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Modelling ingrowth in mediterranean pine forests: A case study from scots pine (*Pinus sylvestris* L.) and mediterranean maritime pine (*Pinus pinaster* Ait.) stands in Spain

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Abstract

National Forest Inventories (NFI) are a basic tool for forestry planning at the National level. A new two-step system for predicting ingrowth compatible with NFI data is presented in order to improve long-term estimation of stand condition. In growth and yield models, an ingrowth submodel is a key feature for long-term estimation. An accurate projection of ingrowth is needed to avoid model projection bias and inaccuracy. A two-step approach was used, which consisted of (I) estimating the probability of ingrowth occurrence on a sample plot and (II) quantifying the ingrowth in terms of basal area. Logistic regression was used for step I, while linear regression was used for step II. A good performance of the joint ingrowth model for Scots pine (*Pinus sylvestris* L.) and Mediterranean Maritime pine (*Pinus pinaster* Ait. Ssp *mesogeensis*) stands was observed. Logistic model include quadratic mean diameter as independent variables for both species while basal area is only included for Mediterranean Maritime. Quadratic mean diameter is the only independent variable in linear model for both species. The presented two-step modeling methodology for ingrowth is applicable to data from National Forest Inventories with concentric plots.

Key words: concentric plot, Upgrowth, Recruitment, National Forest Inventory.

Resumen

Modelo de masa incorporada en pinares mediterráneos: Un caso de estudio en rodales de pino silvestre (*Pinus sylvestris* L.) y pino negral (*Pinus pinister* Ait.) en España

Los Inventarios Forestales Nacionales (IFN) son un instrumento básico para la planificación forestal a nivel nacional. Con el objeto de predecir la masa incorporada, se presenta un nuevo sistema bietápico compatible con los datos del IFN para de esta forma mejorar las estimaciones a largo plazo. En los modelos de crecimiento y producción, un modelo de masa incorporada es clave para la proyección a largo plazo dado que se precisa una adecuada estimación de la masa incorporada para evitar sesgos e imprecisiones. Se utilizó un método bietápico basado en (I) estimar la probabilidad de presencia de masa incorporada en la parcela y (II) cuantificar la masa incorporada en área basimétrica. Para el paso I se utilizó la regresión logística mientras que para el paso II se utilizó regresión lineal. Se observó un buen comportamiento del modelo conjunto tanto para pino silvestre (*Pinus sylvestris* L.) como para pino negral (*Pinus pinaster* Ait. Ssp *mesogeensis*). El modelo logístico incluye el diámetro medio cuadrático como variable independiente para ambas especies mientras que el área basimétrica solo es significativa en el caso del pino negral. En el modelo lineal, el diámetro medio cuadrático es significativo para las dos especies. El método bietápico presentado para estimar la masa incorporada es aplicable a los datos de Inventarios Forestales Nacionales basados en parcelas concéntricas.

Palabras clave: parcelas concéntricas, masa incorporada, regeneración, Inventario Forestal Nacional.

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Introduction

Binary events such as ingrowth and natural non-catastrophic mortality are key components in long-term forest forecast systems. Usually, forest growth and yield models do not include it, or if they do, the ingrowth submodels have a low performance and are the weakest component in forest projection. Tree-mortality (or survival) has been successfully modeled in the past (for example, Hamilton and Edwards, 1976; Monserud, 1976; Buchman *et al.*, 1983; Hamilton, 1986; Hann and Wang, 1990; Vanclay, 1991; Zhang *et al.*, 1997; Monserud and Sterba, 1999; Cao, 2000; Bravo *et al.*, 2001; Fridman and Stahl, 2001; Hann and Hanus, 2001; Trasobares *et al.*, 2004a; Trasobares *et al.*, 2004b; Bravo-Oviedo *et al.*, 2005) and the resulting models have been included in operational models. However, most standard forest models do not include an ingrowth explicit submodel. Among others, CACTOS (Wensel *et al.*, 1987), DFSIM (Curtis *et al.*, 1981; Curtis *et al.*, 1982), FVS (Wykoff, 1990) and ORGANON (Hann *et al.*, 1997) in North America; SILVA (Pretzsch *et al.*, 2002) or GLOBTREE (Soares and Tomé, 2003) in Europe; and other models and yield tables developed recently (e.g., Rojo and Montero, 1996; Montero *et al.*, 2001; Bravo and Montero, 2003; Valbuena *et al*, 2008) do not consider an ingrowth model. Relevant exceptions are some of the FVS variants (e.g., Northern Idaho) do have a recruitment prediction submodel (Ferguson and Crookston, 1991) while PROGNAUS, developed to Austrian forests (Ledermann, 2002; Monserud *et al.*, 2005) and the model developed to Nandewar Bio-Region forests in Australia by Muhairwe (Muhairwe, 2003).

In uneven-aged stands or under continuous cover forestry systems the impact of ingrowth is higher than for even-aged stands where ingrowth ca be lacking during most of rotation.

Forest managers face uncertainty when they try to provide information to stakeholders. As Fox *et al.*, (2001) state, accurate statements of prediction uncertainty are valuable for accounting for risk and uncertainty in forest management. Forest models can be classified into several different categories (empirical vs process models, spatial vs non-spatial models, deterministic vs stochastic models). Most biological processes have a stochastic component. Deterministic models are very useful to represent past growth conditions and give 'average' results but they do not provide much information on the expected variability of outcomes (Buongiorno and Gilles, 2003). Stochastic models attempt to capture the variability and the uncertainty of the outcomes (Messier *et al.*, 2003). Although there is an extensive literature incorporating stochasticity in stand and landscape level models, there is less information on how to incorporate stochasticity into distance-independent individual-tree growth models. Notable exceptions are Wykoff *et al.*, (1982), Hamilton, (1991), Miina, (1993), Stage and Wykoff, (1993) and Fox *et al.*, (2001).

Stochasticity impact on diameter and height growth and mortality is low because mortality rates are very small and trees grow in a fairly constant rate, given their size and stand conditions (density, productivity…). However, as we stated before ingrowth has a major stochastic component that contribute to the low performance of this component in distance-independent individual-tree models that do not consider it or include it in a deterministic manner. If stochasticity is not considered, a biased model outcome should be expected (Hamilton, 1991). This may not be important when foresters are interested in ranking different management alternatives. However, when they are focused on high precision growth and stand structure prediction, a stochastic approach must be considered. In addition, global change processes dramatically increase the stochasticity of forest responses to alternative silvicultural treatments (Bravo et al, 2008), so stochastic model approaches will become more important in the near future as environmental conditions become increasingly uncertain.

Ingrowth refers to those plot trees that during the time between two inventories of the plot have grown into a size that requires them to be measured by the inventory (Shiver and Borders, 1996) Ledermann (2002) and Muhairwe (2003) used this ingrowth definition in their models. However, because in most inventories at the National level, such as in the Finish (METLA, 2000), French (IFN, 1985), Spanish (Bravo *et al.*, 2002), Swiss (Gertner and Kohl, 1992) and American (USDA, 2004), plots are nested concentric with different DBH thresholds, when an stochastic model approach is used, it is necessary to consider ingrowth in the different concentric plots. In a concentric plot, where there is a variable minimum plot radii and tree diameters to be inventoried, there may be a given time when adult trees are not measured which, due to their position with respect to the center of the plot and their size, cannot be inventoried in a specific subplot among those which make up a plot. Between two inventories even some adult trees may reach a size that makes it necessary to include them and to measure them at the next (upcoming) inventory. They therefore become part of the ingrowth, even though they are not young trees as an artifact of concentric plots with a variable minimum radii and diameters method. For our purposes, ingrowth concept includes young trees that become tally trees during the projection timeline (we will call this recruitment) and mature-trees that become tally trees during the projection timeline (we will call this upgrowth). Williams (1998) distinguished between change and growth in forest surveys. While growth is the biological increase in size between inventory times (t and t+1), change is the difference in aggregate quantity of all trees larger than a user-defined size threshold between times t and t+1. Both concepts growth and change, include an ingrowth component. According to Williams (1998) it would be better to have an intensive and specialized inventory of ingrowth, but in most cases it is too expensive for a large scale forest inventory. Ingrowth models can help us to solve, at least partially, the prediction bias when ingrowht is ignored by estimating it in a mid-point between inventory time t and t+1.

Traditional ingrowth models are inappropriate for a concentric plot design because they usually only predict the basal area for the in the innermost plot. Also, the DGB of ingrowth trees is frequently simply assigned to the lower diameter classes. When a deterministic model is used to predict future forest scenarios only a recruitment model is needed because the expansion factor is used as a modifier for mortality and growth impact (Vanclay, 1991). However, when a stochastic model is used to generate forest scenarios for concentric plot-based inventories, then a prediction of ingrowth in the different concentric plots is needed to make accurate predictions. Different strategies have been used to model ingrowth process, Markov chains (Valentine and Furnival, 1989), non-linear models (Moser, 1972; Moser, 1974; Hann, 1980), linear models (Trasobares *et al.*, 2004a; Trasobares *et al.*, 2004b) or a combination of logistic and linear or log-linear models. Two variants of this last approach have been used: (a) first predict through a linear model the amount of ingrowth and then use logistic regression to distribute the predicted amount between the stand species (Vanclay, 1989) or (b) first predict a probability of ingrowth then with probability proportional to the prediction assign the event 'ingrowth' to a stand (by a random draw from Bernoulli distribution) and then use the linear or log-linear model to predict the amount of ingrowth (Ledermann, 2002; Sánchez Orois and Rodríguez Soalleiro, 2002; Muhairwe, 2003). Ledermann (2002) who usesd this approach included functions to estimate ingrowth's specific composition and ingrowth's tree DBH and height.

Explanatory variables in the different models are similar. Stand density expressed as basal area alone (Ek, 1974; Moser, 1974; Hann, 1980; Huebschmann *et al.*, 2000; Trasobares *et al.*, 2004a; Trasobares *et al.*, 2004b) or jointly with number of trees per ha (Huebschmann *et al.*, 2000; Sánchez Orois and Rodríguez Soalleiro, 2002; Muhairwe, 2003) or its derivate Quadratic Mean Diameter (Moser, 1972), number of trees per ha and sum of tree diameters (Hyink and Moser, 1983), crown variables (Shifley *et al.*, 1993) and site index expressed as indicator variables (Vanclay, 1989) or by surrogates (Ledermann, 2002; Trasobares *et al.*, 2004a; Trasobares *et al.*, 2004b). Inclusion of a site index estimation is and explicit acknowledgement that canopy openness and stand density may not be the only factors controlling ingrowth (Batista and Maguire, 1998). Factors such as environmental heterogeneity must be acknowledged whenever possible.

Ingrowth models for Mediterranean forests are scarce. Models for *Pinus sylvestris* and *Pinus nigra* stands (Trasobares *et al.*, 2004a) and for *Pinus halepensis* (Trasobares *et al.*, 2004b) are exceptions. In these models, ingrowth was estimated from linear model with number of trees in the lowest diameter class as the explanatory variable. However, the coefficient of determination for these models was low (R-squared from 0.04 to 0.11). The ingrowth model developed here is part of a distance independent individual-tree model, developed for Scots pine and Mediterranean maritime pine in Spain (Bravo *et al.*, 2005 and 2007). In distance independent individual tree models the development of individual trees is modeled without explicit knowledge about the spatial distribution of the trees. Development of simple and accurate models that allow forest managers to predict, under alternative silviculture paths, different future scenarios is a prerequisite in sustainable forest management.

The objective of this study was to suggest and develop a new ingrowth model for Mediterranean stands of *Pinus sylvestris* L. and *Pinus pinaster* Ait. in central Spain that is compatible with a stochastic individual distance-independent tree growth model and with inventories using concentric plots as in the Spanish National Forest Inventory. The ingrowth model was developed according to a two-step approach. In addition, our results also serve to improve our understanding of the ingrowth process in this area of Spain.

Materials and methods

Database

A database from the Sustainable Forest Management Group plot network (University of Valladolid) was used. The database contains detailed individual tree data from 103 plots located in *Pinus sylvestris* stands and 88 plots located in *Pinus pinaster* stands in central Spain. Plots were measured during the period from year 2002 to 2004. The spatial distribution of plots covers the entire range of site productivity, in accordance with the site index curves of Rojo and Montero (1996), Bravo and Montero (2001) and Bravo-Oviedo *et al.* (2004), density and age. As is usual, the oldest ages, especially at the best qualities, are not fully represented, because more intensive silviculture has been performed on the best sites of both species, and in the case of Maritime pine, due to the tapping of the high-quality stands 50 years ago. The plots are circular and composed of three subplots with radii of 5, 10 and 15 meters. The minimum DBH that qualifies a tree for measurement in the three plots is 75, 125 and 225 mm, respectively (Bravo *et al.*, 2002). Diameter at breast height, total height and radial diameter increment were measured in all tally trees. On the basis of the increment data, auxiliary equations (site index curves and change in dominant height growth, etc.) and static equation (to estimate bark thickness), the dimensions of the trees were calculated backward to their measurements five years ago as a backdating procedure (Hann and Hanus, 2001, Lizarralde, 2008). Such data provide unbiased estimates of permanent plot growth components (Wykoff, 1990), and they have been applied widely both in the evaluation of alternative measures of competition (Biging and Dobbertin, 1992 and 1995; Bravo *et al.*, 2001), and in the development of different stand development models such as CACTOS (Wensel *et al.*, 1987), FVS/Prognosis (Wykoff, 1990), and ORGANON (Hann and Ritchie, 1988; Hann and Larsen, 1991). None of the sampled stands had been treated silviculturally in the past five years.

After the basic tree variables had been backdated, a number of tree and stand variables were calculated for the start of the growth period, including total basal area (BA), trees per ha (N) and Site Index (SI). Site index was calculated from equations of Rojo and Montero (1996) and Bravo and Montero (2001) for Scots pine stands and from Bravo-Oviedo et al. (2004) for Maritime pine stands. The resulting data set contained 33 (32.04 %) plots showing ingrowth for Scots pine stands and 47 (53.41 %) plots showing ingrowth in Maritime pine stands. In Scots pine stands only 3 plots contained recruitment while in 33 plots upgrowth was found. In comparison, 7 Maritime pine plots included recruitment while 47 plots showed upgrowth. So we can see that the ingrowth generated by upgrowth is more important than recruitment which was not detected alone in both species.

The plots (table 1) cover a wide range of basal area (Scots pine stands: from19.19 to 78.89 m^2/ha. Maritime pine: from 13.25 to 55.59 m^2/ha), trees per ha (Scots pine: from 212 to 3958 trees/ha. Maritime pine: from 159 to 2465 trees/ha) and site index, dominant height at 100 years for Scots pine and at 80 years for Maritime pine (Scots pine 12.7 to 38 meters.Maritime pine 7.5 to 23.6 meters).

Table 1. Descriptive statistics for studied Scots pine and Mediterranean Maritime pine stands in Central Spain. SI: Site index, N: Trees per ha, BA: basal area, QMD: Quadratic mean diameter and BA_{ing}: ingrowth expresed as basal area

Variable	Mean	Minimum	Maximum	Standard deviation
Pinus sylvestris (n = 103 plots)				
SI (m)	25.82	12.7	38.0	5.11
N (trees/ha)	759.89	212	3958	601.35
BA (m^2/ha)	48.39	19.19	78.89	12.07
QMD (cm)	32.14	13.06	50.45	8.51
BA_{ing} (m^2/ha)	0.54	0.00	6.35	1.13
Pinus pinaster (n = 88 plots)				
SI (m)	14.93	7.50	23.60	4.29
N (trees/ha)	816.67	159	2465	478.91
BA (m^2/ha)	36.14	13.25	55.59	9.54
QMD (cm)	26.28	9.64	43.49	7.19
BA_{ing} (m^2/ha)	1.07	0.00	6.22	1.49

Statistical Methods

The ingrowth model has two parts: i) a logistic model to predict the probability of ingrowth occurrence in a specific plot and ii) a linear model to predict the basal area (m²/ha) of ingrowth trees conditional on P(ingrowth>determined threshold).

The logistic model was developed for both species. The logistic model has the following general structure:

$$P = \left(1 + e^{-(\alpha + \sum b_i X_i)}\right)^{-1} \qquad \text{[eq. 1]}$$

In which P is the probability that there will be a positive ingrowth in the plot during the next five years, α is the constant term, is a linear combination of parameters $\sum b_i X_i$ and independent variables X_i. The independent variables tested for both species are the site index (SI), the number of trees per ha (N), the basal area (BA) and the quadratic mean diameter (QMD). The "backward" variable selection procedure was used with a probability of 0.05. Hosmer and Lemeshow test (Hosmer and Lemeshow, 1989) and the Akaike information criterion (Zhang *et al.*, 1997) were used to assess goodness of fit. If the predicted probability of ingrowth occurrence was greater than or equal to a threshold, the ingrowth in the plot was considered realized; otherwise it was considered absent. The threshold value, to determine whether the stands have ingrowth or not, was chosen in such a way that the percentage of correctly classified plots was maximized. The logistic equation can be formulated to accept a binary dependent variable, such as a survival indicator or presence/absence of regeneration or ingrowth, and the parameters can be estimated by either weighted nonlinear regression or by maximum likelihood methods (Monserud and Sterba, 1999). The resulting predictions are bounded by 0 and 1. The logistic equation form has been widely applied in the past for modeling different binary events in forest research (Hamilton and Edwards, 1976; Hamilton, 1986; Hann and Wang, 1990; Monserud and Sterba, 1999; Cao, 2000; Bravo *et al.*, 2001; Hann and Hanus, 2001; Álvarez González *et al.*, 2004; Bravo-Oviedo *et al.*, 2005).

The linear component of this model allows us to quantify ingrowth (in basal area terms) in those stands in which, on the basis of the logistic component, it is determined that there is ingrowth. The linear component tested is as follows (eq. 2):

$$BA_{ing} = a_0 + a_1 QMD + a_2 BA + a_3 SI + a_4 N \qquad \text{[eq. 2]}$$

In which BA_{ing} is the ingrowth in m²/ha, QMD is the quadratic mean diameter (cm), BA is the basal area (m²/ha), N is the number of trees per ha, and SI is the site index (m) according with Rojo and Montero (1996), Bravo and Montero (2001) and Bravo-Oviedo *et al.* (2004). Selection of the variables was performed using the backward procedure (probability equal to 0.05). The adjusted coefficient of determination was used to determine the liner model fit's accuracy.

The joint model's adequacy was assessed by estimating a coefficient of determination (eq. 3), through the fit of a straight line between real value and predicted values of the ingrowth (eq. 4), as well as the basal area at the end (BA_2) of the projection period (eq. 5) and by calculating bias of the model (eqs. 6 and 7) to determine the accuracy of the joint two-step model (Huang *et al.*, 2003).

$$R^2 = 100 \cdot \left(1 - \frac{S_e^2}{S_{BA_{ing}}^2}\right) \qquad \text{[eq. 3]}$$

Where and are, respectively, the sample's variance of errors committed and the sample's variance in the dependent variable (basal area).

$$BA_{ing} = c_{10} + c_{11} BA_{ing\_pred} \qquad \text{[eq. 4]}$$

$$BA_2 = c_{20} + c_{21} BA_{2\_pred} \qquad \text{[eq. 4]}$$

$$bias = \frac{\sum (BA_{ing} - BA_{ing\_pred})}{n} \qquad \text{[eq. 6]}$$

$$bias\% = 100 \cdot \frac{\sum (BA_{ing} - BA_{ing\_pred})/n}{\sum BA_{ing\_pred}/n} \qquad \text{[eq. 7]}$$

In which, n is the number of observations, BA_{ing} is the actual ingrowth, BA_{ing_pred} is the predicted ingrowth, BA_2 is the basal area at the end of the project period, 5 years, BA_{2_pred} is the predicted basal area at the end of the projection period, all in m²/ha, while c_{i0} and c_{i1} are the parameters to adjust which, if equal to 0 and 1, respectively, demonstrate that the model is unbiased.

Results

The proposed two-step model allows us to reach a joint model adequacy equal to 63.5 % for Scots pine and to 70.0 % for Maritime pine.

Step I. Logistic Component

On the basis of the complete model (eq. 1), the statistically non significant variables were gradually eliminated by using a backwards elimination procedure, leaving us with the final model for Scots pine only including QMD as independent variable, while in the case of the Maritime pine both the QMD and BA were significant. The sign of the QMD with expectations while BA sign not but with significance close to the limit (p-value equal to 0.0416).

In the case of the Scots pine (table 2), the final model showed a value for the Akaike information criterion equal to 75.709 (if the independent variables are not considered, it is equal to 131.195), and the Hosmer and Lemeshow test (Pr >0.8279) confirm a good fit. On the other hand, for Maritime pine (table 2), the Akaike information criterion value is equal to 49.648 (123.584 in the event of not considering the independent variables), whereas the Hosmer and Lemeshow test also shows that there is no lack of fit (Pr >0.9199). Threshold values were 0.38 for Maritime pine and to 0.43 for Scots pine. These threshold values allow us to classify correctly 88.6 % of Maritime pine plots (sensitivity equal to 95.7 % and specificity equal to 80.5%) and 86.4 % of Scots pine plots (sensitivity equal to 78.8 % and specificity equal to 90.0 %).

Step II. Linear Component

For the two species studied, the linear component that allows us to estimate total basal area quantity incorporated into the stand was reduced to a function of the quadratic mean diameter. As expected, the higher the QMD, the lower is the basal area contribution of ingrowth trees (table 2). For Scots pine plots, the adjusted coefficient of determination was 52.57%. For Maritime pine it was 51.38 %

Validation of the Joint Model

The model for Scots pine shows a joint determination coefficient equal to 63.5%, whereas the case of Maritime pine stands is equal to 70.0%. The result of the fitted validation straight lines between real and predicted values is shown on Table 3. In all cases, the parameter representing the independent term contains the zero in its confidence interval, and the independent variable parameters contain the one in their confidence interval. So, the joint model does not show bias or lack of accuracy (fig 1). The absolute bias for the *Pinus sylvestris* and *Pinus pinaster* ingrowth was very low (-0.095 and –0.079 m^2/ha respectively). In relative terms the *Pinus pinaster* ingrowth bias is low (7.37 %) while the *Pinus sylvestris* is low enough (17.51%) to allow us to accept it. However, additional data and validation is needed to help us reach a better ingrowth model for Scots pine.

Discussion

Usually, ingrowth is not taken in account in growth and yield models (Curtis *et al.*, 1981; Curtis *et al.*, 1982; Wensel *et al.*, 1987; Rojo and Montero, 1996; Hann *et al.*, 1997; Bravo and Montero, 2001; Montero *et al.*, 2001) or, when considered, the resulting prediction is poor or not compatible with concentric plot design. Usually, the low performance of ingrowth models is due to the fact of not considering the stochastic nature of this event and fitting linear models based on database containing a large number of zero events (no ingrowth). Stiff (1979) obtained a low R^2 (0.14) for Appalachian hardwoods. Hyink and Moser (1983) dealing with Northern hardwoods found just 0.08 value of R^2. Trasobares *et al.* (2004a and 2004b) obtained low determination coefficient for ingrowth models for *Pinus sylvestris* (R-squared equal to 0.11), *Pinus nigra* (R-squared equal to 0.11) and *Pinus halepensis* (R-squared equal to 0.04) in a Mediterranean area. On the other hand, some authors have been succesfull in modeling ingrowth. Moser (1972) and Ek (1974), working on Northerns hardwoods, obtained a R^2 over 0.70. Although the determination coefficient cannot be used to compare the performance of models dealing with different dependent variables, it is useful to study the percentage of variance explained by different models. Other authors (Ledermann, 2002; Sánchez Orois and Rodríguez Soalleiro, 2002) have used a compound model with two independent parts (logistic plus linear model) but these do not consider the impact of concentric plot design on ingrowth. The two-step methodology allows us to obtain adequate projections and surpass the results obtained with linear functions, and it is applicable under the widespread concentric plot method.

Density related variables (basal area, just in Maritime pine, and quadratic mean diameter, in both species)

Table 2. Logistic and linear components of the ingrowth models for *Pinus sylvestris* L. and *Pinus pinaster* Ait. stands in Central Spain. BA: basal area, m^2/ha, QMD:quadratic mean diameter, cm

Variables	Estimate	Standard error	Pr >Chi-squared
Pinus sylvestris			
		Logistic Component	
Independent term	8.2739	1.7578	< 0.0001
QMD	-0.3022	0.0600	< 0.0001
		Linear Component	
Independent term	5.7855	0.6992	< 0.0001
QMD	-0.1703	0.0282	< 0.0001
Pinus pinaster			
		Logistic Component	
Independent term	12.3424	3.0208	< 0.0001
BA	0.1108	0.0544	0.0416
QMD	-0.6154	0.1417	< 0.0001
		Linear Component	
Independent term	6.7389	0.6894	< 0.0001
QMD	-0.2235	0.0317	< 0.0001

are significant in our model and show the importance of stand density driving the ingrowth process (figs. 2 and 3).

Joint validation shows that the two-stage model is useful for predicting the ingrowth in stands of Scots pine and Maritime pine (Fig 1 and table 3) inventoried by using concentric plots. Bias values (absolutes and relatives) allow us to recommend the use of the developed model instead of ignoring the fact that ingrowth occurs in targeted forest ecosystems. However a validation procedure, with an independent data set, should be done to confirm the validity of developed model. Most of the ingrowth detected follows from the concentric plot sample design but, in addition, there are small amounts of basal area that correspond with recruitment. In the *Pinus pinaster* stands recruitment represents the 7.69 % of total ingrowth while in *Pinus sylvestris* represents just the 3.03 %. The bias values (absolute and relative) should be used considering the total ingrowth account for both species that is equal to 3.3 % (Scots pine) and 5.2% (Mediterranean Maritime pine) of total basal area at the end of the considered five-year growth period. Low growth rate has influence upon the small basal area amount that ingrowth represents. Parameters signs match the expected in accordance with current knowledge.

Finally, an allocation rule to distribute the ingrowth between the different concentric plots is needed. The past observed ingrowth rate for each concentric plot can be used. This procedure is similar to proportional growth allocation in stand growth distribution between trees in disaggregation models (e.g., Clutter and Jones, 1980; Pienaar and Harrison, 1988; Ritchie and Hann, 1997). Observed ingrowth rates in the different concen-

Table 3. Ingrowth model validation. Linear models show, for both ingrowth and final basal area values, a high determination coefficient and the independent term is not different from zero and the slope is not different from one. In brackets the parameter standard errors are shown

	C_{i0}	C_{i1}	R^2
Pinus sylvestris			
[eq. 4]	-0.0277 (0.0791)	0.8943 (0.0661)	0.644
[eq. 5]	-0.2964 (0.2931)	1.0039 (0.0055)	0.997
Pinus pinaster			
[eq. 4]	-0.0857 (0.1201)	1.0058 (0.0710)	0.700
[eq. 5]	0.5448 (0.3638)	0.984 (0.0091)	0.993

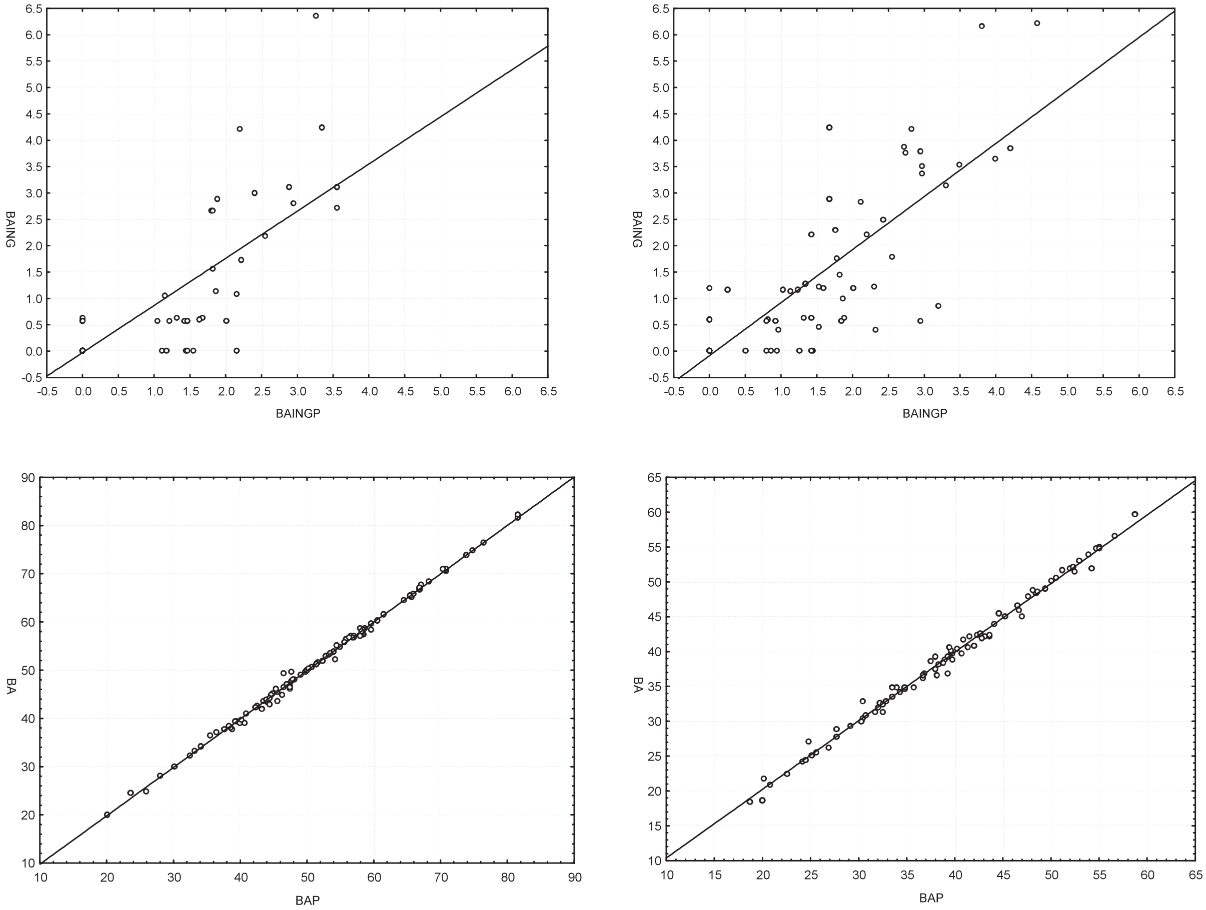

Figure 1. Actual values (y-axis) vs predicted values (x-axis) ingrowths (upper graphs) and. Actual values (y-axis) vs predicted values (x-axis) of basal area at the end of five-year growth period (lower graphs) for Scots pine (left graphs) and Mediterranean Maritime pine (right graphs).

tric plots follow the same pattern for both species. Ingrowth rate is smaller in the inner plot and grows as plot size increase. *Pinus pinaster* ingrowth rates were 8.08, 32.63 and 59.28 percent in each concentric plot while in *Pinus sylvestris* database they were 3.84, 27.18 and 68.98 percent. It is clear that this allocation rule is only a first approximation. However, this simple rule can serve as the starting point. As far as we know there are no experiences on allocating ingrowth under concentric plot design so new research is needed to refine our approach. Different allocation approaches that have been suggested for growth equations (Ritchie and Hann, 1997) can be explored.

Together, logistic and linear models accurately predict ingrowth under concentric plot design forest inventories. Results on Mediterranean species show the importance of density to model ingrowth process. Developed two-step model will be included in a growth simulator to project Spanish National Inventory. In addition, the ingrowth model developed jointly with diameter and height growth, mortality and other relevant equations (taper, site index equations…) composed a model that can be used to optimize stand management practice and to accurately evaluate alternative management regimes.

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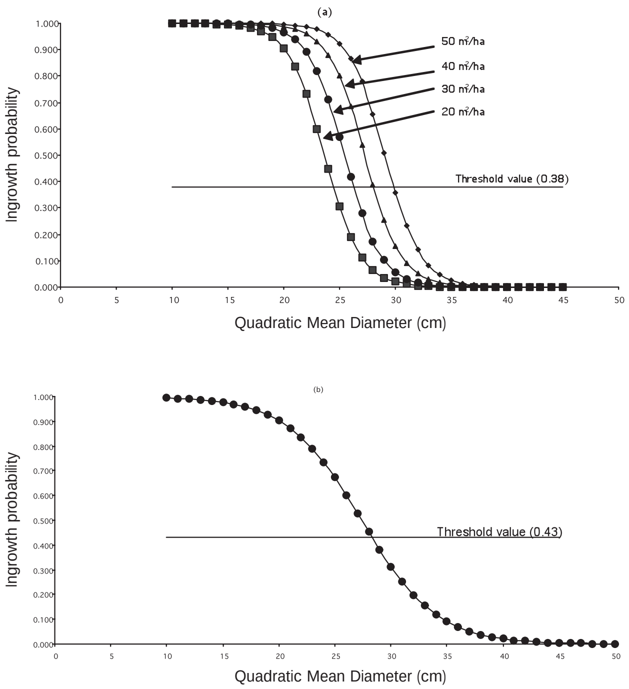

Figure 2. Ingrowth probabilities predicted by the logistic model for different basal area and mean quadratic diameter for Maritime pine (*Pinus pinaster* Ait.) in Central Spain and for different mean quadratic diameter for Scots pine (*Pinus sylvestris* L.).

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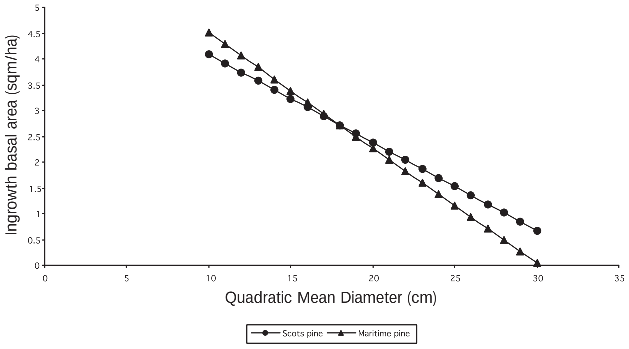

Figure 3. Ingrowth basal area (m²/ha) in Scots pine and Mediterranean Maritime pine in Central Spain.

References

ÁLVAREZ GONZÁLEZ, J.G., CASTEDO DORADO, F., RUIZ GONZÁLEZ, A.D., LÓPEZ SÁNCHEZ, C.A., VON GADOW, K., 2004. A two-step mortality model for even-aged stands of *Pinus radiata* D. Don in Galicia (Northwestern Spain). Annals. of Forest Science 61, 441-450.

BATISTA, J.L.F., MAGUIRE, D.A., 1998. Modeling the spatial structure of tropical forests. Forest Ecology and. Management 110, 293-314.

BIGING, G.S., DOBBERTIN, M., 1992. A comparison of distance-dependent competition measures for height and basal area growth of individual conifer trees. Forest Science 38, 695-720.

BIGING, G.S., DOBBERTIN, M., 1995. Evaluation of competition indices in individual tree growth models. Forest Science 41, 360-377.

BRAVO, F., DEL RÍO, M., PANDO, V., SAN MARTÍN, R., MONTERO, G., ORDÓÑEZ, C., CAÑELLAS, I., 2002. El diseño de las parcelas del Inventario Forestal Nacional y la estimación de variables dasométricas. In: BRAVO, F., DEL RÍO, M., DEL PESO, C. (Eds.), El Inventario Forestal Nacional. Elemento clave para la Gestión Forestal Sostenible Palencia, pp. 19-35.

BRAVO, F., HANN, D.W., MAGUIRE, D.A., 2001. Impact of competitor species composition on predicting diameter growth and survival rates of Douglas-fir trees in southwestern Oregon. Canandian Journal of Forest Resesarch 31, 2237-2247.

BRAVO, F., LEMAY, V., GADOW, K. VON, JANDL, R. (Eds) 2008. Managing Forest Ecosystems: The Challenge of Climate Change. Springer 342 pages

BRAVO, F., LIZARRALDE, I., BRAVO-OVIEDO, A., 2005. Estructura general de un modelo de simulación y proyección aplicable al Inventario Forestal Nacional. In, SEFC: IV Congreso Forestal Nacional, Zaragoza.

BRAVO, F., LIZARRALDE, I., RODRIGUEZ-GARCIA, E., BRAVO-OVIEDO, A, ORDOÑEZ, C., HERRERO, C., PANDO, V., DEL PESO, C., JUEZ, L., GUERRA, B., 2007. Modeling forest dynamics with and empirical approach to support stand management: the case study of Mediterranean *Pinus pinaster* in Central Spain In. PALAHI, M., BIROT Y., ROIS, M. (Eds) Scientific tools and research needs for multifunctional Mediterranean forest ecosystem management 45-55 European Forest Institute

BRAVO, F., MONTERO, G., 2001. Site index estimation in Scots pine (*Pinus sylvestris* L.) stands in the High Ebro Basin (northern Spain) using soil attributes. Forestry 74(4), 395-406.

BRAVO, F., MONTERO, G., 2003. High-grading effects on Scots pine volume and basal area in pure stands in northern Spain. Annals of Forest Science 60:11-18.

BRAVO-OVIEDO, A., DEL RÍO, M., MONTERO, G., 2004. Site index curves and growth model for Mediterranean maritime pine (*Pinus pinaster* Ait.) in Spain. Forest Ecology and Management 201:187-197.

BRAVO-OVIEDO, A., STERBA, H., DEL RIO, M., BRAVO, F., 2005. Competition induced mortality for Mediterranean *P. pinaster* Ait. and *P. sylvestris* L. Forest Ecology and Management 222:88-98

BUCHMAN, R.G., PEDERSON, S.P., WALTERS, N.R., 1983. A tree survival model with application to species of the Great Lakes region. Canadian Journal of Forest Research 13:601-608.

BUONGIORNO, J., GILLES, K.J., 2003. Decision methods for forest resource management. San Diego, California: Kluwer Academic Publishers, 439 pp

CAO, Q.V., 2000. Prediction of annual diameter growth and survival for individual trees from periodic measurements. Forest Science 46:127-131.

CLUTTER, J.L., JONES, E.P., 1980. Prediction of growth after thinning in old field slash pine plantations. USDA Forest Service. Research Paper SE-217.

CURTIS, R.O., CLENDENEN, G.W., DEMARS, D.J., 1981. A new stand simulator for Coast Douglas-fir: DFSIM user's guide. U.S. Forest Service, Portland. Gen. Tech. Rep PNW-128.

CURTIS, R.O., CLENDENEN, G.W., REUKEMA, D.L., DEMARS, D.J., 1982. Yield tables for managed stands of Coast Douglas-fir. U.S. Forest Service, Portland. Gen. Tech. Rep PNW-GTR-135.

EK, A.R., 1974. Nonlinear models for stand table projection in northern hardwood stands. Canadian Journal of Forest Research. 4, 23-27.

FOX, J.C., ADES, P.K., BI, H., 2001. Stochastic structure and individual-tree growth models. Forest Ecology and Management 154, 261-276.

FRIDMAN, J., STAHL, G., 2001. A three-step approach for modelling tree mortality in Swedish forests. Scandinavian Journal of Forest Research 16, 455-466.

GERTNER, G., KOHL, M., 1992. An assessment of some non sampling errors in an National Survey using an error budget. Forest Science 38(3), 525-538.

HAMILTON, D.A., 1986. A logistic model of mortality in thinned and unthinned mixed conifer stands of northern Idaho. Forest Science 32, 989-1000.

HAMILTON, D.A., 1991. Implications of random variation in the Stand Prognosis Model. In, Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Research Note.

HAMILTON, D.A., EDWARDS, B.M., 1976. Modeling the probability of individual tree mortality. USDA Forest Service. Research Paper INT-185.

HANN, D.W., 1980. Development and evaluation of an even- and uneven-aged Ponderosa pine/Arizona fescue stand simulator. USDA Forest Service. Research Paper INT-267.

HANN, D.W., HESTER, A.S., OLSEN, C.L., 1997. ORGANON (edition 6.0) [user's manual]. Dept. of Forest Resources Oregon State University, Corvallis.

HANN, D.W., HANUS, M.L., 2001. Enhanced mortality equations for trees in the mixed conifer zone of southwest Oregon. (Res. Contrib. 34). Forest Research Laboratory, Oregon State University, Corvallis. 34 pp

HANN, D.W., LARSEN, D.R., 1991. Diameter growth equations for fourteen tree species in southwest Oregon. In. Forest Research Laboratory, Oregon State University, Corvallis.

HANN, D.W., RITCHIE, M.W., 1988. Height growth rate of Douglas-fir: a comparison of model forms. Forest Science. 34, 165-175.

HANN, D.W., WANG, C.H., 1990. Mortality equations for individual trees in the mixed-conifer zone of southwest Oregon. Forest Research Laboratory, Oregon State University, Corvallis. Bull 76. 17 pp

HOSMER, D.W., LEMESHOW, S., 1989. Applied Logistic Regression. New York: Wiley Interscience.

HUANG, S., YANG, Y., WANG, Y., 2003. A critical look at procedures for validating growth and yield models. In: AMARO, A., REED, D., SOARES, P. (Eds.), Modelling Forest Systems. Wallingford: CABI Publishing, pp. 271-293.

HUEBSCHMANN, M.M., GERING, L.W., LYNCH, T.B., BITOKI, O., MURPHY, P.A., 2000. An individual-tree growth and yield prediction system for uneven-aged shortleaf pine stands. Southern Journal of Applied Forestry 24(2), 112-120.

HYINK, D.M., MOSER, J.W., 1983. A generalized framework for projecting forest yield and stand structure using diameter distributions. Forest Science 29, 85-95.

IFN, 1985. But et Methodes de l'Inventaire Forestier National. Ministere de l'Agriculture, Service de Forets, Paris.

LEDERMANN, T., 2002. Ein Einwuchsmodell aus den Daten der Österreichischen Waldinventur 1981-1996. Centralblatt für das gesamte Forstwesen 119, 40-77.

LIZARRALDE, I., 2008. Dinámica de rodales y compentencia en las masas de pino silvestre (*Pinus sylvestris* L.) y pino negral (*Pinus pinaster* Ait.) de los Sistemas Central e Ibérico Meridional PhD Thesis, University of Valladolid 229 pp

MESSIER, C., FORTIN, M.J., SCHMIEGELOW, F., DOYON, F., CUMMING, S.G., KIMMINS, J.P., AL., E., 2003. Modelling tools to assess the sustainability of forest management scenarios. NRC Research Press, Ottawa, Ontario.

METLA, 2000. Multi-Source National Forest Inventory of Finland, Materials, From http://www.metla.fi/ohjelma/vmi/nfi-mate.htm.

MIINA, J., 1993. Residual variation in diameter growth in a stand of Scots pine and Norway spruce. Forest Ecology and Management 58, 111-128.

MONSERUD, R.A., 1976. Simulation of forest tree mortality. Forest Science 22, 438-444.

MONSERUD, R.A., LEDERMANN, T., STERBA, H., 2005. Are self-thinning constraints needed in a tree-specific mortality model?. Forest Science 50(6), 848-858.

MONSERUD, R.A., STERBA, H., 1999. Modeling individual tree mortality for Austrian forest species. Forest Ecology and Management 113, 109-123.

MONTERO, G., CAÑELLAS, I., RUIZ PEINADO, R., 2001. Growth and yield models for *Pinus halepensis* Mill. Investigación Agraria: Sistemas y Recursos Forestales 10(1), 179-201.

MOSER, J.W., 1972. Dynamics of an uneven-aged forest stand. Forest Science 18, 184-191.

MOSER, J.W., 1974. A system of equation for the components of forest growth. Dep. For. Yield Res., Royal Coll., For., Stockholm.

MUHAIRWE, C.K., 2003. Biometric models. Nandewar Bio-Region NSW Western Regional Assesmentes. In, Project number: NAND 08 (vol 5) Resource and Conservation Assesment Council, p. 46.

PIENAAR, L.V., HARRISON, W.M., 1988. A stand table projection approach to yield prediction in unthinned even-aged stands. Forest Science 34, 804-808.

PRETZSCH, H., BIBER, P., DURSKY, J., 2002. The single tree-based stand simulator SILVA: construction, application and evaluation. Forest Ecology and Management. 162, 3-21.

RITCHIE, M.W., HANN, D.W., 1997. Implications of disaggregation in forest growth and yield modeling. Forest Science 43(2), 223-233.

ROJO, A., MONTERO, G., 1996. El pino silvestre en la Sierra de Guadarrama. Ministerio de Agricultura, Pesca y Alimentación. Madrid. 293 pp

SÁNCHEZ OROIS, S., RODRÍGUEZ SOALLEIRO, R., 2002. Modelling the growth and management of mixed uneven-aged Maritime Pine-Broadleaved species forests in Galicia, North-western Spain. Scandiavian Journal of Forest Research 17, 538-547.

SHIFLEY, S.R., EK, A.R., BURK, T.E., 1993. A generalized methodology for estimating forest ingrowth at multiple threshold diameters. Forest Science 39(4), 776-798.

SHIVER, B.D., BORDERS, B.E., 1996. Sampling techniques for forest resource inventory. New York: John Wiley. & Sons. 356 p

SOARES, P., TOMÉ, M., 2003. GLOBTREE, an individual tree growth model for *Eucalyptus globulus* In: AMARO, A., REED, D.E., SOARES, P. (Eds.), Modelling forest systems. CAB International, Wallingford, UK., pp. 97-110.

STAGE, A.R., WYKOFF, W.R., 1993. Calibrating a model of stochastic effects o diameter increment for individual-tree simulations of stand dynamics. Forest Science 39, 692-705.

STIFF, C.T., 1979. Modeling the growth dynamics of natural mixed-species Appalachian hardwood stands. In. Polytechnic Institute and State University, Virginia.

TRASOBARES, A., PUKKALA, T., MIINA, J., 2004a. Growth and yield model for uneven-aged mixtures of *Pinus sylvestris* L. and *Pinus nigra* Arn. In Catalonia, north-east Spain. Annals of Forest Science 61, 9-24.

TRASOBARES, A., TOMÉ, M., MIINA, J., 2004b. Growth and yield model for *Pinus halepensis* Mill. in Catalonia, north-east Spain. Forest Ecology and Management 203, 49-62.

USDA, 2004. Forest inventory and analysis. National core field guide, volume 1: Field data collection procedures for phase 2 plots, version 2.0. In, USDA Forest Service, Internal report. On file at USDA Forest Service, Washington Office, Forest Inventory and Analysis. USDA Forest Service, Washington, D.C.

VALBUENA, P., DEL PESO, C., BRAVO, F., 2008. Stand density management diagrams for two Mediterranean species in Eastern Spain Investigación Agrarias: Sistemas y Recursos Forestales 17(2), 97-104

VALENTINE, H.T., FURNIVAL, G.M., 1989. Projections with ingrowth by Markov chains. Forest Science 35(1), 245-250.

VANCLAY, J.K., 1989. A growth model for north Queensland rainforests. Forest Ecology and Management 27, 245-271.

VANCLAY, J.K., 1991. Compatible deterministic and stochastic predictions by probabilistic modeling of individual trees. Forest Science 37(6), 1656-1663.

VANCLAY, J.K., 1994. *Modelling forest growth and yield. Applications to Mixed Tropical Forests*, CAB International, Wallingford, 312 pp

WENSEL, L.C., MEERSCHAERT, W.J., BIGING, G.S., 1987. Tree height and diameter growth models for northern California conifers. Hilgardia 55, 1-20.

WILLIAMS, M.S., 1998. Distinguishing between change and growth in forest surveys. Canadian Journal of Forest Research 28, 1099-1106.

WYKOFF, W.R., 1990. A basal area increment model for individual conifers in the northern Rocky Mountains. Forest Science 36, 1077-1104.

WYKOFF, W.R., CROOKSTON, N.L., STAGE, A.R., 1982. Users's guide to the Stand Prognosis Model Ogden, UT. In. U. S. Department of Agriculture, Forest Service. General Technical Report.

ZHANG, S., AMATEIS, R.L., BURKHART, H.E., 1997. Constraining individual tree diameter increment and survival models for loblolly pine plantations. Forest Science 43, 414-423.