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GROWTH MODELS FOR NATURAL STANDS OF CALABRIAN PINE IN THE CENTRAL MEDITERRANEAN REGION OF TÜRKİYE

MODELI RASTA PRIRODNIH SASTOJINA KALABRIJSKOG BORA U SREDIŠNJEM MEDITERANSKOM PODRUČJU TURSKE

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SUMMARY

Stand growth models are needed for a variety of forestry practices, primarily management plans and silvicultural studies. The goal of this study was to create stand-level models for natural, pure even-aged stands of Calabrian pine in the central Mediterranean region of Turkey. The study area consists of pure and natural Calabrian pine stands located within the boundaries of the Antalya and Mersin Regional Forestry Directorates in the central Mediterranean region of Turkey. Data was collected from 486 temporary plots scattered throughout the region. Two trees (the dominant tree and the tree representing the quadratic mean diameter of the stand) were measured in each plot, yielding 972 trees. The data showed that the age varied from 6 to 135 years, the site index (SI) from 8.5 to 33.5 m, and the density from 0.3 to 12.4. The density-dependent yield tables were generated using regression equations based on stand age, SI, and stand density with individual, two-factor, and three-factor interaction effects. For SI classes I, II, and III, the optimal rotation period that would result in the highest yields for pure Calabrian pine stands is 60, 65, and 75 years, respectively. The stand growth models developed (i.e., density-dependent yield tables) agreed with the fundamental growth principles and data provided in the literature.

KEY WORDS: stand models, density-dependent yield table, Calabrian pine, density, Generalized Algebraic Difference Approach (GADA).

INTRODUCTION
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Growth models are classified into three categories based on the unit of analysis: whole stand models, size class models, and individual tree models (Vanclay, 1994). The number of trees, basal area, volume, mean diameter, and mean height of a stand can be predicted using whole stand models. The stand characteristics determined by whole stand models are averages and these models do not make predictions at the individual tree level (Vanclay, 1994; Weiskittel et al., 2011; Özçelik and Altınkaya 2019). Yield tables are a tabular representation of whole stand models and generally provide straight forward and accurate predictions. Yield tables are auxiliary tables that are used to calculate growth estimates.

The initial yield experiments in growth models, which have a 250-year history, were carried out in even-aged, pure stands. According to Schwappach, Réaumer proposed the nascent ideas for generated yield tables in the first quarter of

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the 18th century. And then, the first studies on yield tables were conducted in pure stands towards the end of the 18th and beginning of the 19th centuries (Vanclay, 1994). These original tables were simplified counterparts of contemporary yield tables. Pretzsch (2009) classified growth models into four historical stages: i) simple yield tables organized using limited data from growth models (between the final quarter of the 18th century and the 19th century), ii) regular yield tables based on age and site index yield strength variables (between the final quarter of the 19th century and the beginning of 20th century), iii) yield tables where growth relationships are calculated using computerized mathematical models (between the first and last quarter of the 20th century), iv) extremely detailed stand simulation models that can be challenging to execute even on systems with a lot of Read Access Memory (RAM) (from the final quarter of the 20th century to the present) (Kahriman et al., 2016a).

Due to its range, growth and increment characteristics, and economic significance, Calabrian pine (*Pinus brutia* Ten.) is one of Türkiye's most important main forest tree species (Sönmez et al., 2016). According to the 2020 forest inventory data released by the General Directorate of Forestry, Türkiye's total forest area is 22,933,000 ha, which corresponds to 29.4 percent of the country's total area. The Calabrian pine is distributed on the 5,215,292 ha of the total forest area (22.74 percent of the total forest area). The Calabrian pine is composed of high stands that cover 3,407,368 ha (65.33%) and degraded stands that cover 1,807,924 ha (34.67%) (General Directorate of Forestry, 2021). The total growth stock, annual volume increment, regeneration site area, and average annual allowable cut of Calabrian pine stands are 270 million m^3, 7.95 million m^3, 262,000 ha, and 3.4 million m^3, respectively (General Directorate of Forestry, 2021) (Directorate General of Forestry, 2016). Consequently, there is significant potential for applying the findings in practice.

Many researchers have investigated Calabrian pine stands, and they have produced yield tables as a result of their research. For instance, using temporary site data obtained from even-aged, pure, and untreated stands, Alemdağ (1962) produced the first normal yield tables for Calabrian pine stands. Afterwards, normal yield tables for Calabrian pine stands were established by Erkan (1995) and Çatal (2009) for the Mediterranean region (Kahramanmaraş, Adana, Mersin, Antalya, and Muğla) and the western Mediterranean region (Muğla), respectively. However, Yeşil (1992) created yield tables for Calabrian pine stands that depend on density for the entire country, while Şahin (2015) did so for the Mersin Forest Regional Directorate. Additionally, Karaca (2012) compared the values of yield tables for treated Calabrian pine stands in Bucak-Çamlık Forest Management Unit with the values of normal yield tables for Calabrian pines prepared by Alemdağ (1962), Yeşil (1992), Erkan (1995) and Çatal (2009).

The total economic values at the end of the rotation age for the Calabrian pine and other tree species based on the yield tables were investigated by many researchers (Yaprak, 1977; Öztürk and Türker 1998; Öztürk and Türker 2000; Erkan et al., 2002) in Turkey. Their aim was to find the best economic maturity age for the investigated species. According to Yaprak (1977), the technical maturity age of the Calabrian pine tree species in Turkey for site index classes of good (I), medium (II), and poor (III) was 55, 57, and 110 years, respectively. For site index classes I, II, and III, the maturity age for the highest wood yield (ages where the general average growth is greatest) was 50-55, 55-60, and 60-65 years, respectively. The administration period for pole production was 30, 40, and 50 years, respectively. The economic maturity administration period and the highest land value were 25 years for good sites, 30 years for medium and poor sites (if they are cut at this age), and 40 years for poor sites (only pole, pole and firewood can be obtained). The highest average growth yield was given at the administration period of 65, 75 and 90 years (Yaprak, 1977). The physical administration period (the age of natural maturity) was determined as 310 years in the 120 cm diameter Calabrian pine tree grown in Fethiye-Incirköy (Asan, 1998).

In the last century, some yield tables and stand growth models or growth and yield models have been developed for pure and natural Calabrian pine stands in some neighboring countries. Palahí et al. (2008) developed growth and yield models for Calabrian pine in northeastern Greece. Shater et al. (2011) developed a system of models that allows managers to simulate the dynamics of Calabrian pine stands in Syria using 83 temporary plots. de-Miguel et al. (2010) developed a system of models that allows them to simulate the stand dynamics of Pinus brutia in the Middle East (Lebanon and Syria) using 133 semi-permanent sample plots.

The objective of this study is to develop stand-level growth models as yield tables needed for various forestry applications, especially for management plans and silvicultural practices of pure and natural Calabrian pine stands distributed in the central Mediterranean region (Antalya and Mersin) of Turkey. Thus, growth models will be established, which are one of the prerequisites for multipurpose use of pure, natural and even-aged Calabrian pine stands. These models will allow determining the effects of silvicultural interventions on stand growth as well as to create and compare planning options in the management plan decision- making process with regards to multi-purpose utilization.

MATERIALS AND METHODS
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The study area consists of pure and natural Calabrian pine stands located within the boundaries of the Antalya and

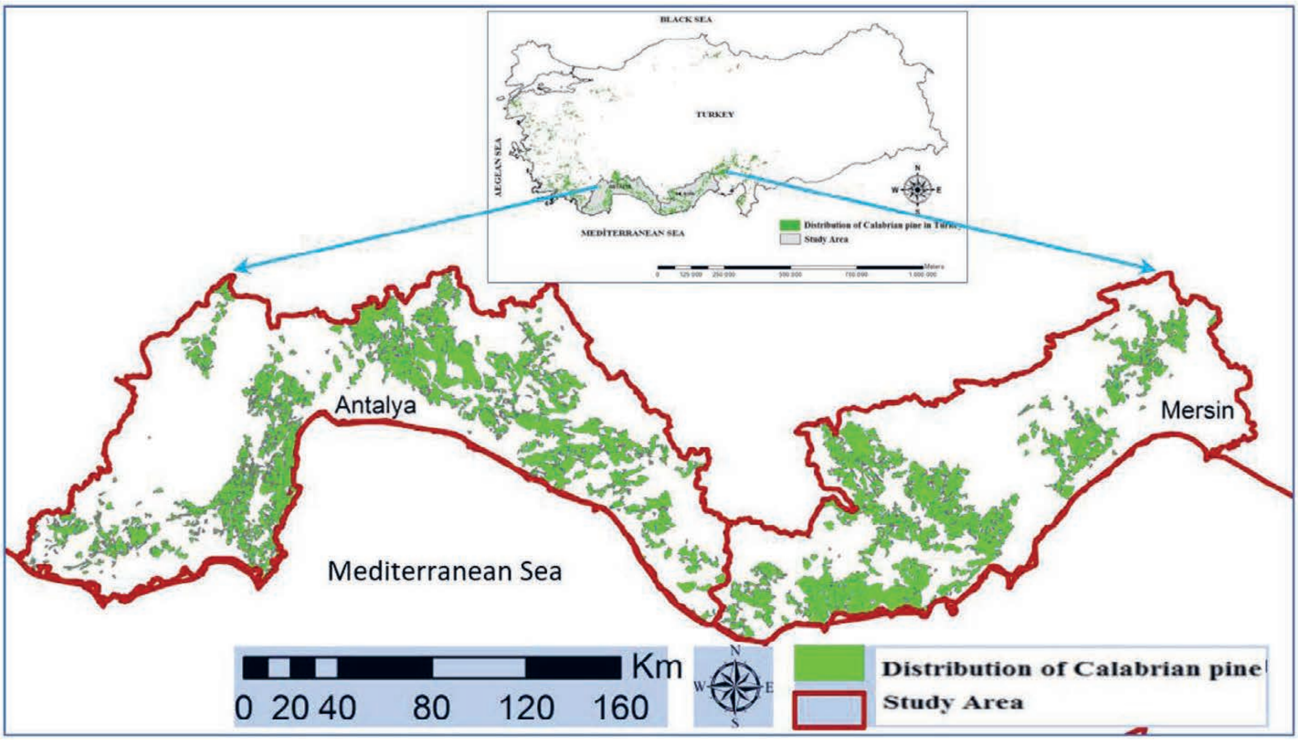

Figure 1. The study site and the distribution of pure Calabrian pine stands within the site
Slika 1. Istraživano područje i distribucija čistih sastojina kalabrijskog bora unutar nalazišta

Mersin Regional Forest Directorates in the central Mediterranean region of Turkey. The provinces of Antalya and Mersin, where the stands are located, lie between 33˚-35˚ east longitude and 36˚-37˚ north latitude (Figure 1). In the central Mediterranean region (Antalya and Mersin), there are 1,981,596 ha of forested area, of which 1,060,827 ha (53.5%) is Calabrian pine stand. 761,194 ha (38.41%) of this area are pure Calabrian pine stands (Directorate General of Forestry, 2018). The other dominant tree species are juniper 19.4%, Lebanon cedar 15.2%, oak species *(Quercus coccifera, Quercus cerris, Quercus infectoria, Quercus ilex, and Quercus libani)* 14.4%, Cilician fir 6.0%, Black pine 4.9%, and other deciduous trees 7.7% (maple, hornbeam, olive, black locust, wild olive, carob). The study area has a Mediterranean climate with hot and dry summers and mild and rainy winters. The average annual rainfall is 1069.8 mm/m² and 585.4 kg/m² for Antalya and Mersin provinces, respectively. The elevation of the study area varies from 79 to 1473 m (= 578.7 m) and the slope ranges from 2% to 150% (=40.9%). 262 of the sample plots are in shady aspects and 224 of the sample plots are in sunny aspects.

Data from 486 temporary sample plots within even-aged stands found in the Antalya and Mersin Forest Regional Directorates were used in this context. Additionally, 972 measurements of two trees selected for harvesting (including the dominant tree to determine site index and the tree to determine the mean stand diameter) in each plot were used (Kahriman et al., 2016b). The number of sample plots was determined considering the combination of nine age classes (0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-80, 81-100, > 100 years), three SI classes (height class I: 23.5< m, height class II: 16.5-23.5 m, height class III: < 16.5 m), three closure classes (11-40%, 41-70%, > 70%) with three replicates in two regional forest directorates.

Depending on the stand structure, the sample plots in this study range in size between 400 m² for crown closure >70 %, 600 m² for 41-70%, 800 m² for 11-40%, and 800-2000 m² for stands that had standing seed trees and seedlings in the transition stage. On each sampling plot, diameters at breast height (dbh) of all trees were measured. Additionally, 10–15 trees from each sampling plot were selected to have their height, age counted by annual rings from core samples in addition to the age up to the height of dbh, double bark thickness on opposite sides, and most recent 5-year diameter growth measured at breast heights. These trees were evenly distributed across the diameter classes of 0-4 cm, 4-8 cm, 8-12 cm, 12-16 cm, …., 96-100 cm. In order to create stand growth models in the form of yield tables, the values for quadratic mean diameter (), mean height (), dominant height (h_{100}), number of stems (N), basal area (BA), stand volume (V), stand age (t), site index (SI), and stand density (sd) were calculated. Descriptive statistics of variables measured on individual trees (dbh, height, age, double bark thickness, and increment) and stand variables estimated from these measurements (stand age, site index, stand density, root mean square diameter, mean height weighted

Table 1. Descriptive statistics of individual tree measurements and stand level estimates
Tablica 1. Deskriptivna statistika mjerenja pojedinačnih stabala i procjene razine sastojine

Level Razina	Variable Varijabla	Number Broj	Mean Aritmetička sredina	Min. Min	Max. Max	Std. Dev. Standardna devijacija
Individual tree Pojedinačno stablo	Breast height diameter (cm) Prsni promjer (cm)	13495	24.77	0.7	87.1	13.10
	Height (m) Visina (m)	13430	14.09	2.5	34.0	6.38
	Age (year) Starost (year)	4092	53.63	10.0	165.0	30.55
	Bark thickness (mm) Debljina kore (mm)	5062	55.72	8.0	141.0	23.91
	Radial growth (mm/godina) Rast promjera (mm/godina)	7094	3.02	0.4	15.6	2.07
Stand Stanište	Stand age (year) Starost sastojine (godina)	486	49.8	6.0	135.0	32.1
	Site index (m) Indeks staništa (m)	486	21.7	8.5	33.8	5.5
	Stand density Gustoća sastojine	486	4.8	0.3	12.4	2.3
	Mean diameter (cm) Srednji promjer (cm)	486	25.6	3.7	61.8	13.6
	Mean height (m) Srednja visina (m)	486	14.2	1.7	31.2	7.1
	Dominant height (m) Dominantna visina (m)	486	16.5	1.9	32.4	7.6
	Basal area (m^2/ha) Osnovna površina (m^2/ha)	486	25.5	0.3	69.5	15.9
	Stand volume (m^3/ha) Volumen sastojine (m^3/ha)	486	207.7	2.5	983.7	170.9
	Number of stems (number/ha) Broj stabala (broj/ha)	486	933.6	80.0	7800.0	1337.0

by basal area, stand volume, number of trees per hectare, and stand density) are presented in Table 1.

In order to create stand models, or in other words, yield tables, stand parameters like age, mean diameter, dominant height, number of trees per hectare, basal area, and volume are first estimated using data gathered from these temporary sample plots. In the second phase, stand density levels were calculated for use in density-based yield tables. When stand age and canopy height or stem analyzes were carried out in the third stage, SI tables were created based on the values for the age and heights of individual trees. Additionally, the site index of all stands in which sample plots are located were determined. In the fourth stage, stand variables such as root mean square diameter, mean height, number of trees per hectare, basal area, and standing tree volume were estimated using the appropriate regression equations as a function of stand age, site index, and degree of stand density. In the fifth phase, the volume of stand removed was estimated using appropriate regression equations as a function of stand age, SI, and degree of stand density, similar to the standing tree calculations using information on dead or dying trees obtained from observations on the sample plots. In the sixth and final stages, volume increments of the entire stand were calculated and the results were presented in tables (Yavuz et al., 2010; Kahriman et al., 2016a).

In our study, the age of 10-15 trees was measured in each sample plot. The stand age (t) was calculated using the arithmetic mean of the age of trees near the root mean square diameter. The site index of the stands was calculated using the dynamic site index models obtained by Kahriman et al. (2016b and 2018) through the Generalized Algebraic Difference Approach (GADA). Among the GADA models of the Chapman-Richards (Chapman and Meyer, 1949; Goelz and Burk, 1992), Hossfeld (Cieszewski, 2001), Log-logistic (Cieszewski, 2000), Hossfeld IV (Cieszewski and Bella 1989), Lundqvist (Cieszewski, 2004), Weibull (Cieszewski, 2004), King-Pardon (Krumland and Eng, 2005), and Bertalanffy-Richards (Cieszewski, 2004), the Hossfeld model was produced the highest score based on the root mean square error (RMSE), the Akaike's information criterion difference (AICd) (Akaike, 1974), and the Durbin-Watson (DW) tests (White, 1992). So, the Hossfeld Model was chosen as the best fit model for the Site Index. Stand density (sd) was calculated using the Relative Density Index developed by Curtis et al. (1981). The quadratic mean diameter ($\bar{d}_g$) of the stand represents the tree with the mean basal area (Laar and Akça 2007). The mean stand height ($\bar{h}_g$) was calculated as the heights of the mean basal area tree on each sampling plot. The dominant height of stand (h_{100}) was calculated as the arithmetic mean of the 100 tallest trees per hectare (Kalıpsız, 1984; Kahriman et al., 2018). The number of trees per hectare (N) was calculated by multiplying the number of trees with a stem diameter of > 4 cm in the sample plots by the hectare conversion coefficient. The basal area of the stand (BA) was calculated by adding the basal area of each tree in the sample plot and converting to hectares. Double-entry tree volume equations developed by Kahriman et al. (2016b) were used to estimate sample plot volume (V). Stand volume was determined by converting the sum of individual tree volumes calculated using the double-entry tree volume equations to hectares. The double-entry tree volume (R^2_{adj} = 0.992, RMSE= 0.041 m3, and Cf= 1.009) and the dynamic model SI (R^2_{adj} = 0.984) from Kahriman et al. (2016b) are provided below.

The double-entry tree volume equation of Calabrian pine was given in Eq.1:

$$LnV = -3.292 + \frac{2.834}{d} + \frac{1.024}{h} + 0.978 \ln d^2 h \quad (1)$$

The model structure of the Hossfeld equation obtained by autoregressive modeling can be expressed as:

$$h_0(SI) = h \cdot \frac{t_0^{1.370244} \cdot (t^{1.370244} \cdot X_0 + e^{9.491999})}{t^{1.370244} \cdot (t_0^{1.370244} \cdot X_0 + e^{9.491999})} \quad (2)$$

$$X_0 = h - 15.94558 + \sqrt{(h - 15.94558)^2 + 2 \cdot h \cdot \frac{e^{9.491999}}{t^{1.370244}}}$$

Where; h is the dominant tree height on the sample plot, t is the age and t_0 is the standard age (a.k.a. base age) which is generally used as at 25 and 50 age for fast growing trees, and at 100 age for slow growing trees (Kalıpsız, 1984; Vanclay, 1994; Laar and Akça, 2007; Pretzcsh, 2009). In this study, the standard age was chosen at 60-year for Calabrian pine. The site index of a plot whose dominant height and stand age were determined can be calculated directly for a desired standard age using these equations (Kitikidou et al., 2012; Kahriman et al., 2018; Suliman et al., 2021).

This GADA model had a root mean square error (RMSE) of 0.8013 m, an Akaike's information criterion difference (AICd) value of 0, and a Durbin-Watson test (DW) value of 2.0099. The fact that the Durbin-Watson value of the model was very close to 2 (DW: 2.0099) indicates that using autoregressive analysis greatly reduced the serial correlation. The developed Hossfeld dynamic site index model successfully modeled age-top height relationships with the S type, polymorphism, multiple asymptotes, and base-age invariable to expected growth principles.

The stand volume and yield parameters such as number of trees per hectare (N), basal area (G), stand volume (V), quadratic mean diameter (), and mean height () of the main stand were predicted using regression equations as a function of stand age (t), site index and stand density. Elements of the remaining trees were predicted using appropriate regression equations generated using variables such as stand age (t), site index (SI) and stand density (sd) and the independent variables derived from these variables using the SPSS statistical software program (SPSS 19.0 Inc., 2010) with forward, backward, and stepwise selection modes. The models that were statistically significant ($p < 0.05$) and those had the highest adjusted coefficient of determination (R^2_{adj}), the lowest root-mean-square error (RMSE) and that also complied with the biological laws were selected.

Adjusted Coefficient of Determination

$$R^2_{adj} = 1 - \left(\frac{\sum (V_i - \hat{V}_i)^2}{\sum (V_i - \bar{V}_i)^2} \right) \quad (3)$$

Root-Mean-Square Error

$$RMSE = \sqrt{\frac{\sum (V_i - \hat{V}_i)^2}{N - p}} \quad (4)$$

Where; V_i and represent calculated and predicted stand volume, and N and p represent sample size and number of variables used in the model respectively.

The removed stand volume and the yield elements are needed to determine the total stand volume yield since the total stand volume is equal to the sum of the standing timber volume at a given age and the volume removed up to that age (Vanclay, 1994; Pretzsch, 2009). In this study, the volume elements of removed stand were calculated using data on dying or dead trees in the stand. Also the number of trees removed was calculated using the difference between the number of trees in successive age intervals within the same site index and density class (Kalıpsız, 1984).

In addition, the volume of total yield and the percentage of intermediate yield to volume of total yield were computed, along with the current annual volume increment (CAI) and increment percentage. The mean annual increment (MAI) of standing timber and overall yield values were calculated in addition to volume and yield volume elements related to standing timber and removed trees (Vanclay, 1994; Pretzsch, 2009; Kahriman et al., 2016a).

RESULTS
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The relationships of quadratic mean diameter ($\bar{d}_g$), mean height ($\bar{h}_g$), number of trees per hectare (N), basal area (G) and volume (V) with stand age (t), site index (SI), and stand

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Table 2. Certain statistical information on the growth relations of the main stands

Tablica 2. Određeni statistički podaci o odnosima rasta glavnih sastojina

Variable Varijabilna	R^2_{adj}	RMSE	Cf	F_{ratio}	p
$\bar{d}_g$ (cm)	0,953	0,178	1,0161	2313,22	<0.001
$\bar{h}_g$ (m)	0,967	0,101	1,0051	3252,48	<0.001
BA (m^2/ha)	0,965	0,173	1,0151	6236,85	<0.001
N (number/ha)	0,822	0,280	1,0399	512,68	<0.001
V (m^3/ha)	0,979	0,163	1,0133	4306,12	<0.001

*Cf (correction factors of logarithmic functions)

density (sd) were examined for standing trees. The following regression models were used to model these relationships. Statistical information on the regression equations were given in Table 2.

$$\text{Ln}\ \hat{d}_q = -0.8375 - \frac{322.142}{t \cdot SI} + 0.6141 \ln t \cdot SI + \frac{33.066 \cdot sd}{t \cdot SI} - 0.003635 sd^2 \quad (5)$$

$$\text{Ln}\ \hat{h}_q = -6.3186 + 1.3570 \ln t \cdot SI - 0.0003\ t \cdot SI + \frac{0.03863 \cdot SI}{sd} - \frac{0.00937 \cdot t}{sd} \quad (6)$$

$$\text{Ln}\ \widehat{BA} = -3.2944 + 0.11848 \ln SI \cdot sd + 0.6504 \ln t \cdot SI \cdot sd \quad (7)$$

$$\text{Ln}\ \widehat{N} = 10.5271 + 0.00001632\ t^2 - 1.1718 \ln t - 0.0008041 SI^2 + 0.0145 sd^2 \quad (8)$$

$$\text{Ln}\ \widehat{V} = -3.4113 + 1.1039 \ln t - 0.00001816\ t^2 + 0.9174 \ln sd + 0.9145 \ln SI \quad (9)$$

These equations are subject to systematic error because they are logarithmic (Akalp, 1978). Therefore, the values obtained from the equations must be multiplied by the correction factor (f) of natural logarithm (ln) to correct this systematic error (Baskerville, 1972).

$$\text{Correction factor} = \text{Cf} = e^{\frac{s^2_{y,x}}{2}} \quad (10)$$

Where *e* represents the natural logarithm (2.718281828) and $S_{y.x}$ represents the standard error of the equation in these equations.

Standing timber and removed tree elements in the yield tables were determined as a function of stand age, site index and stand density using the equations given in Eq. 5-9 and density-dependent Calabrian pine yield tables were constructed. The other elements of the yield table were also predicted by these equations. The standing timber and removed trees elements and the other elements of the yield table were calculated separately for 5-year age intervals (between 10 and 140), 5 degrees of stand density (for 2.0 – 4.0 - 6.0 – 8.0 -10.0), and 3 classes of SI (I-II-III). In addition, our relative density values ranges from 0.3 to 12.4. How-

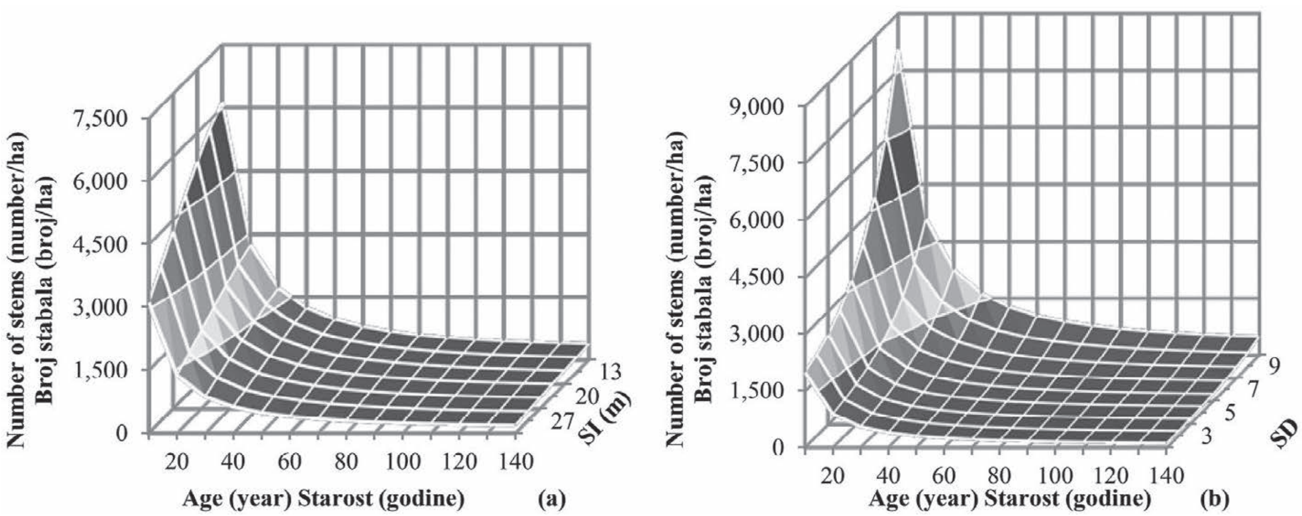

Figure 2. The change in number of stems per hectare according to (a) stand age and site index at normal stand density, and (b) stand age and stand density for medium site index class

Slika 2. Promjena u broju stabala po hektaru prema (a) starosti sastojine i indeksu staništa pri normalnoj gustoći sastojine, i (b) starosti sastojine i gustoći sastojine za razred srednjeg indeksa staništa

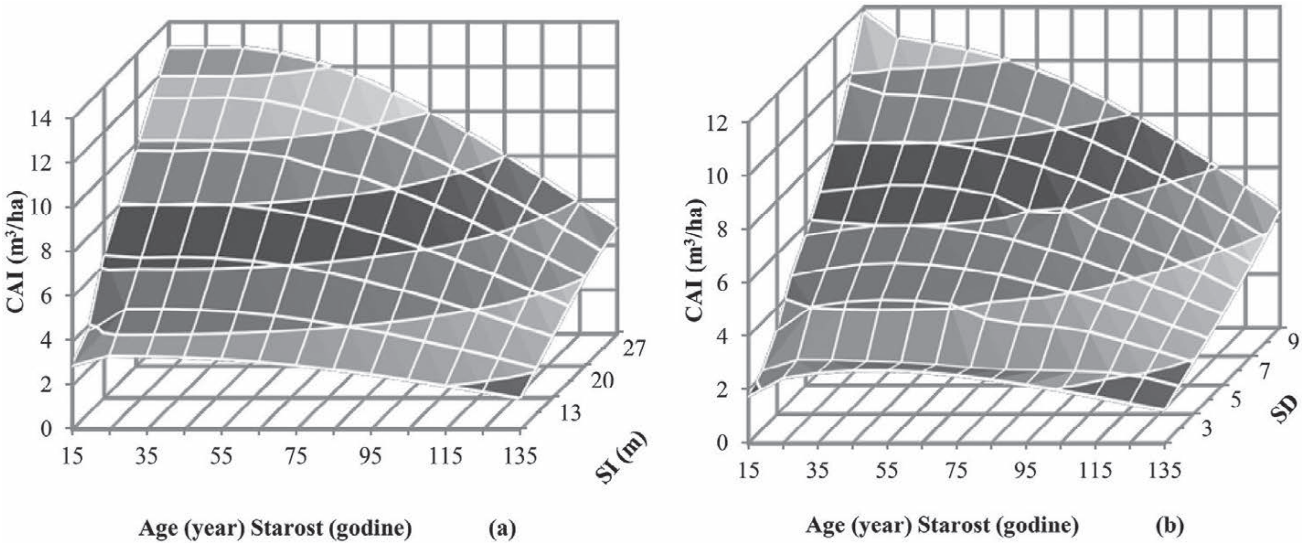

Figure 3. The change in the current annual volume increment (CAI) according to (a) stand age and site index at normal stand density, and (b) stand age and stand density for medium site index class

Slika 3. Promjena trenutnog godišnjeg volumenskog prirasta (CAI) prema (a) starosti sastojine i indeksu staništa pri normalnoj gustoći sastojine, i (b) starosti sastojine i gustoći sastojine za razred srednjeg indeksa staništa

ever, taking into account the stand density of the measured plots of Calabrian pine stands, the normal density value was chosen at 8.0 which is at the 90th percentile for the weighted average relative density measures (Curtis, 1982).

The number of trees in Calabrian pine stands decreases with age, and increases with increasing stand density and worsening of site index (Figure 2). At a normal stand density of 8.0 and an age of 60 years, there were 477, 622, and 749 trees per hectare for site index classes I, II, and III, respectively, while there were only 291, 379, and 457 trees per hectare for 100-year-old trees. In contrast, according to the density grades 2.0, 4.0, 6.0, 8.0, and 10.0, the number of trees per hectare in the middle class site index at 60 years of age was 261, 310, 415, 622, and 1047, and at 100 years of age, it was 159, 189, 253, 379, and 639, respectively.

The current annual volume increases in all SI classes and density grades of Calabrian pine up to 30-40 years of age and after reaching a maximum, decreases with increasing age of the stands. On the other hand, the current annual volume increases with increasing stand density and an improved site index value regardless of age (Figure 3).

Age, stand density, and improved site index all lead to an increase in total stand volume increment in Calabrian pine stands (Figure 4). Total stand volume at normal stand density of 8.0 was 622.0, 447.0 and 263.4 m^3/ha at age 60 and 989.4, 713.7 and 424.4 m^3/ha at age 100 for SI classes I, II

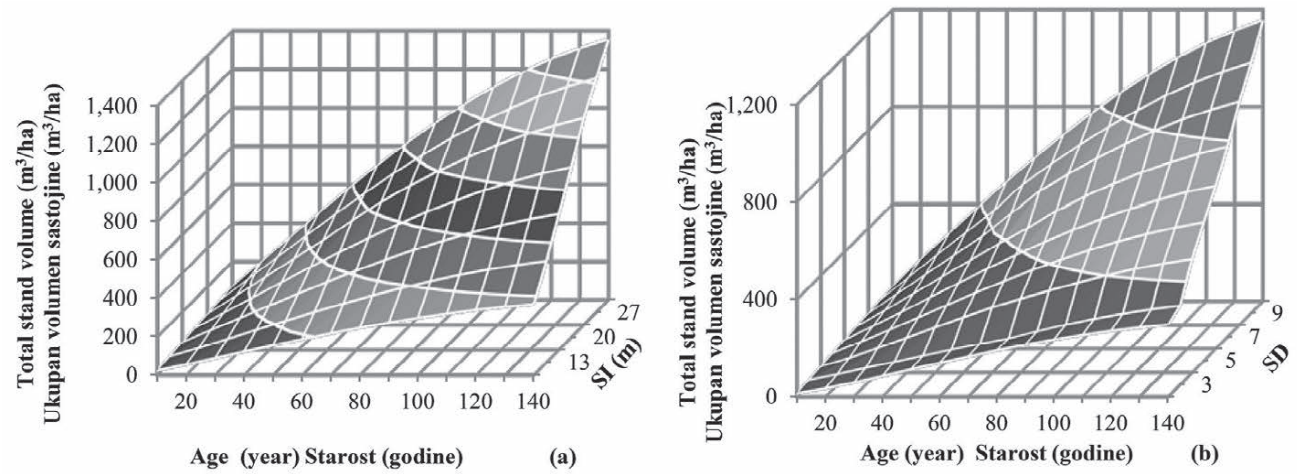

Figure 4. The change of total stand volume according to (a) stand age and site index for normal stand density, and (b) stand age and stand density for medium site index class

Slika 4. Promjena ukupnog volumena sastojine prema (a) starosti sastojine i indeksu staništa za normalnu gustoću sastojine, i (b) starosti sastojine i gustoću sastojine za srednju klasu indeksa staništa

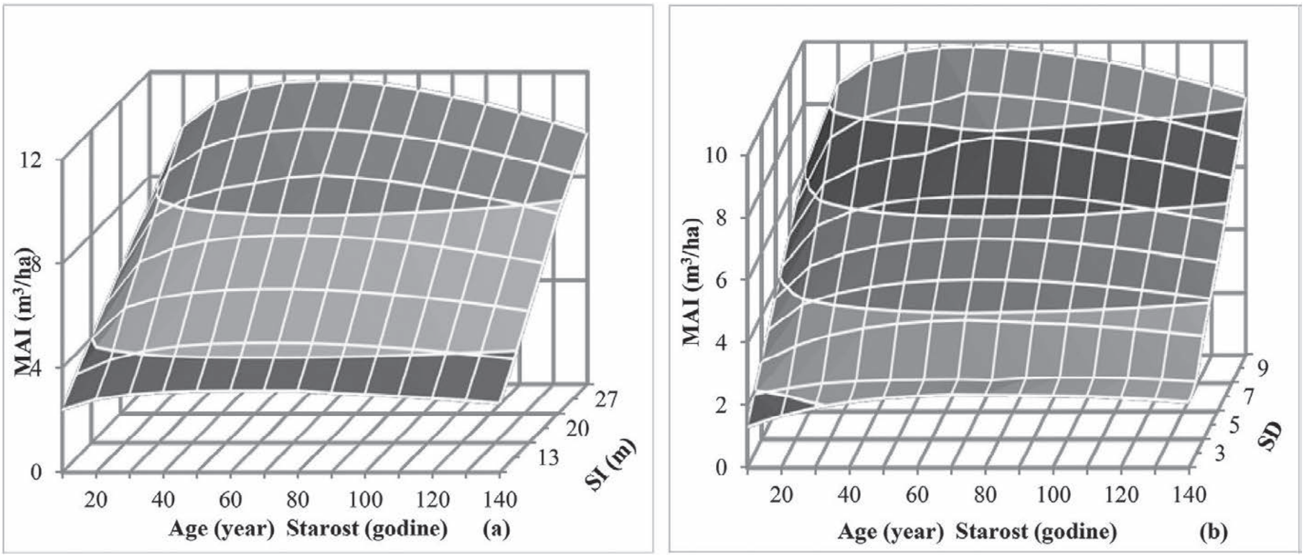

Figure 5. The change of mean annual volume increment (MAI) according to (a) stand age and site index for normal stand density, and (b) stand age and stand density for middle site index class

Slika 5. Promjena srednjeg godišnjeg volumenskog prirasta (MAI) prema (a) starosti sastojine i indeksu staništa za normalnu gustoću sastojine i (b) starosti sastojine i gustoću sastojine za srednju klasu indeksa staništa.

and III, respectively. In the medium site index class, the total volume of stand was 139.2, 231.6, 330.4, 444.7 and 590.6 m^3/ha at age 60 and 229.5, 380.9, 536.2, 713.7 and 935.0 m^3/ha at age 100 corresponding to density classes 2.0, 4.0, 6.0, 8.0 and 10.0, respectively.

Mean annual volume increment in Calabrian pine stands increases across all site index classes and stand densities up to a certain age, reaches its maximum and then begins to decline around a certain age (55- 60 in SI class I, 65-70 in SI class II and 70-75 in SI class III). Mean annual volume increment also increases with increasing stand density and better site quality (Figure 5). Mean annual volume increment at normal stand density of 8.0 was 10.33, 7.41 and 4.38 m^3/ha at age 60 and 9.89, 7.14 and 4.24 m^3/ha at age 100 for site index classes I, II and III, respectively.

The relationship between CAI and MAI was also examined for each SI class separately at the normal stand density of 8.0 in the Calabrian Pine yield table (Figure 6). MAI slowly declines after peaking at the 55-60 years in SI class I, 65-70 years in SI class II and 70-75 years in SI class III. We also

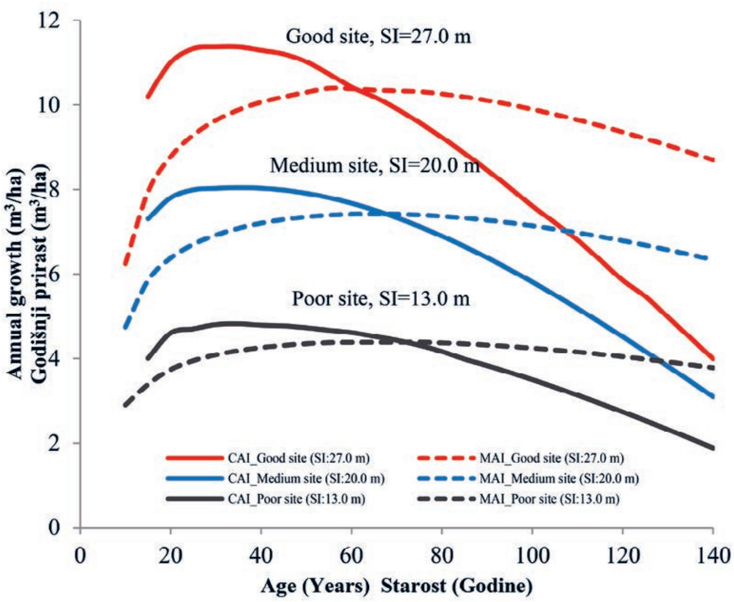

Figure 6. Relationship between CAI and MAI for SI classes of I, II and III

Slika 6. Odnos između CAI i MAI za SI razrede I, II i III

Table 3. The change in total stand volume and mean volume increment according to stand age, site index class and stand density level
Tablica 3. Promjena ukupnog volumena sastojine i prosječnog volumnog prirasta prema starosti sastojine, klasi indeksa staništa i razini gustoće sastojine

Total stand volume (m^3/ha) Totalan volumen sastojine (m^3/ha)					Mean annual volume increment of main stand (m^3/ha) Prosječni godišnji volumni prirast glavne sastojine (m^3/ha)				
Density Gustoća	Age Godine	I. SI	II. SI	III. SI	Density Gustoća	Age Godine	I. SI	II. SI	III. SI
10.0	30	385.9	281.2	148.9	10.0	30	12.86	9.37	4.96
	60	815.5	590.6	321.5		60	13.59	9.84	5.36
	100	1281.5	935.0	526.3		100	12.82	9.35	5.26
	140	1569.2	1155.4	660.7		140	11.21	8.25	4.72
8.0	30	288.9	207.6	122.5	8.0	30	9.63	6.92	4.08
	60	622.0	444.7	263.4		60	10.33	7.41	4.38
	100	989.4	713.7	424.4		100	9.89	7.14	4.24
	140	1217.1	886.5	529.1		140	8.69	6.33	3.78
6.0	30	213.9	151.8	90.9	6.0	30	7.13	5.06	3.03
	60	468.4	330.4	195.8		60	7.81	5.51	3.26
	100	752.7	536.2	317.4		100	7.53	5.36	3.17
	140	929.8	669.2	396.9		140	6.64	4.78	2.84
4.0	30	150.1	104.2	62.4	4.0	30	5.00	3.47	2.08
	60	337.0	231.6	134.9		60	5.62	3.86	2.25
	100	545.9	380.9	220.3		100	5.46	3.81	2.20
	140	677.6	478.0	276.7		140	4.84	3.41	1.98
2.0	30	94.5	58.4	36.1	2.0	30	3.15	1.95	1.20
	60	224.6	139.2	78.5		60	3.74	2.32	1.31
	100	363.4	229.5	128.8		100	3.63	2.29	1.29
	140	451.7	291.2	161.9		140	3.23	2.08	1.16

observed that in the age groups where MAI was highest, its value was equal to CAI. Consequently, the optimal management period (the optimal rotation period) that would lead to the highest yields for pure Calabrian pine stands in Antalya and Mersin can be set at 60, 65 and 75 years for the SI classes of I, II and III, respectively. Site productivity described by maximum MAI, was 10.39 at 60 years, 7.42 at 65 years and 4.39 m^3/ha at 70 years per year for good, medium and poor sites, respectively (Figure 6).

Total stand volume for Calabrian pine for a given age generally increases steadily with decreasing rates as they get older with improving site quality or increasing density. The mean annual volume increment of stand for Calabrian pines for a given age increases irregularly for different site quality classes and stand density levels (Table 3).

DISCUSSION
RASPRAVA

The results of the density-dependent yield tables generated in this study for the Calabrian pine were compared with the previous yield tables generated by Shater *et al.* (2011) in Syria, de-Miguel *et al.* (2010) in Syria and Lebanon, Çatal (2009) in Turkey, Palahí *et al.* (2008) in northeastern Greece, Erkan (1995) and Alemdağ (1962) in Turkey, and with the density-dependent yield table developed by Yeşil (1992) in Turkey. The results were similar and consistent with the growth rules associated with the stand models. The reciprocal equivalents of the variables were considered in the comparisons. For example, the values of the table for the normal stand density level of 8 in this study were compared with the values of the table given by Yeşil (1992) for the normal stand density level. Similarly, yield table values for stands of tree species with optimal growing conditions (i.e., SI class I) were compared for consistency (Akalp, 1978; Kahriman et al., 2016a). Comparisons of the number of trees, total stand volume, current and mean annual volume increment of Calabrian pine stands in high SI class and at normal density with previous studies are shown in Figures 7 and 8.

In study of Palahí *et al.* (2008), the number of trees was consistently higher between 40 and 100 years. With the exception of Alemdağ (1962) up to the age of 50 and Palahí *et al.* (2008) between 40 and 100 years, the number of trees in Calabrian pine stands reported in the yield tables of this study was higher than in the other studies. All studies found that the number of trees converged after age 60, with Çatal (2009)'s values being the most similar to our findings (Figure 7a).

Erkan (1995) obtained the total stand volume values that were most similar to our findings. Total stand volume was also consistently lower in the study by Alemdağ (1962). Our

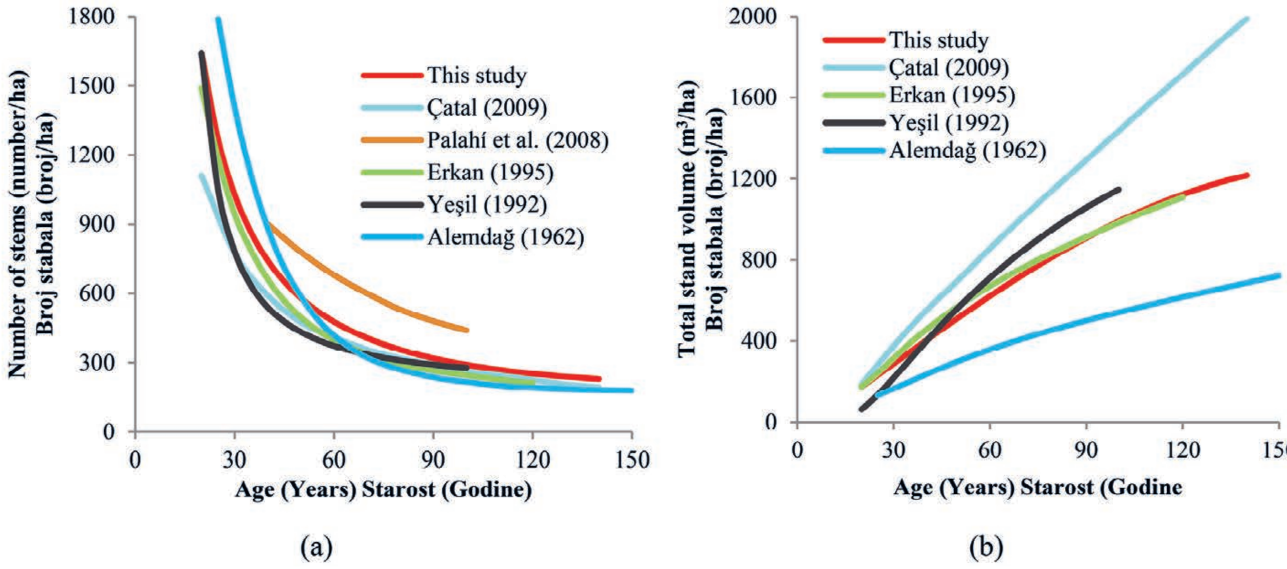

Figure 7. Comparison of the number of trees (a) and total stand volume (b) for Calabrian pine
Slika 7. Usporedba broja stabala (a) i ukupnog volumena sastojine (b) za kalabrijski bor

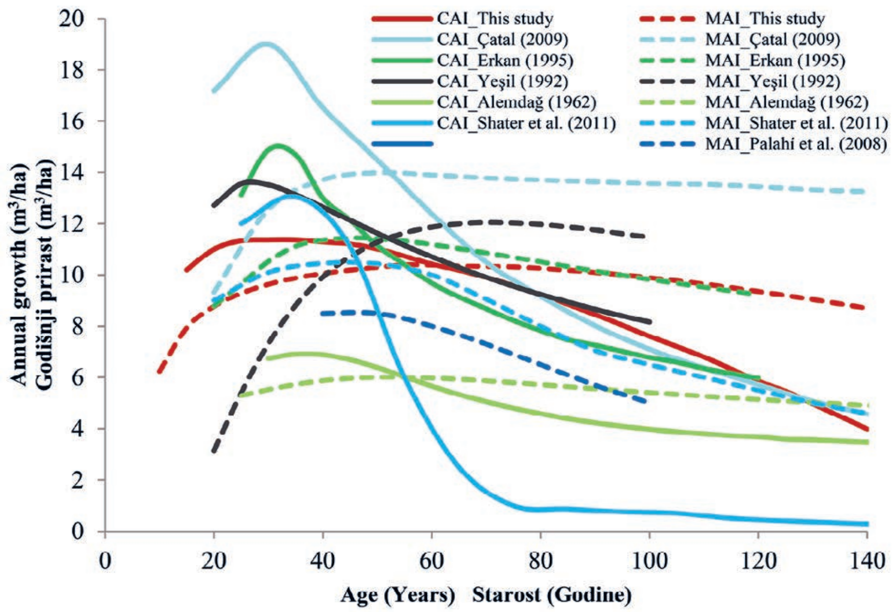

Figure 8. Comparison of current (CAI) and mean annual volume increment (MAI) for Calabrian pine in good site (SI: 27 m) and normal stand density (SD: 8.0)
Slika 8. Usporedba tečajnog (CAI) i prosječnog godišnjeg volumenog prirasta (MAI) za kalabrijski bor na dobrom staništu (SI: 27 m) i normalnoj gustoći sastojine (SD: 8,0)

total stand volume values were greater than Yeşil's (1992) findings until 40 years of age and were lower than to the values reported by Yeşil (1992), and Çatal (2009) after 40 years of age (Figure 7b). Values reported for age 60 for the total stand volume were 358.7 m^3/ha in Alemdağ (1962), 622.0 m^3/ha in this study, 670.9 m^3/ha in Erkan (1995), 712.0 m^3/ha in Yeşil (1992) and 857.6 m^3/ha by Çatal (2009).

CAI tends to increase up to a certain age and then decreases sharply with increasing age of stands in all studies. CAI by Alemdağ (1962) was consistently lower than all other studies up to age 55, while the values determined by Shater *et al.* (2011) were smaller after 55 years for good site. The value CAI determined in this study was larger than that determined by Alemdağ (1962), Erkan (1995), Shater *et al.* (2011) after 50 years and by Çatal (2009) after 80 years for good site (Figure 8). The MAI tends to increase and reach a maximum up to a certain age and then slowly decrease or remain almost the same over time. The age at which the maximum MAI was reached was 40 years in Palahí et al. (2008), 50 years in Erkan (1995) and Shater et al. (2011), 55

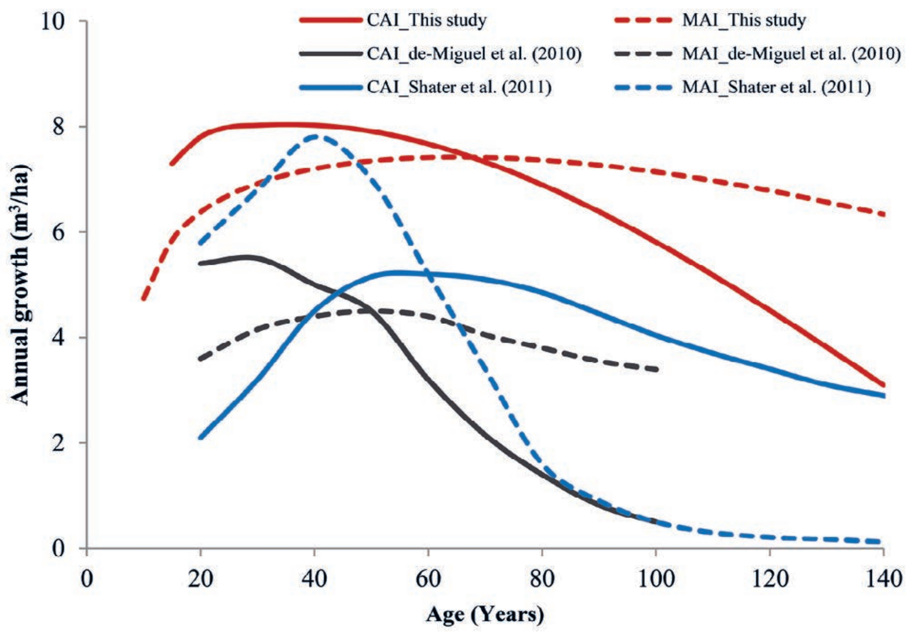

Figure 9. Comparison of current (CAI) and mean annual volume increment (MAI) for Calabrian pine in medium site (SI: 20 m) and normal stand density (SD: 8.0)

Slika 9. Usporedba tečajnog (CAI) i prosječno godišnjeg volumenog prirasta (MAI) za kalabrijski bor na srednjem položaju (SI: 20 m) i normalnoj gustoći sastojine (SD: 8,0)

years in Alemdağ (1962), Yeşil (1992) and Çatal (2009), and 60 years in this study, respectively for good site (Figure 8).

Figure 9 compares the current and mean annual volume increment of Calabrian pine stands of this study in the medium class site index and at normal density with some earlier researchers (de-Miguel et al. 2010; Shater et al. 2011). The MAI and CAI values found for medium site in this study (SI:20 m) were much greater than those found in the de-Miguel et al. (2010)'s (SI:19 m) and Shater et al. (2011)'s (SI:18 m) studies (Figure 9). The maximal MAI was reached at 65 years for our study (7.42 m³/ha) while it was reached at 50 years for de-Miguel et al. (2010) (4.5 m³/ha) and 60 years for Shater et al. (2011) (5.2 m³/ha) (Figure 9).

Yaprak (1977) and Soykan (1978) examined the economic analysis of the Calabrian pine to determine the rotation period in Türkiye. According to Yaprak (1977), the goal of managing and operating the forests of Calabrian pine is to produce high-quality or thick-diameter products that are both accurate and cost-effective, but also have the highest volume possible to meet the demands of the growing forest products industry. The overall average volume increase also reached its maximum at this time. Soykan (1978) reported that the rotation periods must be established as 50, 60, and 70 years based on the information from the current income tables, and the technical maturity rotation age for the Calabrian pine. The administration period for Calabrian pine stands in the Eastern Mediterranean (Syria and Lebanon) was determined by de Miguel Magana (2014) to be 40, 49, and 71 years for the medium and bad site index classes. The General Directorate of Forestry (2008) changed its policy after 2004 by allowing each forest enterprise directorate to determine its own administration period for conditions such as operating objectives and priorities, silvicultural needs, the requirements of the market, and the marketing facilities, and other services of forests for Calabrian pine stands. However, the most current administration period for Calabrian pine stands is 60-80 years in manufacturing purposes and 100 years for protection function purposes (General Directorate of Forestry, 2008).

CONCLUSIONS
ZAKLJUČAK

In this study, increment and growth models were established for pure Calabrian pine only stands in the central Mediterranean Region (Antalya and Mersin provinces). The stand models for Calabrian pine stands were developed as density-dependent yield tables. Using regression equations in the density-dependent yield tables, it was possible to compute the quadratic mean diameter, quadratic mean height, number of trees per hectare, basal area, and volume of standing trees of the stand as a function of stand age, SI, and stand density. Five-year age intervals, five levels of stand density, and three classes of SI were used to present the change in the elements of the density-dependent yield tables connected to standing and removed trees of the stands. While the number of trees in the stand declines with increasing tree age, the total stand volume increases with increasing tree age, SI quality, and stand density (Figure 4 and Table 3). Between the ages of 30 and 50, CAI typically increases, achieves its peak, and then declines across all SI and density classes, however it continues to rise with rising SI quality and stand density. Between the ages of 55 and 60 for SI class I, 65 and 70 for SI class II, and 70 and 75 for SI class III, MAI rises and achieves its maximum, after which it falls throughout density levels. Similar to CAI, MAI rises consistently as stand density and SI quality rise.

To ascertain the Calabrian pine's rotation period in Turkey, according to Yaprak (1977) and Soykan (1978), the rotation times should be set at 50, 60, and 70 years based on data from the present income tables and the Calabrian pine's technical maturity rotation age. We concluded that as many specialists (Gezer, 1985; Richardson, 1998; Awada et al. 2003; Boydak, 2004; Boydak et al. 2006; de Miguel Magana, 2014) claim that the rotation length would be at an age of no more than 60 years for the managed Calabrian pine stands with medium efficiency. Each forest enterprise directorate, however, may choose its own administration period for factors like operational goals and priorities, silvicultural requirements, market demands, and needs for marketing infrastructure and other forest services as the current laws permit.

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SAŽETAK

Modeli rasta sastojina potrebni su za različite prakse u šumarstvu, ponajprije planove gospodarenja i studije uzgoja šuma. Cilj ove studije bio je stvoriti modele na razini sastojina za jednodobne, čiste i prirodne sastojine kalabrijskog bora u središnjem mediteranskom području Turske. Područje istraživanja sastoji se od čistih i prirodnih sastojina kalabrijskog bora, smještenih unutar granica regionalnih uprava za šumarstvo Antalije i Mersina u središnjoj mediteranskoj regiji Turske. Podaci su prikupljeni s 486 privremenih ploha razasutih diljem regije. Dva stabla (dominantno stablo i stablo koje predstavlja kvadratni srednji promjer sastojine) izmjerena su na svakoj plohi, dajući 972 stabla. Podaci su pokazali da je starost varirala od 6 do 135 godina, indeks staništa (SI) od 8,5 do 33,5 m, a gustoća od 0,3 do 12,4. Prirasno-prihodne tablice ovisne o gustoći generirane su korištenjem regresijskih jednadžbi na temelju starosti sastojine, SI i gustoće sastojine s pojedinačnim, dvofaktorskim i trofaktorskim interakcijskim učincima. Optimalno razdoblje ophodnje koje bi rezultiralo najvećim prinosima za čiste sastojine kalabrijskog bora može se odabrati kao 60, 65 i 75 godina za SI klase I, II, odnosno III. Razvijeni modeli rasta sastojine (tj. Prirasno-prihodne tablice ovisne o gustoći) slagali su se s temeljnim zakonima rasta i podacima prikazanim u literaturi.

KLJUČNE RIJEČI: modeli sastojina, Prirasno-prihodne tablice ovisna o gustoći, kalabrijski bor, gustoća, generalizirani algebarski diferencijski pristup (GADP).