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PRELIMINARY INDIVIDUAL TREE GROWTH MODEL, SITE INDEX MODEL «MORTALITY» MODEL FOR ALEPPO PINE (*Pinus halepensis* MILL.) IN CHALKIDIKI (NORTHERN GREECE)

MODELO INDIVIDUAL PRELIMINAR DE CRESCIMENTO DE ÁRVORE, MODELO DE ÍNDICE DE LOCAL E MODELO DE "MORTALIDADE" PARA PINHEIRO-DE-ALEPPO (*Pinus halepensis* Mill.) EM CHALKIDIKI (GRÉCIA DO NORTE)

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ABSTRACT

Preliminary height models, a volume model, a site index model and a survival analysis for *Pinus halepensis* Mill. in Chalkidiki (Northern Greece) were preliminarily developed based on measurements of 20 experimental plots established in 2010. The data for the height, volume and 'mortality' models consisted of 790 observations taken from 40 trees (20 dominant and 20 co-dominant). An equation derived from the hyperbolic function was selected to model the dominant height and the volume development. The height growth model was used as a guide curve to develop two site index curves. Mean dominant and codominant height was estimated at 10m (site I) and 7m (site II) (base age of 17 years). Kaplan-Meier survival and hazard functions applied for the 'mortality' analysis, confirmed the site index curves developed from the height model (SI10 and SI7).
Keywords: tree modelling; survival analysis.

RESUMO

Modelos preliminares de altura, modelo de volume, modelo de índice de sítio e análise de "sobrevivência" para *Pinus halepensis* Mill., em Chalkidiki (Norte da Grécia) foram preliminarmente desenvolvidos baseados em medidas de 20 parcelas experimentais estabelecidas em 2010. Os dados para altura, volume e modelos de «mortalidade» consistiram em 790 observações obtidas de 40 árvores (20 dominantes e 20 codominantes). Uma equação derivada da função hiperbólica foi selecionada para modelar altura dominante e volume de desenvolvimento. O modelo de crescimento em altura foi usado como uma curva-guia para desenvolver duas curvas de índice de sítio. A altura média dominante e codominante foi estimada em 10 m (Local I) e 7 m (Local II) (idade-base de 17 anos). A sobrevivência de Kaplan-Meier e as funções de risco aplicadas para a análise de "sobrevivência", confirmaram as curvas de índice de sítio desenvolvidas pelo modelo de altura (SI10 e SI7).
Palavras-chave: modelagem em árvore; análise de sobrevivência.

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INTRODUCTION

Aleppo pine (*Pinus halepensis* Mill.) is a common forest species of the western Mediterranean; we find it in Spain, France, Italy, Croatia, Albania, Greece, Morocco, Algeria, Tunisia, Libya and Malta, and a few populations in the eastern Mediterranean (Turkey, Syria, Israel, Jordan and Lebanon). Its total forest cover is estimated at 3.5 million hectares (CRITCHFIELD; LITTLE, 1996).

Aleppo pine constitutes the main source of wood and forest cover in many Mediterranean countries. Mean productivity is estimated at 1–2 m^3/ha/year and maximum yield can reach 12–15 m^3. The wood is used in construction, industry, carpentry, firewood and pulp, while seeds are used for making pastry (MUENCHOW, 1986).

As regards the species relation to nutrient recycling, litter production enriches the soil with nutrient input (BRAY; GORHAM, 1964, RODIN; BAZILEVICH, 1967). In ecosystems where there is a lack of available nutrients in the soil, as in the Mediterranean ecosystems, both litter production and decomposition turn out to be essential for nutrient recycling (ARIANOUTSOU, 1989; HARCOMBE, 1987). Arianoutsou and Radea (2000) estimate that Aleppo pine species offers a significant amount of energy annually, based on the fact that approximately 0.17 kgm/m^2 of litter, analogous to 816 Kcal (1 Kg litter equals 4800 Kcal (MCFADYEN, 1971)) is produced annually by Aleppo pines, and the litter of the understorey shrubs add about 773 Kcal of energy to the subsoil. Removal of needles and thin branches frequently, although it reduces the possibility of fire, is not recommended, given that forest floor represents up to 50% of the total biomass and contains a great number of nutrients (ALIFRAGIS et al., 2001; SMIRIS et al., 2000). As expected, biomass production depends on the site; in good quality sites more biomass is found (SMIRIS et al., 1998); consequently, more energy is restored. Thus, the development of site index models is essential from an energy point of view.

SSeveral studies aiming at investigating Aleppo pine have been conducted (DASKALAKOU; THANOS, 2004; GOUDELIS et al., 2007; HERRANZ et al., 1997; MARTINEZ-SANCHEZ et al., 1999; PAPAGEORGIOU, 2011; PAUSAS et al., 2003; PAUSAS et al., 2004; THANOS; DASKALAKOU, 2000; THANOS et al., 1996; TSITSONI, 1997; VERROIOS; GEORGIADIS, 2002). Growth models can be classified as stand-level models or tree-level models, depending on the measurements provided (VANCLAY, 1994). When we have individual tree measurements and we develop tree-level models, these models give a more detailed description of the stand structure and its dynamics than stand-level models (MABVURIRA; MIINA, 2001). There are many tree-level models developed (among others, ALDER, 1979; CAO, 2000; KITIKIDOU et al., 2011; KITIKIDOU et al., 2012; KITIKIDOU et al., 2011; MABVURIRA; MIINA, 2001; PALAHÍ et al., 2004; PUKKALA, 1988; 1989; RAUTIAINEN, 1999; SCHRÖDER et al., 2001; SHAFII et al., 1990; TENNENT, 1982; VANCLAY, 1991; ZHANG et al., 1997). The development of individual tree-level growth models for Aleppo pine would help in applying forest management in forest-level planning (PALAHÍ; GRAU, 2003).

The aim of this study was to develop a preliminarily model set from measurements on young Aleppo pine trees in Chalkikidi (Northern Greece). The model set includes a height model, a volume model, a site index model, and a 'mortality' probability model. Moreover, the sampled trees classification from the site index model is compared to classification based on soil depth.

MATERIAL AND METHODS

Data

The data were measured in 20 experimental plots established in 2010, in an area where a forest fire took place in spring of 1990, in Peninsula of Kassandra in Chalkidiki (Northern Greece). In particular, the plots were established in areas where the cover by the tree canopy projection is over 80%. In these areas the soil depth was measured in soil profiles in order to classify sites (PAPAGEORGIOU, 2011). Two sites were determined: site A where the soil depth was 50 to 55+ cm (approximately 55 cm, only in one profile the soil depth was 57 cm) and site B where the soil depth was 35 to 40 cm (PAPAGEORGIOU, 2011). In each Site 10 plots of 25 m² (5m x 5m) were established using the simple random sampling method. Site A represents the productive sites, while Site B represents the medium productivity sites (PAPAGEORGIOU, 2011). The soil depth was used for the classification of site productivity, since in Greece is dry during summer regions, the water storing capacity and the depth of soil is strongly related to site productivity (DAFIS, 1986; HATZISTATHIS; DAFIS, 1989). The geological substratum in the area where the plots were established is sedimentary white marls, while the soil in the Aleppo pine stands of Kassandra Peninsula is sandy to sandy-loam (KLONARIS, 1990). In the nearest meteorological station the annual rainfall is 602.5 mm and the mean yearly temperature is 16.1 °C (KLONARIS, 1990). During summer (June, July and August) the 9.5 % of the annual rainfall has fallen in the area (data from KLONARIS, 1990). One dominant and one codominant tree were cut from each plot in the winter of 2010 -2011. Sampled trees summary statistics are given in Table 1.

The max age of trees is 22 years, since some trees survived the forest fire as 1-year old seedlings. The stands were naturally regenerated with no thinning treatments. From each sampled tree, cross-sectional discs were cut and removed from various heights. In each cross-sectional disc the number and the width of annual growth rings were counted with the LINTAB system of RinnTech and the program TSAP-Win (RINN, 2003). A stem analysis was conducted in each tree. Annual heights were calculated using the modified algorithm of Carmean (CARMEAN, 1972; NEWBERRY, 1991), while volumes were calculated using XLSTEM formulas of Regent Instruments (FORTIN; LABRANCHE, 1996). Stem analysis resulted in 796 age/height/volume observations.

Height and volume model

After several testings in the estimation data, we ended up in a hyperbolic function of the form:

$$Y = b_0 X^{b_1}$$

which was found to be appropriate for both height and volume models.

To determine the accuracy of model predictions, bias and precision of the models were calculated (GADOW; HUI, 1998; SOARES et al., 1995; VANCLAY, 1994). Absolute and relative biases and root mean square error (RMSE) were calculated as follows:

$$bias = \frac{\sum (y_i - \hat{y}_i)}{n}$$

$$bias\% = \frac{\sum (y_i - \hat{y}_i)/n}{\sum \hat{y}_i/n} 100$$

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

$$RMSE\% = \frac{\sqrt{\sum (y_i - \hat{y}_i)^2/(n-1)}}{\sum \hat{y}_i/n} 100$$

where n is the number of observations; and y_i and $\hat{y}_i$ are observed and predicted values, respectively.

Site index model

Among various techniques for developing site index curves, the guide curve method is considered appropriate where the re-measurements of the permanent plot data for forest stands are lacking (CARMEAN, 1972; MCFADYEN, 1971); therefore, this method was used in the present study. Considering the age of culmination of mean annual increment, as recommended by various researchers (CURTIS et al., 1974; THESHOME;

TABLE 1: Summary statistics of the sampled trees.
TABELA 1: Estatísticas descritivas das árvores analisadas.

Variable	Site									
	A					B				
	N	Mean	Standard Deviation	Min	Max	N	Mean	Standard Deviation	Min	Max
Age (years)	20	20	2	16	22	20	20	1	18	22
Height (m)	20	9.96	1.31	7.90	12.30	20	6.63	0.93	5.20	8.20
Volume (dm^3)	20	43.87	26.52	13.93	107.24	20	13.02	8.57	2.66	37.90
Diameter at breast height DBH (cm)	20	12.1	3.7	6.6	19.5	20	7.3	2.5	3.4	13.7

PETTY, 2000, TROUSDELL et al., 1974), 17 years was adopted as the appropriate base age for the determination of site index of Aleppo pine.

2.4. «Mortality» model

Kaplan–Meier survival and hazard functions are used to quantify the «mortality»'s probability distribution in a population (MARTINEZ-SANCHEZ et al., 1999). Survival function is defined as (BERKSON; GAGE, 1950; COLLETT, 1994; COX; OAKES, 1984):

$$S(t) = P(T > t)$$

where $S(t)$ is the probability for the sample unit to die in a time T later than t. The random variable T, which counts time till death, doesn't have any restriction besides being greater than zero.

Hazard function expresses instantaneous «mortality», therefore is a conditional probability defined as (COLLETT, 1994; COX; OAKES, 1984):

$$h(t) = \lim_{\Delta t \to 0} \frac{P(t \le T \le t + \Delta t \,|\, T \ge t)}{\Delta t}$$

where $h(t)$ is the probability for the sample unit to die exactly at time t, given that death didn't occur before t. We can note that hazard function derives from survival function.

Hypothesis H_0, that survival functions are homogeneous for two groups can be tested by applying the nonparametric logrank test (LANDAU; EVERITT, 2004):

$$U_L = \sum_{j=1}^{r} \left(d_j - e_j \right)$$

where U_L is the sum of the differences between the number of observed deaths d and the number of expected deaths e at times r, if there is at least one death. Squaring and dividing U_L by the estimated variance we calculate the logranks' test chi-square. With stratified logrank test, the U_L function is calculated per factor, and we can examine if there are variables related to survival. In this work, we used site quality (sites I and II) as factor.

As we can see in mathematical formulas used in survival analysis, the time that an event takes place is crucial. Therefore, the main obstacle as regards the application of the method in forest inventories is the lack of age measurements and the exact time of the tree death (FLEWELLING; MONSERUD, 2002). The knowledge of age, however, is not necessary in order to apply survival analysis. Any kind of measurement showing changes in the tree status as time passes, can replace traditional age measurements (HARCOMBE, 1987; KITIKIDOU; APOSTOLOPOULOU, 2011; KITIKIDOU; MATIS, 2011; WOODALL; GRAMBSCH; THOMAS, 2005). In the present study, we used height measurements, as they were calculated from stem analyses, instead of survival measurements, and the tree social status (dominant-codominant) as the status variable, running SURVIVAL from the SPSS statistical package (LANDAU; EVERITT, 2004). Site types (I, II) were used as factor.

RESULTS

Height and volume model

Fitting height and volume equations to data gave the following results:

$$h = 0.2263t^{1.3386} \quad (1)$$

$$v = 0.0003t^{4.0721} \quad (2)$$

where h is the tree height (m) and t is the tree age and v is the tree volume (dm^3). Fitting statistics for both models are presented in Table 2, while independent-dependent variable graphs are given in Figures 1 and 2, respectively.

Site index model

The anamorphic form of the hyperbolic equation was selected to model height growth of Aleppo pine stands. The function is as follows:

$$H_2 = \frac{H_1}{T_1^{1.3386}} T_2^{1.3386} \quad (3)$$

where H_1, H_2 are height (m) at ages (years) T_1 and T_2 respectively, and 1.3386 is the estimated parameter from the data. Site index curves are illustrated in Figure 3. The mean heights of dominant and co-dominant trees were estimated at 10m for the good site (SI10) and 7m for the medium site (SI7), respectively.

TABLE 2: Absolute and relative biases and RMSEs of the height and volume growth models.
TABELA 2: Desvios absolutos e relativos e RQMEs da altura e modelos de crescimento de volume.

Criteria	Height growth model	Volume growth model
Bias	-2.43	-31.56
Bias%	-22.66%	-52.60%
RMSE	3.16	42.31
RMSE%	9.31%	29.83%

From the 10 dominant trees that were cut from plots of the site A (true classification, using soil depth) 6 were classified in Site I (good) and 4 in Site II (medium). On the other hand, all the dominant trees that were cut in site B (true classification, using soil depth) were classified in Site II (medium) (Table 3). Classification in Sites I and II was accurately estimated, using formula (3),

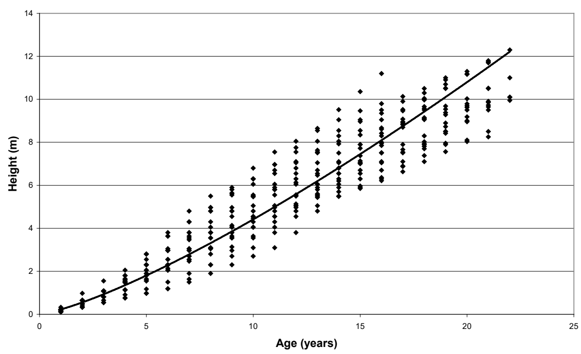

FIGURE 1: Height-age graph of sampled trees.
FIGURA 1: Gráfico altura-idade das árvores amostradas.

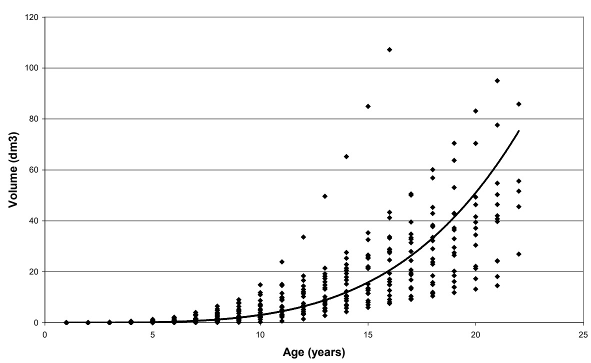

FIGURE 2: Volume-age graph of sampled trees.
FIGURA 2: Gráfico de volume-idade das árvores amostradas.

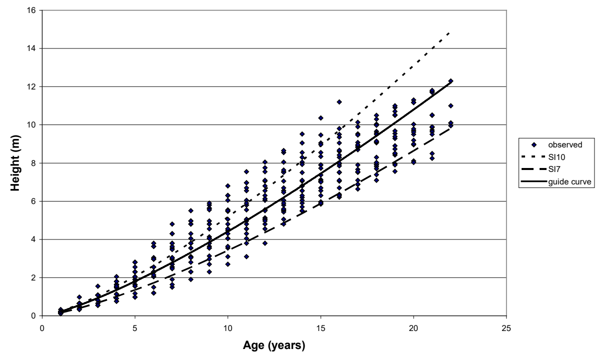

FIGURE 3: Site index curves for Aleppo pine stands.
FIGURA 3: Curvas de índice de sítio para povoamentos de pinheiro-de-alepo.

where H_2 is the height of the sampled tree at the age of 17 years, T_2 equals to 17, and H_1 is the height of the sampled tree at age T_1.

Mortality model

Survival estimates for each site type are given in Table 4.

Survival and hazard functions were estimated separately for each site type (Figures 4 and 5). We can see clearly that in the good quality site we have a greater probability of occurring a tall tree, (Figure 4), while the risk of occurring a short tree, is greater in the medium quality site (Figure 5). Survival analysis confirmed the site index curves developed from the height model, with mean heights of dominant and co-dominant trees at 10m for the good site (I) and 7m for the medium site (II), respectively. Log rank test for checking the factors' influence at height increment was found to be statistically significant (Table 5).

TABLE 3: Sampled tree classification from the site index model compared to the classification based on soil depth.
TABELA 3: Classificação das árvores amostradas pelo modelo de índice de sítio comparada com a classificação baseada em profundidade do solo.

Site	Tree status	No of classified trees		Incorrect percentage	Age range of incorrectly classified trees (years)
		True	Predicted		
I	Dominant	10	6	40,00%	21-22
	Codominant	10	2	80,00%	19-22
II	Dominant	10	10	0,00%	-
	Codominant	10	10	0,00%	-

TABLE 4: Mean heights estimated from the «mortality» model.
TABELA 4: Alturas médias estimadas pelo modelo de «mortalidade».

Site	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
I (good)	10,597	0,398	9,817	11,376
II (medium)	7,033	0,278	6,488	7,578
Overall	9,424	0,442	8,559	10,290

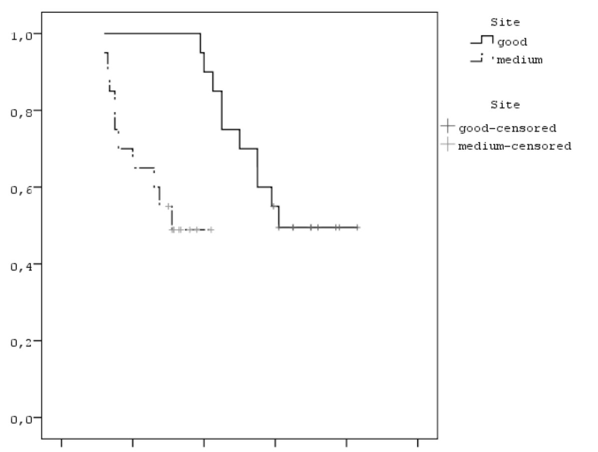

FIGURE 4: Kaplan-Meier survival functions for the two site types.
FIGURA 4: Funções de sobrevivência de Kaplan-Meier para os dois tipos de locais.

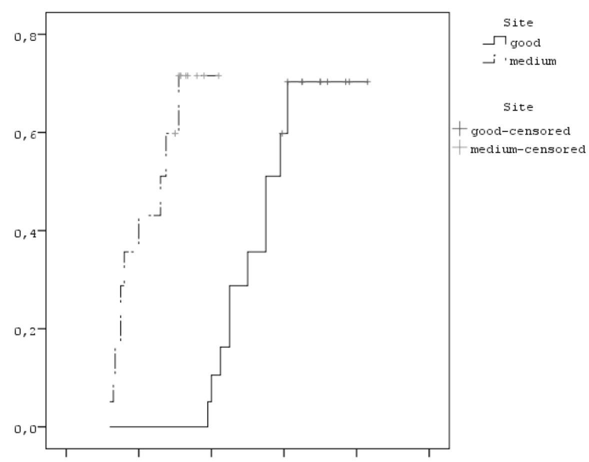

FIGURE 5: Hazard functions for the two site types.
FIGURA 5: Funções de risco para os dois tipos de local.

DISCUSSION

This study presents preliminary individual-tree models for *P. halepensis* stands in Chalkidiki (northern Greece), based on 20 temporary sample plots. Due to the small amount of data, and especially the young ages of the trees, the models must be regarded as preliminary and they should not be used beyond the range of the tree characteristics presented in the modelling data.

There are no great differences among the classification of dominant trees (and plots) in different sites using soil depth and the developed site index model. However, the usage of the

TABLE 5: Log rank test for height distributions' homogeneity in the factor levels (sites).
TABELA 5: Teste de Log-rank para a homogeneidade de distribuição de altura nos níveis de fator (locais).

Factor	χ^2	Degrees of freedom	*p*-value
Site	12.561	1	0.000

site index model leads to a more conservative classification, since more of the sampled dominant trees (and consequently the corresponding plots) were classified in medium sides (Table 3). A reason for this classification difference is probably the young age of trees; classification errors tend to be very large at young ages (NIGH; MARTIN, 2001). Another possible reason is the fact that both dominant and co-dominant trees were used in the development of the site index model. The use of dominant and co-dominant trees, instead of only dominant trees, reduces considerably the accuracy of site index determination (KER, 1952). Apart the abovementioned discussion, the productivity classification of sites using soil depth can not be rejected for another reason too, all the dominant trees of site A (based on the site productivity classification using soil depth) had higher height than that of all dominant trees of site B at the age of 17 years (measurements from original data). Even one dominant tree of Site As it was 16 years old, at the time of cut, was taller than all the dominant trees of site B at the age of 17 years. Soil depth, direct or indirect, alone or in combination with other parameters, has been used for site productivity (quality) determination in many research papers in Greece (MILIOS, 2004; ADAMOPOULOS et al., 2009; PAPALEXANDRIS; MILIOS, 2010; STAMBOULIDIS; MILIOS, 2010; MILIOS et al., 2012; ADAMOPOULOS; WIMMER; MILIOS, 2012; STAMPOULIDIS; MILIOS; KITIKIDOU, 2013). In the case of Adamopoulos et al. (2009), the site quality was also verified using site index curves.

Due to little data, it is difficult to discuss and compare the results presented to others previously developed. However, the adequate classification of the sampled trees in the two estimated site types using the developed site index curves - confirmed in our study by the «mortality» model - could allow us to risk an estimation of past tree growth (TRASOBARES; TOMÉ; JARI MIINA, 2004). In Thanos, Daskalakou, and Nikolaidou (1996), a tree height is estimated to be up to 0.72m at 3 years of age, while in our study is estimated to be 1m on average. In Tsitsoni (1997), a tree height is estimated to be 0.3m at 1 year of age, while in our study is estimated to be 0.33m in the good site. Finally, in Pausas et al. (2003), a tree height is estimated to be 0.24m at 2.5 years of age, while in our study is estimated to be 0.77m on average. Comparing studies with tree ages within or close to our age interval, we found that in Ares and Peinemann (1992) estimated mean heights at 20 years is 15.7m (good site) and 13.4m (medium site), while in our study they are estimated at 13.1m and 8.6m, respectively.

Another point that we should discuss is the advantages of the «mortality» methodology used in this study, where height was the independent variable. A variable can be defined as longitudinal if it can measure transition from one state to another (COLLETT, 1994). The greatest difficulty in survival analysis application in forest inventories is to find appropriate longitudinal variables to quantify survival and «mortality» risk (ZENS; PEART, 2003). When using passage time or age as longitudinal variables, several problems can arise (BURGMAN et al., 1994; HARCOMBE, 1987; PREISLER; SLAUGHTER, 1997; VOLNEY, 1998). Firstly, most observations are censored, meaning that the exact time of death of a tree is uncertain. Secondly, the survival function depends on when and where measurements are taking place. The survival estimation can be biased, if inventory takes place in a specific area with many dead trees. Thirdly, it is difficult to estimate stand age in forest inventories of large scale. Therefore, a «mortality» model from a survival analysis using time-dependent variables can be useful in showing the trend of a growth variable, such as tree height.

CONCLUSIONS

A set including a height model, a volume model, a site index model and a «mortality» model for *Pinus halepensis* Mill. in Chalkidiki (Northern Greece) were preliminarily developed based on measurements of 20 experimental plots established in 2010. Based on the results, mean dominant and co-dominant height was estimated at 10m (site I) and 7m (site II) (base age of 17 years). Kaplan-Meier survival and hazard functions applied for the «mortality» analysis, confirmed the site index curves developed from the height model (SI10 and SI7).

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