

FRI, BAS

Tzvetan Zlatanov

Ivaylo Velichkov

Georgi Hinkov

Margarita Georgieva

Olafur Eggertsson

Saevar Hreidarsson

Magdalena Zlatanova

Georgi Georgiev

## **Project**

*State and prospects of the *Castanea sativa* population in Belasitsa mountain: climate change adaptation; maintenance of biodiversity and sustainable ecosystem management.*

*Funded by: EEA and Norway Grants.*

*Beneficiary: Forest Research Institute at the Bulgarian Academy of Sciences*

## **Report**

Modelling height growth of European chestnut (*Castanea sativa* Mill.) on the northern slopes of Belasitsa mountain, Southwest Bulgaria

## **Modelling height growth of European chestnut (*Castanea sativa* Mill.) on the northern slopes of Belasitsa mountain, Southwest Bulgaria**

Tzvetan Zlatanov<sup>1</sup>, Ivaylo Velichkov<sup>1</sup>, Georgi Hinkov<sup>1</sup>, Margarita Georgieva<sup>1</sup>, Olafur Eggertsson<sup>2</sup>, Saevar Hreidarsson<sup>3</sup>, Magdalena Zlatanova<sup>1</sup>, Georgi Georgiev<sup>1</sup>

1 – Forest Research Institute, BAS; 2 – Iceland Forest Research, Mogilsa; 3 – The Agricultural University of Iceland

### **Recommended citation:**

Zlatanov T, I Velichkov, G Hinkov, M Georgieva, M Zlatanova, O Eggertsson, S Hreidarsson, M Zlatanova, G Georgiev. 2011. Modelling height growth of European chestnut (*Castanea sativa* Mill.) on the northern slopes of Belasitsa mountain, Southwest Bulgaria. In: Zlatanov T, I Velichkov, B Nikolov (eds.) State and prospects of the *Castanea sativa* population in Belasitsa mountain: climate change adaptation; maintenance of biodiversity and sustainable ecosystem management. Project BG 0031 EEA report.

**Abstract:** Richards, Lundqvist–Korf and Hossfeld growth functions were fitted to age–height data of European chestnut (*Castanea sativa* Mill.) dominant trees on the northern slopes of Belasitsa mountain, Southwest Bulgaria. The model prediction performance was evaluated using quantitative as well as qualitative examinations. Goodness of fit of each model was estimated by the regression coefficient  $R^2$ , F-test for significance of the regression and t-tests for significance of the coefficients of the model. Models were further compared by the evaluation of the standard error of the model and Akaike's Information Criteria. Site Index Curves were constructed following the “guide curve method” procedure. In accordance with the evaluation tests, the Richard's function was chosen as most adequate to express the age–dominant height relationship. Accordingly, it was further employed as a guide function to derive site index curves for studied chestnut population.

### **Key words**

*Castanea sativa*, height growth, site index curves

## **Introduction**

One of the most widely used methods for assessing the growth of a tree species is based on the dominant height–age relationship and is termed the site index (Savill et al. 1997; Avery and Burkhart 2002; Fontes et al. 2003). The dominant height of a tree species on a given site is insignificantly influenced by the thinning intensity (Hamilton 1981) hence being good indicator of the species potential productivity on that particular site (Cailliez and Alder 1980). Based on Eichhorn’s hypothesis (Eichhorn, 1904) the total production from a fully stocked stand, which is the volume of currently standing trees plus anything removed in previous thinnings, is a function of its dominant height (Savill et al. 1997). One of the major needs in forest management planning is to predict forest stand development under various treatment alternatives. In this respect, a thorough knowledge of tree growth on different sites is critical, and an aid to successful forest management and silviculture. Hence, construction of site index curves is a fundamental task.

No literature data has been found to suggest that site index curves have been developed in the Balkan Peninsula in order to determine the growth of European chestnut (*Castanea sativa* Mill.) along the site gradients in regions where it grows. Accordingly, the objective of the study is (i) to model the age – dominant height growth relationship and (ii) to elaborate site index curves (the dominant height–age relationship curves along the site gradient) for chestnut on the northern slopes of Belasitsa mountain, Southwest Bulgaria.

## **Materials and methods**

### **Study area**

The European chestnut forests are Mediterranean communities, which have limited distribution in Bulgaria. The forests in Belasitsa mountain (Southwest Bulgaria) where the chestnut is one of the main tree species are the most representative ones. Due to the latitudinal position of Belasitsa mountain the climate on its northern slopes is not as strongly influenced by the Mediterranean as the climate of the surrounding territories. The average annual precipitation of the nearest climatic station (climatic

station Petrich, 200 m a.s.l.) for the years 1965–2010 is 580 mm, predominantly occurring in the period November – February (240 mm). The driest period is June – September (150 mm). The mean annual temperature for the climatic station Petrich is 14 °C, with a July mean of 25 °C and a January mean of 3 °C. Chestnut forests grow at elevation between 400 and 900 m a.s.l., on often steep slopes with predominantly northern exposures. The soil is loamy-sand Eutric Cambisols with depth varying between 50 and 80 (100) cm (Zlatanov et al 2011).

### **Data collection**

Data for the elaboration of the chestnut age – dominant height relationship and site index curves was collected from a systematic network of temporary sample plots. As a part of the systematic sampling approach, a grid was drawn between the 176000 and 186000 meridian lines (coordinate system: UTM 35 North, WGS 1984) across the most recently updated forestry map of Belasitsa mountain, Southwest Bulgaria (PFEM 2010). The interval between grid lines was set to 250 m in both longitudinal and latitudinal direction. As reported by Velichkov et al. (2010), the area of chestnut dominated stands in the Bulgarian part of Belasitsa mountain totals 648 ha, 592 ha (91%) out of which located between the 176000 and 186000 meridian lines and thus covered by the grid. A total of 67 grid intersections fell within the boundaries of chestnut dominated stands as depicted in the Petrich Forest Enterprise Management Plan (PFEMP 2010). Accordingly, 67 temporary sample plots sized 0.125 ha (40 m in diameter) were installed, plot centres coinciding with the grid intersection points. Grid intersections were positioned on the field by GPS (Trimble Juno SB) navigation.

In the plots, the “leading tree” status approach (Rondeux 1999) was employed to select dominant trees for further analyses. This type of selection differs from the usual one, in which dominant height corresponds to the average height of the 100 trees of largest diameter per ha (Bradley 1971) or the 20% largest trees in the forest stand (M.L.W.F. 1980). As reported by Thibaut et al. (2004), the method of dominant height determination by employing the “leading tree” status approach fits well the investigation of small-size sampling units or the presence of only a few trees

appropriate for measurement. Accordingly, 97 dominant trees of “leading tree” status were selected from the systematic network of temporary plots. Additionally, in order to achieve better coherence of the sample along the age gradient, and following the same approach of selection, 32 dominant chestnut trees were selected in younger stands (aged 10 to 33) at various altitudes and sites. Finally, a total of 129 dominant trees were chosen for further analyses. The height of the selected trees was measured by Vertex IV heightmeter with accuracy of 0.1 m. Increment core samples were extracted at dbh (1,3 m) to obtain the age. The tree rings were counted using a stereo microscope.

### Data analyses

The following equations which have been widely used in modelling biological growth phenomena were used as candidate functions to model dominant height (H) of studied chestnut population: (i) Richards, Eq. 1 (Richards 1959; Pienaar and Turnbull 1973; Zeide 1993; Rennolls 1995; Rojo and Montero 1996; Amaro et al. 1998); (ii) Lundqvist–Korf Eq. 2 (Stage, 1963; Tome 1988; Zeide 1993; Carvalho et al. 1994); and (iii) Hossfeld, Eq. 3 (Pita 1964; Elfving and Kiviste 1997; Palahí 2004)

$$H = a[1 - \exp(-kA)]^c \quad (1)$$

$$H = a \exp(-kA^{-c}) \quad (2)$$

$$H = \frac{a}{1 + \frac{k}{A^c}} \quad (3)$$

where  $A$  is the age,  $a$  is the asymptote of  $H$ ,  $k$  is a growth rate related parameter, and  $c$  is a shape parameter.

The procedure used to evaluate the models incorporated qualitative as well as quantitative examinations. The goodness of fit of all regression models was assessed through the coefficient of determination ( $R^2$ ),  $F$ -test for significance of the regression and  $t$ -tests for significance of the coefficients of the models. Plots of the predictor variables against the residuals and the predicted values against the residuals were examined to check for model deficiencies (Draper & Smith, 1981). Cook’s distance, Leverage and DFFit residual statistics were employed to identify potential influence cases.

Models were further compared by the evaluation of the standard error of the model  $Sy$  (Eq. 4) and Akaike's Information Criteria ( $AIC$ , Eq. 5):

$$Sy = \sqrt{\frac{s}{M-m}} \quad (4)$$

$$AIC = M \ln(S/M) + 2m \quad (5)$$

where  $M$  is the sample size,  $S$  is the residual sum of squares, and  $m$  is the number of coefficients of the regression. At this stage, the residual plots of the models were further examined in order to check for violation of the assumptions of linearity and homoscedasticity. Biological realism and graphical appearance of the models were also considered.

The elaboration of Site Index Curves (SIC) for studied chestnut population followed the "guide curve method" procedure as suggested by Clutter et al. (1983).

## Results

It is apparent from the model statistics shown in Table 1 that each growth function was well fitted to the tree age/height data. The overall fit of the models was significant at  $\alpha < 0.01$  and they accounted for at least 60% of the total variation in dominant height, which according to Cohen (1986) is a large effect. Richard's function performed marginally better compared to the others with  $R^2 = 0.62$ . The Richard's function had the smallest values of Standard error of the model ( $Sy$ ) and  $AIC$  coefficients:  $Sy = 3,12$  and  $AIC = 296,3$ . As reported in literature (Stankova et al. 2006; Field 2009) a regression model with smaller values of  $Sy$  and ( $AIC$ ) is considered as more adequate. The Richard's function was the only one with all model coefficients being statistically significant at  $\alpha < 0.05$ . Although the three growth functions were fitted to the same data set, they resulted in different asymptote coefficients. The asymptote of the height was greatest for the Lundqvist-Korf function (28.9149) and lowest for the Richards function (23.2652) (Table 1). The three growth functions used in the current study similarly predicted the tree dominant heights for most age classes with exception for the older trees (Fig.1). The Lundqvist-Korf function predicted larger tree heights, followed by the Hossfeld and Richards functions. Furthermore, at older ages the Lundqvist-Korf and Hossfeld equations produced a less-asymptotic trend than the

Ricards one, hence the latter being considered as more biologically realistic. The residuals for the three models showed a random manner of distribution (Fig. 2), which suggested that there were no violations of the assumptions about the errors.

**Table 1.** Results from the statistical tests examining the goodness of fit of the regression models for the age–dominant height relationship

Model	R <sup>2</sup>	Sig. F	Coefficients		Sy	AIC	
			B	Sig.			
Richards	0,62	< 0,01	<i>a</i>	23,2652	<0,01	3,12	296,35
			<i>k</i>	0,0414	<0,01		
			<i>c</i>	1,0301	<0,01		
Lundqvist–Korf	0,60	< 0,01	<i>a</i>	28,9149	<0,01	3,18	301,04
			<i>k</i>	8,8475	0,06		
			<i>c</i>	0,8115	<0,01		
Hossfeld	0,61	< 0,01	<i>a</i>	25,8926	<0,01	3,15	299,00
			<i>k</i>	54,0394	0,14		
			<i>c</i>	1,3372	<0,01		

In accordance with the evaluation tests, the Richard’s function (Eq. 1) was chosen as most adequate to express the age–dominant height relationship and further employed as a guide function to derive site index curves for studied chestnut population.

When  $A = 50$ , the calculated  $H$  value is

$$H = 23,2652[1 - \exp(-0,0414 \times 50)]^{1,0301} = 22,39 \text{ m} \quad (6)$$

The curve from Eq. 6 is the site index curve for a site index value of 22.39 m and index age of 50 years. Curves for other site index values were obtained from the guide curve equation by holding the shape parameters  $k$  and  $c$  constant and varying the asymptote parameter  $a$  as necessary to achieve the required  $H$  value when  $A$  (the index age) equals 50. The equation of the curve for site index  $S$  was therefore

$$S = a_i[1 - \exp(-0,0414 \times 50)]^{1,0301} \quad (7)$$

so that

$$a_i = S[1 - \exp(-0,0414 \times 50)]^{-1,0301} \quad (8)$$

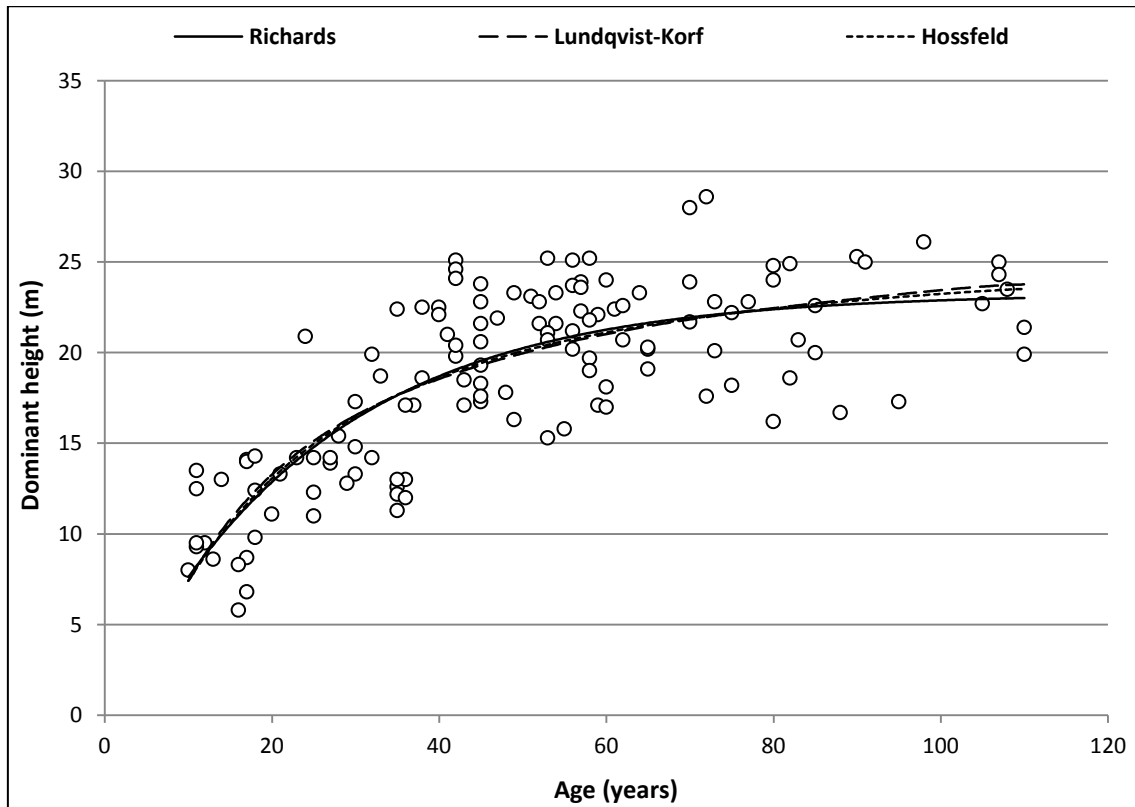
and

$$H = S \left[ \frac{1 - \exp(-0,0414A)}{1 - \exp(-0,0414 \times 50)} \right]^{1,0301} \quad (9)$$

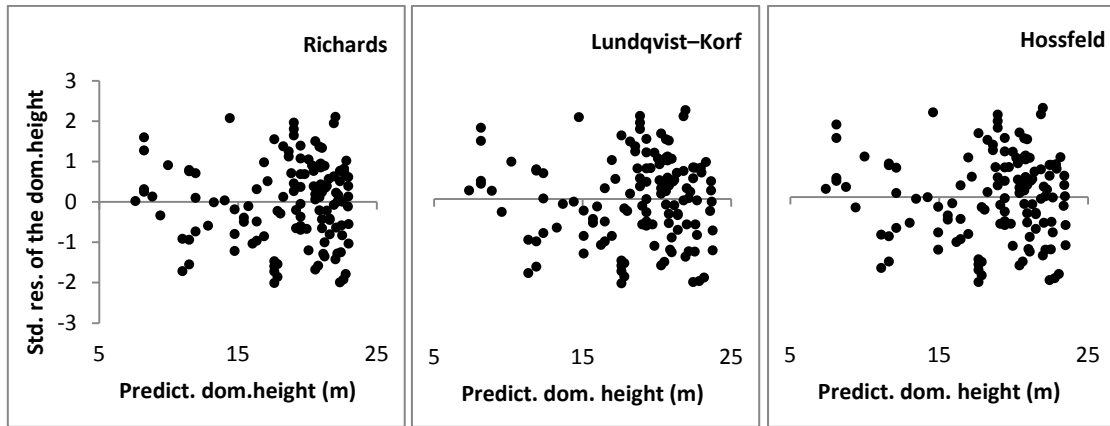
or, for prediction of site index from dominant height and age

$$S = H \left[ \frac{1 - \exp(-0,0414 \times 50)}{1 - \exp(-0,0414A)} \right]^{1,0301} \quad (10)$$

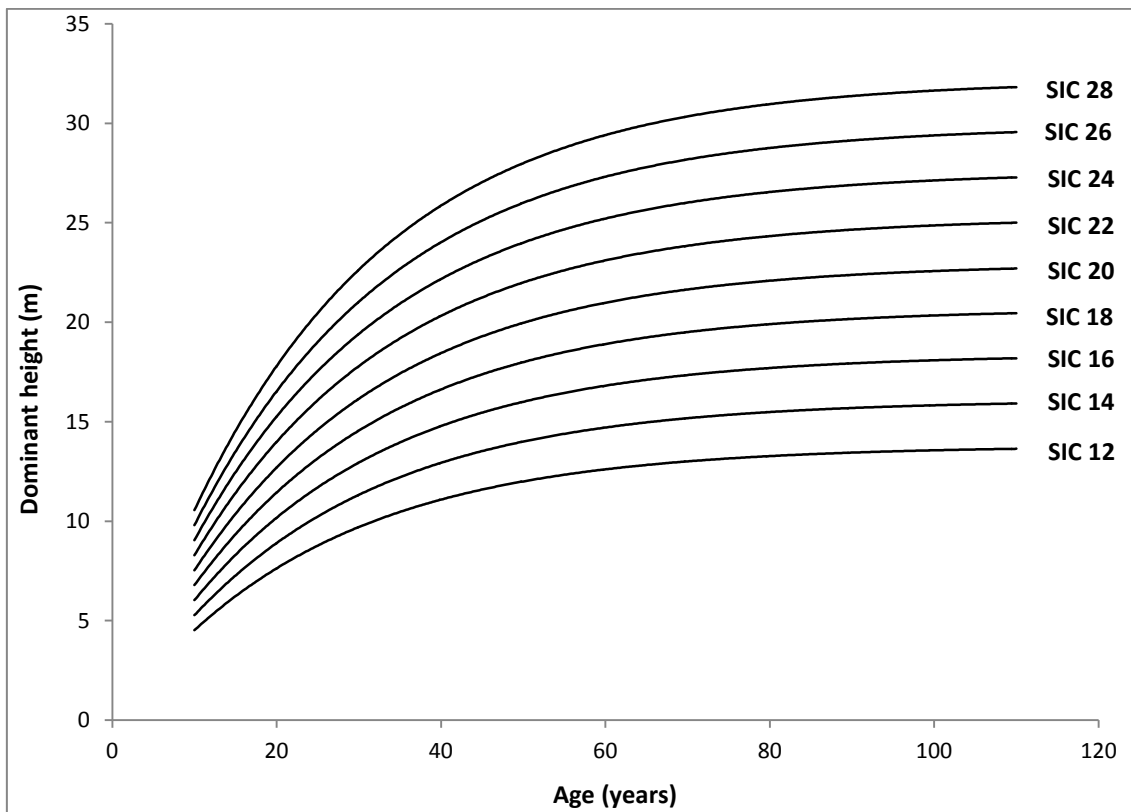
For given age and dominant height, site index can also be derived from the graphical representation of the site index curves fitted for the Richards guide curve at index age of 50 years (Fig. 3)



**Fig. 1.** Age-dominant height curves based on Richards, Lundqvist-Kort and Hossfeld growth functions.



**Fig. 2.** Predicted values against standardized residuals plots for the age-dominant height curves based on Richards, Lundqvist-Kort and Hossfeld growth functions



**Fig. 3.** *Castanea sativa* site index curves fitted by the Richards guide curve at index age of 50 years

## Discussion

The lack of sample plots measured at young ages was an important restriction in the initial data set of the study. Accordingly, the inclusion of additional dominant trees selected in younger stands at various altitudes and sites was crucial to develop a model that could predict accurately dominant height development at young ages. Some authors (Rojo and Montero 1996, Palahi et al. 2004) recommend the inclusion of tree stem analysis data instead. It is emphasized that models based on temporary plots and stem analyses data give higher dominant heights at young ages than models based only on temporary plots which supports the conclusion that the analysed sample trees were dominant at young ages as well. Stem analyses data was not used in the current study due to the pronounced uneven structure of *Castanea sativa* dominated stands on the Northern slopes on Belassitsa mountain (as suggested by Zlatanov et al. 2011) and to avoid the risk of violation of the assumption of the independence of the error term. According to West (1995), the violation of this assumption is likely to produce an estimator of the covariance matrix of the parameter estimates that is negatively biased, leading to the invalidation of the normal statistical hypothesis test about the fitted equation.

The relatively large difference between the asymptotic coefficients of the three functions used in the current study is in accordance with the relevant literature. Zhang (1997) reports of greater asymptotic height predicted by Lundqvist–Korf function in comparison with the Richards one. According to Ratkowsky (1983), the asymptotic coefficient is the least stable parameter in non-linear growth functions and the least-squares fit often results in biologically unreasonable upper asymptotes, especially when there are few data observations near the asymptote. In such cases, overestimation or underestimation of the height of the large-sized trees might be expected, regardless the function fitted.

Top height growth for chestnut has been modelled in other European countries where the species is present. Examples are: the curves of Everard and Christie (1995) for chestnut plantations in Great Britain, the curves of Mannety et al. (2001) for chestnut coppice and high forests based on aggregated data from different regions of Europe

and the curves of Alvares et al. (2010) for chestnut plantations in Northern Spain aged up to 20 years. In comparison, current study data set is characterized by more balanced and extended age distribution than data used in the order studies attempting to derive representative height growth curves for *Castanea sativa*. Despite the fewer observations in the older age classes (e.g. more than 70-80 years) it covers the range of 10–110 years whereas data sets of all other studies do not comprised trees over than 70 years of age. Accordingly the SCI curves elaborated in the current study provide basis for reliable SCI estimation for mature (over than 80 years of age) chestnut stands as well: although most of the non-linear growth functions can adequately predict height growth, they may produce large errors when applied beyond the range of model development data (Zhang, Moore and Newberry, 1996).

The variation in chestnut top height in the current study is greater than it might be expected providing the comparatively small area of distribution of the species in the mountain and the similarity of site conditions where it grows. One hypothesis to explain the pronounced variation in chestnut top height would be the presence of variety of genotypes, which itself would indirectly support the theory that chestnut is not an autochthonous species in the mountain but has rather been introduced from various localities (Stoyanov 1921).

According to Clutter et al. (1983), most techniques for site index curve construction can be viewed as special cases of three general methods: (1) the guide curve method; (2) the parameter prediction method; and (3) the difference equation method. One-time (single) measurement of stand height and age on temporary plots is sufficient for the guide curve method whereas the implementation of the others require either measurement of height and age over time with monumental trees or plots (the parameter prediction method), or reconstruction of height/age development patterns for individual trees through stem analyses (the difference equation method). Shortcomings of using stem analyses data in the case of the current study has already been discussed. Measurement over time was also avoided due to the mass occurring of chestnut dieback in Belasita mountain caused by the ascomycete fungus *Cryphonectria parasitica* (Murrill) Barr. According to Zlatanov et al. (2011), each year

many trees are infected by the fungus in a rather chaotic manner. The guide curve method assumes that the full range of site indices is well presented in all age classes within the sample (Clutter et al. 1983). This assumption is not violated with respect to the current study data set. Still, we are aware that the guide curve method derives anamorphic site index curves, only asymptote coefficient is changed while the shape of the curves stays constant. Some studies (Garcia Abejon 1981, Alemdag 1991) suggest that the shape of the curves might also vary from site to site.

It can be generalized from the results of the current study that the growth model based on the Richards growth function best fitted the age – dominant height relationship for the *Castanea sativa* dominated stands in the Bulgarian part of Belasitsa mountain (Fig. 1, Table 1), hence the Richards guide curve (Eq. 7) being employed for the construction of the population site index curves. It is recommended that the growth model elaborated in the current study is used within the data range 10–110 years.

#### **References:**

- Alemdag I (1988) Site index equations for White Spruce in the Northwest Territories, Canada. For Ecol Manage 23: 61–580
- Alvares A, Varela E, Obregon A, Khoury E (2010) Relating growth and nutrition to site factors in young chestnut plantations established on agricultural and forest land in northern Spain. Agroforest Syst 79:291–301.
- Amaro A, Reed D, Tome M, Themido I (1998) Modelling dominant height growth: eucalyptus plantations in Portugal. For Sci 44: 37–46.
- Avery T, Burkhart E (2002) Forest Measurement, 5<sup>th</sup> ed. McGraw-Hill, New York.
- Bradley R (1971) Thinning control in British woodlands (Metric), forestry Commission Booklet 32. Artisan Press Ltd, Anstey, Leicester.
- Cailliez F, Alder D (1980) Forest Volume Estimation and Yield Prediction. Vol. 2. Yield Prediction. Food and Agriculture Organization of the United Nations, Rome.
- Carvalho A, Falcao A, Carvalho L, Coucelo F (1994) TWIGGY um modelo de producao para a Portucel. Twin globulus growth yield. In: Proceedings of the 3<sup>rd</sup>

- Congresso Florestal Nacional (Ed. Pascoa F). Os recursos no desenvolvimento rural, pp. 222–230.
- Cluter J, Fortson J, Pienaar L, Brister G, Bailey R. 1983. Timber management: A quantitative approach. John Wiley & Sons, New York.
- Cohen J (1988) Statistical power analyses for behavioural sciences, 2<sup>nd</sup> ed. Academic Press, New York.
- Garcia Abejon J. 1981. Tablas de produccion de densidad variable para *Pinus sylvestris* en el Sistema Iberico. Comunicaciones I.N.I.A Serie: Recursos Naturales, No. 10, pp. 47.
- Eichhorn F (1904) Beziehungen zwischen Bestandshöhe und Bestandsmasse. Allgemeine Forst und Jagdzeitung 80: 45–49
- Everard J, Christie J. 1995. Sweet chestnut silviculture, timber quality and yield in the forest of Dean. Forestry 68:133–144.
- Elfving B, Kiviste A (1997) Construction of site index equations for *Pinus sylvestris* L. using permanent sample plots data in Sweden. For Ecol Manage 98: 125–134.
- Field A (2009) Discovering statistics using SPSS, 3<sup>th</sup> ed. SAGE Publications Ltd, London.
- Fontes L, Tome M, Coelho M, Wright H, Luis J, Savi P (2003) Modelling dominant height growth of Douglas-fir (*Pseudotsuga menziesii* Mirb.) Franco) in Portugal. Forestry 76: 509–523.
- Hamilton G (1981) The effects of high intensity thinning on yield. Forestry 54:1–15.
- Manetti M, Amorini E, Becagli C, Conedera M, Giudici F. 2001. Productive potential of chestnut (*Castanea sativa* Mill.) stands in Europe. For Snow Landsc Res 76: 471–476.
- M.L.W.F. (1980) Hilfstafeln für die Forsteinrichtung (zur FA 72). M.L.W.F. (Ministerium für Landwirtschaft, Weinbau und Forsten), Wiesbaden, pp 6–7.
- Palahí M, Tomé M, Pukkala T, Trasobares A, Montero G (2004) Site index model for *Pinus sylvestris* in north-east Spain. For Ecol Manage 187:35–47.
- Pienaar L, Turnbull K (1973) The Chapman–Richards generalization of Von Bertalanffy's growth model for basal area growth and yield in even-aged stands. For Sci 19: 2–22.

- Pita A (1964) La calidad de la estacion en las masas de *Pinus sylvestris* de la Peninsula Iberica. *Anales del Instituto Forestal de Investigaciones y experiencias* 9: 5–28
- PFEM (2010) “Petrich” Forest Enterprise Map, Agrolesproekt, Sofia.
- PFEMP (2010) “Petrich” Forest Enterprise Management Plan, Agrolesproekt, Sofia.
- Ratkowsky D (1983) *Nonlinear regression modelling*. Marcel Dekker Inc., New York.
- Rojo A, Montero G (1996) *El pino silvestre en la Sierra de Guadarrama*. Centro de publicaciones del Ministerio de Agricultura, Pesca y Alimentacion, Madrid.
- Rennolls K (1995) Forest height growth modelling. *For Ecol Manage* 71: 217–225.
- Richards F (1959) A Flexible Growth Function for Empirical Use. *J Exp Bot* 10: 290–301.
- Rondeux J (1999) *La mesure des arbres et des peuplements forestiers*. Les Presses agronomiques de Gembloux, Gembloux, Belgium.
- Savill P, Evans J, Auclair D, Falck J (1997) *Plantation Silviculture in Europe*. Oxford University Press, Oxford.
- Stage A (1963) A mathematical approach to polymorphic site index curves for grand. *For Sci* 9: 167–180.
- Stankova T, Stankov H, Shibuya M (2006) Mean-dominant height relationship for Scots and Austrian pine plantations in Bulgaria. *Ecological Engineering and Environmental Protection* 2: 59–66.
- Stoyanov N. 1921. Floristic materials from Belasitsa. *Annals of Sofia University* 15–16: 31–73.
- Thibaut A, Claessens H, Rondeux J (2004) Site index curves for *Alnus glutinosa* (L.) Gaertn. in Southern Belgium: effect of site on curve shape. *Forestry* 77: 159–171.
- Tome M (1988) *Modelacao do crescimento da arvore individual em povoamentos de eucalyptus globulus Labill. Regiao Centro de Portugal*. Ph.D. Dissertation, Technical University of Lisbon.
- Velichkov I, Hinkov G, Zlatanov T, Zlatanova M, Hristova H (2010) Area distribution dynamics of *Castanea sativa* forests on the northern slopes of Belasitsa mountain. *Silva Balcanica* 11: 21–26.
- Zeide B (1993) Analysis of Growth Equations. *Forest Sci* 39: 594–616.

- Zhang L (1997) Cross-validation of non-linear growth functions for modelling tree height–diameter relationships. *Ann bot* 79: 251–257.
- Zlatanov T, I Velichkov, B Nikolov (Eds.). 2011. State and prospects of the *Castanea sativa* population in Belasitsa mountain: climate change adaptation; maintenance of biodiversity and sustainable ecosystem management. Project BG 0031 EEA report, Sofia.
- West P. 1995. Application of regression analysis to inventory data with measurements on successive occasions. *For Ecol Manage* 71: 227–234.