SITE INDEX MODELS FOR CALABRIAN PINE (*Pinus brutia* Ten.) IN THASOS ISLAND, GREECE

MODELOS DE ÍNDICE DE SÍTIO PARA O PINHEIRO CALABRÊS (*Pinus brutia* Ten.) NA ILHA THASOS GRÉCIA

Kyriaki Kitikidou[1]   Diamantis Bountis[2]   Elias Milios[3]

ABSTRACT

A site index model for Calabrian pine (*Pinus brutia* Ten.) in Thasos island (North Aegean sea, Greece) is presented. The model was fitted and validated from 150 stem analyses, obtained from 75 fixed-area plots from five experimental sites. Four height growth equations of difference form were tested and the BAILEY and CLUTTER (1974) function was considered appropriate due to its good performance with both fitting and validation data. The results show errors lower than 5% and little bias.

Keywords: difference equations; *Pinus brutia* Ten; site index model.

RESUMO

Um modelo de índice de sítio para o pinheiro calabrês (*Pinus brutia* Ten.) na ilha Thasos Grécia foi apresentado. O modelo foi ajustado e validado com dados de análises de tronco de 150 árvores, obtidas de 75 parcelas de área fixa provenientes de cinco sítios experimentais. Quatro equações de crescimento em altura na forma de diferença algébrica foram testadas, sendo que a função de BAILEY e CLUTTER (1974) foi considerada apropriada devido à sua boa performance tanto com dados de ajuste como os de validação. Os resultados mostraram erros mais baixos do que 5 % e pouco viés.

Palavras-chave: Curvas de sítio; *Pinus brutia* Ten; método da diferença algébrica.

INTRODUCTION

One of the most important conifer forests in Greece are *Pinus brutia* Ten. The great ecological variability of this species and the geographical isolation among its populations imply the existence of several geographic races, which present different genetic characteristics and behavior (FRANKIS, 1993). Calabrian pine extends primarily in Turkey and far Eastern Greece, secondarily in the Crimea, Caucasus coast, Azerbaijan, Iraq, Syria, Lebanon, Crete and Cyprus (FRANKIS, 1993).

In spite of its low productivity, Calabrian pine plays a very important role in Mediterranean forest ecosystems, with multi-purpose uses like wildlife, hunting, recreation, protection, etc. (FRANKIS, 1993; 1999). Especially important are the stands reforested post-fire in order to prevent soil erosion (FRANKIS, 1993; 1999). A sap-sucking insect, *Marchalina hellenica*, produces large amounts of honey-dew, harvested by honeybees and sold as "pine honey" (FRANKIS, 1993; 1999).

Yield tables are static standmodels, frequently based on fully-stocked stands, which do not accurately reflect the stand evolution under different thinning intensities (GARCÍA, 1994). On the other hand, site index models which include a good description of the state of the stand at any

1. Forester, Dr., Lecturer, Department of Forestry and Management of the Environment and Natural Resources, Demokritus University of Thrace, Pandazidou 193, PO Box 68200, Orestiada, Greece. kkitikid@fmenr.duth.gr
2. Forester, MSc., Department of Forestry and Management of the Environment and Natural Resources, Demokritus University of Thrace, Pandazidou 193, PO Box 68200, Orestiada, Greece. diamantis22@windowslive.com
3. Forester, Dr., Assistant Professor, Department of Forestry and Management of the Environment and Natural Resources, Demokritus University of Thrace, Pandazidou 193, PO Box 68200, Orestiada, Greece. emilios@fmenr.duth.gr

point in time, as well as the change rates as a function of this state are able to adequately predict the stand development. (GARCÍA, 1994), evaluate forest instant changes due to thinning and assess forest productivity (ÁLVAREZ-GONZÁLEZ et al. , 2002). The development of a flexible growth model could facilitate the decision making, in order to guarantee the sustainable management. The modeling level is often dictated by available data, desired level for prediction and time horizon for projection (BURKHART, 2003).

In the last few years, some partial aspects of the growth and yield of Calabrian pine in Greece have been studied (HATZISTATHIS et al. , 1995; SKORDILIS and THANOS, 1997; SPANOS et al. , 2000; PALAHÍ et al. , 2008; ADAMOPOULOS et al. , 2009). Data collected in the net of permanent area plots for studying growth in *P. brutia* stands in Greece (SPANOS, I. et al. , 2000) are limited for the development of an individual-tree model because of the scarce information measured at tree-level. On the other hand, the low economical value and the extensive character of the management of Calabrian pine stands in the Mediterranean area make it advisable to choose a stand modeling level which requires only basic input data, such as site index (ARNOLD et al. , 2005). Taking into account these premises, the aim of this work was to develop a site index model for Calabrian pine in Thasos island (North Aegean sea, Greece), which could be used to evaluate forest productivity and changes due to future thinning (ÁLVAREZ-GONZÁLEZ, J. et al. , 2002).

MATERIAL AND METHODS

Data

Plots from Calabrian pine forests in Thasos island (North Aegean sea, Greece) that were burned in the wildfire of 1989 were established covering different site quality. In order to determine different sites, only large areas that were covered almost totally by Calabrian pine stand were used. Five sites were determined: Site 1 (rock: limestone, soil depth: 50-60 cm), site 2 (rock: limestone, soil depth: 30-35 cm), site 3 (rock: limestone, soil depth: 20-25 cm), site 4 (rock: schist, soil depth: 40-45 cm) and site 5 (rock: schist, soil depth: 20-25 cm). Data were obtained from 75 fixed-area plots, 15 from each site. This network was established in 2008 to assess, among others, forest productivity and attempt the development of a site index model. No silvicultural operations were made in plots.

From each plot and in similar stand conditions in each site, two dominant/co-dominant trees were felled at installation time for stem analysis purposes, resulting in 150 trees. From each tree, cross-sectional discs were cut and removed from the stump height ($\approx$0 m), at breast height (1.3 m) and every 1 m, up to the bole. The last disc was collected from the 2 cm-bole diameter. In each cross-sectional disc the number of annual growth rings was counted using the LINTAB system of RinnTech and the program TSAP-Win (RINN, 2003). Annual height values were interpolated from cross section data using the modified algorithm of Carmean (CARMEAN, 1972; NEWBERRY, 1991). Summary statistics are given in Table 1.

Fitting method

Site index models usually need an index-age to estimate the site index value. Index-age selection may be problematic as results in errors and low flexibility of the shape of the curves and may, also, influence the accuracy of site index estimates (HEGER, 1973). To avoid this problem base-age invariant equations were preferred.

Several methods have been proposed in the literature to generate site index curves with desirable characteristics: asymptote, inflection point, base-age invariance or logical behavior among others (GOELZ and BURK, 1992; ELFVING and KIVISTE, 1997). BAILEY and CLUTTER (1974) used an equation of the differential form $H_2 = f(T_2, T_1, H_1)$ where H_2 and H_1 are heights at age T_2 and T_1, respectively. This method gathers many of the desirable characteristics of a well-behaved site index model. In this study, the BAILEY and

TABLE 1: Initial mean values of forest attributes used in fitting and validation data.
TABELA 1: Valores médios iniciais dos atributos florestais usados no ajustamento e validação dos dados

Variable	Units	No. of stems	Mean	Standard deviation	Minimum	Maximum
Age	year	150	17,09	1,253	12	19
Total height	m	150	6,2165	2,12041	2,35	11,56

CLUTTER (1974) function and the CHAPMAN and RICHARDS (1959) function were considered as candidate functions to be differentiated. There are as many difference equations as parameters in the original function, which may come from height–age equation or differential forms (CAO, 1993). In this work, only those parameters related to growth rate and asymptote were considered as free. In accordance with this, we have fitted four difference form models to our data. Table 2 shows the difference form of all tested functions.

According to HUANG (1997), there are six types of data structures that can be used to fit difference equation growth models: The longest non-descending growth interval (I), the longest growth intervals (II), the non-overlapping, non-descending growth interval (III), the non-overlapping growth intervals (IV), the all possible non-descending growth intervals (V) and the all possible growth intervals (VI), and he found that structure type VI provided the most stable and consistent results, as GOELZ and BURK (1992) noted before. In this study, 150 stem analyses and all possible growth intervals were used resulting in 977 pairs of observations.

Fitting coefficients from the data of temporal series, such as stem analysis may present auto-correlation. This means that the error term is not independent and does not follow a normal distribution. To avoid this, fitting was performed in a two step procedure using SPSS (LEVESQUE and SPSS Inc., 2006). In the first step the parameters are fitted according to ordinary non-linear least squares.

After that, the error term is expanded and the model is fitted again. The expansion of the model leads to a first order auto-regressive procedure in order to make the error term independent. Let the difference model be:

$$H_{ij} = f(T_i, H_j, T_j, \beta) + e_{ij}$$

where H_{ij} is a prediction of height i by using height j, T_i, is age i, T_j is age j, β is the vector of parameters and e_{ij} is the error term that is not independent and not identically distributed (MONSERUD, 1984; GOELZ and BURK, 1992; GOELZ and BURK, 1996). This error is expanded in the following way:

$$e_{ij} = \rho\varepsilon_{i-1,j} + \gamma\varepsilon_{i,j-1} + \varepsilon_{ij}$$

where ρ is the auto-correlation between the residual of estimation H_{ij} and the residual that corresponds to estimation H_{i-1} when H_j is used as a predictor variable, γ is the relationship between the current residual and the residual from estimating H_i using H_{j-1} as a predictor variable. ε_{ij} represents independent errors, with mean value equaling zero and constant variance equaling η^2. ρ and γ have no further use in the site index model as ε_{-1} ($\varepsilon_{i-1,j}$ and $\varepsilon_{i,j-1}$ values) is not observable without stem analysis (MONSERUD, 1984).

Validation method

For site index model validation purposes, data were split in two groups. The first group (80%

TABLE 2:   Tested functions to represent site index.
TABELA 2: Funções testadas para expressar o índice de sítio

Original function	Free parameter	Difference form	
(1) CHAPMAN and RICHARDS, (1959) $Y = A[1 - exp(-kT)^c]$	A	$H_2 = H_1\left[\dfrac{1 - exp(kT_2)}{1 - exp(kT_1)}\right]^c$	(1.1)
	k	$H_2 = A\left\{1 - \left[1 - \left(\dfrac{H_1}{A}\right)^{\frac{1}{c}}\right]^{\frac{T_2}{T_1}}\right\}^c$	(1.2)
(2) BAILEY and CLUTTER, (1974) $\ln Y = a + bT^c$	a	$H_2 = H_1 exp\left\{b\left[T_2^c - T_1^c\right]\right\}$	(2.1)
	b	$H_2 = exp\left[a + (\ln H_1 - a)\left(\dfrac{T_2}{T_1}\right)^c\right]$	(2.2)

Symbols: Y is total tree height at age T; H_2 and H_1 are heights at age T_2 and T_1, respectively; A, k, a, b, c are model parameters; exp is the symbol for the base of the natural logarithm ln.

of the trees – 120 stem analyses) was used as fitting data, and the second group (20% of the trees – 30 stem analyses) was used as validation data. This validation method is known as cross-validation (EZEKIEL and FOX, 1959; LAIRD and CADY, 1969; STONE, 1974; MARQUARDT and SNEE, 1975; McCarthy, 1976).

The significance of the bias was studied. Absolute mean residual, AMRES (Eq. (3)), root of mean square error (RMSE) (Eq. (4)) and model efficiency, EF (Eq. (5)) are measures of the accuracy of the model (SOARES et al. , 1995; GADOW et al. , 2001) and they were computed with the fitting data set as well as with the independent data set for validation purposes. The percentage of AMRES and RMSE was also computed. The model that accounted for the best accuracy in fitting and validation data was chosen.

$$AMRES = \frac{\sum |y_i - \hat{y}_i|}{n} \qquad (3)$$

$$RMSE = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n - 1 - p}} \qquad (4)$$

$$EF = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2} \qquad (5)$$

where y_i is observed value, $\hat{y}_i$ is estimated value, $\bar{y}$ is average observed value, n is the number of data and p is the number of parameters in the model.

RESULTS

Results of the site index models estimation are shown in Table 3. All the parameters are significant except for those of Chapmand and Richards function (Eqs. (2.1) and 1.2) which did not meet the convergence criterion, so it will not be taken into account for further discussion.

Errors measures and model efficiency value are better for the Bailey and Clutter model with free asymptote (Eq.(2.1)). The Bailey and Clutter model with common asymptote (Eq. (2.2)) is unbiased. Some bias is shown in the Bailey and Clutter function with free asymptote (0.23 m).

With independent data (Table 4), Eqs. (2.1) and (2.2) are quite precise, with relative AMRES lower than 5%. Eq. (2.2) is statistically biased, resulting in overestimation of prediction. Eq. (2.1) is quite precise and shows a little underestimation that it is not statistically biased. Moreover, the Bailey and Clutter model with free asymptote has better errors measures and efficiency value, so we determine that this model is appropriate for our data and it is chosen as apt for evaluating site quality through site index estimation of *P. brutia* Ten.

Figure 1 shows the curves obtained when heights 3, 5, 7, 9 and 11 are reached at age 16.

DISCUSSION

The site index model has been developed using a difference equation approach. Among the four tested equations, the Bailey–Clutter expression

TABLE 3:   Fitting results of the site index models.
TABELA 3: Resultados do ajuste dos modelos de índice de sítio

Model	Free Parameter	Estimated Parameters			SSE	MSE	EF	Bias
		a	b	c				
2.1	a		1.356 (0.869)	0.332 (0.124)	108.977	0.162	74.13	0.23[**]
2.2	b	0.436 (0.117)		1.205 (0.194)	117.576	0.175	68.50	-0.02[n.s.]

Symbols:

SSE (Sum of Squared Errors) = $\sum (y_i - \hat{y}_i)^2$

MSE = SSE/(n-1-p)

$EF = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2}$

y_i is observed value, $\hat{y}_i$ is estimated value, $\bar{y}$ is average observed value, n is the number of data and p is the number of parameters in the model

In parenthesis approximate standard error. Parameters as in Table 2.
[**] P < 0.01.

TABLE 4:   Site index validation results.
TABELA 4: Resultados de validação de índice de sítio

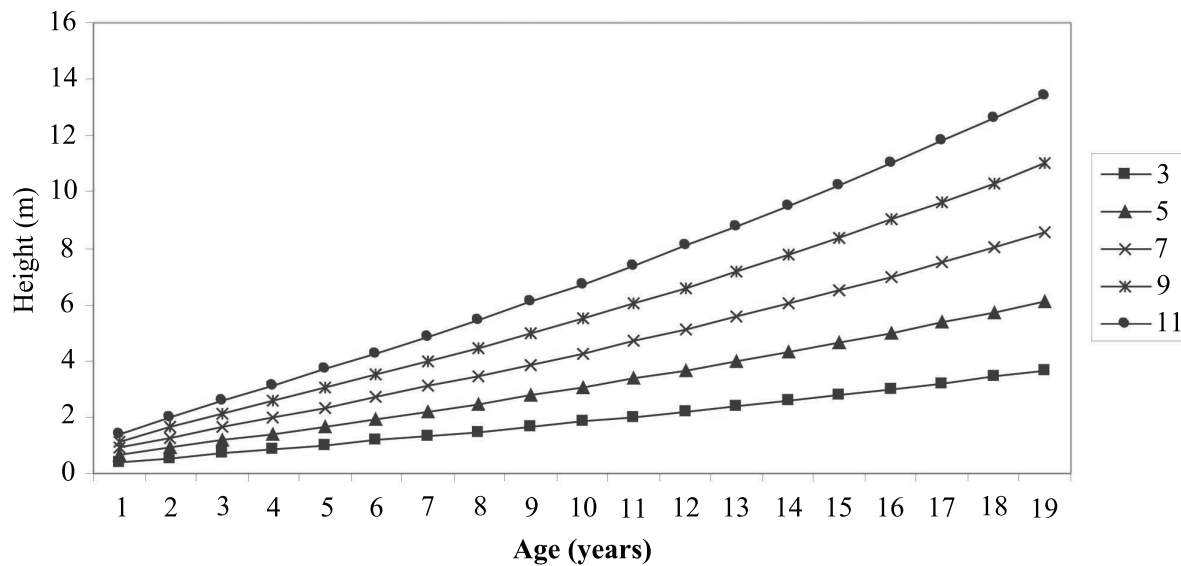| Model	N	AMRES	Error (%)	RMSE	Error (%)	EF (%)	Bias
2.1	30	1.04	3.30	0.02	0.55	84.88	0.06[n.s.]
2.2	30	1.39	4.41	0.03	0.80	79.73	−0.24[**]

n.s.: no significance.
[**] $P < 0.01$.

FIGURE 1: Site index curves from the Bailey and Clutter model for *Pinus brutia* in Thasos island Greece.
FIGURA 1: Curvas de sítio com base no modelo de Bailey e Clutter para *Pinus brutia* na ilha Thasos Grécia.

with free asymptote (Eq. (2.2)) shows the best results with fitting and validation data. The Bailey–Clutter model is a modification of Korf's equation and presents all the desirable characteristics (BAILEY and CLUTTER, 1974). Among them, polymorphism is sometimes considered (GOELZ and BURK, 1992), although the growth pattern of every species must be studied comparing different sort of equations. In this work, a model with free asymptote and polymorphic has been chosen as appropriate, in similar way as for *Pinus pinea* L. (CALAMA et al. , 2003), and *Pinus pinaster* Ait. (BRAVO-OVIEDO et al. , 2004), two others Mediterranean pine species. The anamorphic Chapman and Richards model did not converged, so further studies by regions might be interesting in order to assess the anamorphic growth pattern of the species.

Bailey and Clutter's model is the integral form of a basal area increment model and may be considered part of a growth model (BAILEY and CLUTTER, 1974). In the model proposed for thinned loblolly pine stands (*Pinus taeda* L.) by CLUTTER (1963), height growth depended on the state of the stand and the site index. RÍO and MONTERO (2001) reported the same result for *Pinus sylvestris* L. in Spain. Basal area and age are good enough estimators of the state in pine stands where silviculture is applied, on the assumption that the range of ages does not include low values, where growth rate is higher and growth depends more on site index. This indicates that other variables such as site index may not be included in basal area projections for stands of these species (BRAVO-OVIEDO et al. , 2004).

A model is often considered adequate when low values for statistics are computed, no bias and high efficiency are found in the fitting procedure; however, a good model should perform properly also with independent data. In this sense, the function developed in this work shows little bias, low error and high efficiency with independent data provided by managed plots.

CONCLUSION

Modeling is one of the main management keys due to its flexibility and utility in decision planning. In this work, a site index model for Calabrian pine (*Pinus brutia* Ten.) in Thasos island (North Aegean sea, Greece) is fitted and validated from 150 stem analyses. Stand-level measurements approach seems adequate for the extensive management of *P. brutia* stands in the Mediterranean area. Nevertheless, if more detailed data are available, as is in our study, a tree-level approach could be interesting in order to investigate some aspects of sustainable management, such as structural diversity or fauna habitat assessment.

ACKNOWLEDGEMENTS

REFERENCES

ADAMOPOULOS, S. et al. Ring width, latewood proportion and dry density in stems of *Pinus brutia* Ten. **European Journal of Wood and Wood Products**, Berlin, v. 67, n. 4, p. 471-477, Nov. 2009.

ÁLVAREZ-GONZÁLEZ, J. et al. Modeling the effect of thinnings on the diameter distribution of even-aged maritime pine stands. **Forest Ecology and Management**, v. 165, n. 1-3, p. 57–65, July 2002.

ARNOLD, R. et al. Genetic variation and tree improvement. In: NAMBIAR, S.; FERGUSON, I. (Eds.). **New Forests**: Wood production and environmental services. Melbourne: CSIRO Publishing, 2005. p. 248.

BAILEY, R.; CLUTTER, J. Base-age invariant polymorphic site curves. **Forest Science**, v. 20, n. 2, p. 155–159, June 1974.

BRAVO-OVIEDO, A. et al. Site index curves and growth model for Mediterranean maritime pine (*Pinus pinaster* Ait.) in Spain. **Forest Ecology and Management**, v. 201, n. 2-3, p. 187-197, Sept. 2004.

BURKHART, H. Suggestions for choosing an appropriate level for modeling forest stands. In: AMARO, A. et al. (Eds.). **Modeling Forest Ecosystems**. Wallingford: CABI Publishing, 2003. p. 3–10.

CALAMA, R. et al. Inter-regional variability in site index models for even-aged stands of stone pine (*Pinus pinea* L.) in Spain. **Annals of Forest Science**, v. 60, n. 3, p. 259–269, Apr. 2003.

CAO, Q. Estimating coefficients of base-age-invariant site index equations. **Canadian Journal of Forest Research**, Ottawa, v. 23, p. 2343–2347, Apr. 1993.

CARMEAN, W. Site index curves for upland oaks in the Central States. **Forest Science**, v. 18, n. 2, p. 109-120, 1972.

CLUTTER, J. Compatible growth and yield models for Loblolly pine. **Forest Science**, v. 9, n. 3, p. 354–371, Sept. 1963.

ELFVING, B.; KIVISTE, A. Construction of site index equations for *Pinus sylvestris* L. using permanent plot data in Sweden. **Forest Ecology and Management**, v. 98, n. 2, p. 125–134, Nov. 1997.

EZEKIEL, M.; FOX, K. **Methods of correlation and regression analysis**. New York: John Wiley and Sons, 1959. 550 p.

FRANKIS, M. Morphology and affinities of *Pinus brutia*. In: TASHKIN, O. (Ed.). **Papers International Symposium** *Pinus brutia*. Marmaris, Ankara, 1993. p. 11-18.

FRANKIS, M. *Pinus brutia*. **Curtis's Botanical Magazine**, London, v. 16, n. 3, p. 173-184, Aug. 1999.

GADOW, K. et al. Modelización del crecimiento y la evolución de bosques. **IUFRO**, Vienna, v. 12, p. 234-242, Sept. 2001.

GARCÍA, O. The state space approach in growth modeling. **Canadian Journal of Forest Research**, Ottawa, v. 24, p. 1894–1903, 1994.

GOELZ, J.; BURK, T. Development of a well-behaved site index equation: jack pine in North Central Ontario. **Canadian Journal of Forest Research**, Ottawa, v. 22, p. 776–784, 1992.

GOELZ, J.; BURK, T. Measurement error causes bias in site index equations. **Canadian Journal of Forest Research**, Ottawa, v. 26, p. 1585–1593, 1996.

HATZISTATHIS, A. et al. **Growth and yield of *Pinus brutia* reforestations in relation with soil and physiographic factors**. Aristotle University of Thessaloniki, Greece, Scientific Annals of the Department of Forestry and Natural Environment, Aristotle University of Thessaloniki, 1995. v. 38.

HEGER, L. Effect of index age on the precision of site index. **Canadian Journal of Forest Research**, Ottawa, v. 3, n. 1, p. 1–6, 1973.

HUANG, S. Development of compatible height and site index models for young and mature stands

within an ecosystem-based management framework. In: AMARO, A.; TOMÉ, M. (Eds.). **Empirical and process based models for forest tree and stand growth simulation**. Oeiras: Salamandra. 1997. p. 591.

LAIRD, R.; CADY, F. Combined analysis of yield data from fertilizer experiments. **Agronomy Journal**, Madison, v. 61, p. 829-834, May 1969.

LEVESQUE, R.; SPSS Inc. **SPSS programming and data management. 3rd edition. A guide for SPSS and SAS users**. Chicago, USA: SPSS Inc., 2006. 388 p.

MARQUARDT, D.; SNEE, R. Ridge regression in practice. **The American Statistician**, v. 29, n. 1, p. 3-20, Feb. 1975.

MCCARTHY, P. The use of balanced half-sample replication in cross-validation studies. **Journal of the American Statistical Association**, v. 71, n. 355, p. 596-604, 1976.

MONSERUD, R. Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest habitat type. **Forest Science**, v. 30, n. 4, p. 943–965, Dec. 1984.

NEWBERRY, J. A note on Carmean's estimate of height from stem analysis data. **Forest Science**, v. 37, p. 368-369, 1991.

PALAHÍ, M. et al. Modeling site quality and individual-tree growth in pure and mixed *Pinus brutia* stands in north-east Greece. **Annals of Forest Science**, v. 65, n. 5, p. 501-515, July 2008.

RICHARDS, F. A flexible growth function for empirical use. **Journal of Experimental Botany**, v. 10, p. 290–301, 1959.

RÍO, M.; MONTERO, G. **Modelo de simulación de claras en masas de *Pinus sylvestris* L**. Madrid: Ministerio de Ciencia y Tecnología, 2001. (Monografías INIA: Forestal n. 3).

SKORDILIS, A.; THANOS C. Comparative ecophysiology of seed germination strategies in the seven pine species naturally growing in Greece. In: ELISS, R. et al. (Eds.). **Basic and applied aspects in seed biology**. Dordrecht: Klower Academic Press, 1997. p. 623-632.

SOARES, P. et al. Evaluating a growth model for forest management using continuous forest inventory data. **Forest Ecology and Management**, v. 71, n. 3, p. 251–265, Feb. 1995.

SPANOS, I. et al. Postfire, natural regeneration of *Pinus brutia* forests in Thasos island, Greece. **Acta Oecologica**, v. 21, n. 1, p. 13-20, Jan. 2000.

STONE, M. Cross-validation choice and assessment of statistical predictions (with discussion). **Journal of the Royal Statistical Society Series B**, v. 36, p. 111-147, 1974.