M. and H. E. Burkhart. 1989. Distance-dependent competition measures for predicting growth of individual trees. *Forest Science* 35(3): 816–831.

Vanclay, J. K. 1991. Mortality functions for north Queensland rainforest. *Journal of Tropical Forest Science* 4(1): 15–36.

Valles G., A. G. y R. C. Valadez C. 2006. Evaluación de índices de competencia independientes de la distancia para predecir el crecimiento de bosques mezclados en San Dimas, Durango. *Revista Chapingo Serie Ciencias Forestales y del Ambiente* 12(1): 39–44.

Wykoff, W. R., N. L. Crookston and A. R. Stage. 1982. User's guide to the stand prognosis model. USDA Forest Service. Intermountain Forest and Range Experiment Station. General Technical Report INT-133. Ogden, UT, USA. 112 p.



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