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A distance-independent basal area growth model for oriental spruce (*Picea orientalis* (l.) Link) growing in mixture with oriental beech (*Fagus orientalis* Lipsky) in the Artvin region, North-East Turkey

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In this study, we developed an individual tree basal area growth model for oriental spruce (*Picea orientalis* (L.) Link) growing in mixture with oriental beech (*Fagus orientalis* Lipsky) in the Artvin, Turkey. In our modeling approach, the basal area growth variables were divided into 4 main groups, which included size, competition, site and mixture. The parameters of these variables were biologically consistent with general growth trends of forest growth models and we found them each to be statistically significant at the probability level of 0.05. Our model explained 62.4% of the basal area growth variation of oriental spruce with a standard error of 0.836 cm^2. Furthermore, we found that the absolute and relative (%) biases and the root mean square error (RMSE and RMSE%) of the 5 year basal area growth of oriental spruce were 0.00823 cm^2, 0.1353%, 0.8234 cm^2, 33.39% respectively. We evaluated this model by plotting the biases with respect to considerable regressor variables. These graphical analyses of the model biases showed no meaningful and evident trend of bias values along with these independent variables. Our model provides a clear frame of reference for understanding about the individual tree basal area growth patterns of for oriental spruce growing in mixture with oriental beech. This model further shows that the parameter of the mixture proportion (BP) for oriental beech trees in the mixture model component was positive, indicating that basal area growth of spruce increases as the proportion of beech in the forest mixture goes up if other variables remain constant. This positive effect of admixture may be due to the facilitation process occurring in oriental spruce stands mixed with beech trees. The facilitation pattern of beech trees in mixing spruce stands suggests that poor or degraded forest sites may be improved by mixing beech trees for forest areas in this region.

Key words: Oriental spruce, oriental beech, Individual tree basal area growth model, mixed species stands.

INTRODUCTION

Worldwide interest in mixed-species forest stands has recently been stimulated by the shift in emphasis from timber production to forest ecosystem management practices that enhance biodiversity and ecosystem management concepts (Salwasser, 1994; Anglestam, 1998). In this respect, mixed-species forest stands have the potential to improve nutrient cycling (Binkley et al., 1992), soil fertility (Montagnini, 2000), forest biomass production (DeBell et al., 1985; Parrotta, 1999; Van Winden, 2001) and carbon storage (Kaye et al., 2000; Resh et al., 2002). These stands also provide other benefits through improved risk management and protection from pests, fires and diseases (FAO, 1995; Montagnini, 2000).

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The management of mixed-species stands requires growth and yield models to support decision making for forest management policies. Growth and yield models have been widely used to update inventories, predict future yield and explore forest management alternatives and silvicultural options and they are thus used in providing important information for decision-making in pure stands (Burkhart, 1995; Vanclay, 1994). However, there are few research and model-based management tools for growth projections in mixed stands (Jogiste, 2000). Even when a multi-species stand is composed of only 2 different species, there are an enormous number of possible dynamics within the stands. This complexity and the lack of data regarding multi-species stands make their dynamics particularly difficult to model. Since the 1970s, there is a growing demand for models of mixed-species forests with the necessity to update forest inventories, predict future yield and explore alternative management and silvicultural options (Pretzsch, 1999).

In complex systems as mixed-species stands, the describing growth of these stands requires individual tree modeling approaches to account for competition effects and the different characteristics of different species (Porté and Bartelink, 2002). Especially, individual tree-level models use individual trees as the basic modeling unit for tree growth and mortality and thus, these tree models provide more detailed tree growth and yield trends than do stand-level models, which estimate growth and yield in terms of volume, basal area, mean diameter, height and numbers of tree per hectare (Gadow and Hui, 1999; Peng, 2000).

Individual linear tree models can be further classified as distance-dependent (spatial) tree models, wherein the tree location is known and distance-independent (non-spatial) tree models, wherein tree location is unspecified (Porté and Bartelink, 2002). In most forest inventories and applications, the spatial information from mapped tree locations is not available, thus distance-independent tree models have been widely used for growth and yield predictions (Wykoff et al., 1982; Monserud and Sterba, 1996; Sterba et al., 2002; Zhao et al., 2004). Distance-independent tree models do not use spatial information of trees to express as a measure of competition, although they often use proportional attributes of subject tree to its neighbors to account for competition. Thus, a distance-independent (non spatial) tree model is a practical and realistic option for forest management alternatives in the spatial knowledge of tree locations is not known.

Oriental spruce (*Picea orientalis* (L.) Link) and oriental beech (*Fagus orientalis* Lipsky) are 2 important tree species in Turkey, both in terms of high-value wood products and social economic significance. Oriental spruce, one of the 40 spruce species in the world, is distributed between west of the Melet River and the Southern section of Caucasian Mountain in Georgia, growing from the coastal zone to 2400 m altitude (Atalay, 1984; Saatcioglu, 1976). This tree is economically important and the species covers 297, 396 ha with a standing volume of 50.6 million m^3 (Konukcu, 2001). Oriental beech is the major timber species growing in the Black Sea Region forests of Turkey. Oriental beech is native to Turkey and is found in the Black Sea, Marmara, Aegean and East Mediterranean regions, as well as in many other regions of the world (Davis, 1982). Oriental beech forests in Turkey cover 615,000 ha and have a standing timber volume of 154 million m^3, composing nearly 20% of the country's total standing timber volume. The oriental spruce mixture with oriental beech is widespread in the inner regions of the Northeast Black Sea area (Atalay, 1984).

The management of mixed stands of these species is of increasing importance to forest managers in Turkey. In order to effectively manage these mixed stands, foresters require detailed information regarding individual tree growth patterns for each species. Stand level growth models using population mean values have proven useful for managing even-aged stands. Such models have already been developed and are widely used in Turkey (Kalıpsız, 1962; Akalp, 1978; Akalp, 1983; Atıcı, 1998; Carus, 1998; Köse et al., 2001; Ercanlı, 2003). However, these models are of limited utility to mixed even-aged forests, where species and sizes of individual trees are very diverse. Therefore, aim of this study was to develop a distance-independent individual-tree basal area growth model for mixed oriental spruce and oriental beech stands in the Artvin region in the North-east Turkey. This model provides a clear understanding framework for individual-tree basal area growth patterns of oriental spruce growing in mixture with oriental beech. Furthermore, this model demonstrates the influence of the presence of beech species on the basal area growth of oriental spruce stands.

MATERIALS AND METHODS

Study area

This study was carried out in mixed oriental spruce and beech stands located in the Artvin province, North-east Turkey (lat. 41º15' N, long. 41°45' E). The site is about 800 - 2000 m above sea level, characterized by a high mountainous landscape, with moderate to very steep slopes, with inclines ranging from 34 - 92% (62% of whole area). The annual temperature ranges between –2.5 and 31.4 °C and the mean annual precipitation is 719 mm. These meteorological data were interpolated to the study area from the Artvin meteorogical station located at an altitude of 597 m. Winters are mild and wet and summers are relatively cool and dry. The main soil types are sandy clay loam, clay loam and sandy loam (Gunlu, 2003). In addition to *P. orientalis* (L.) Link, *F. orientalis* Lipsky, *Abies nordmanniana* (Stev.) Matt., *Pinus silvestris* L., *Castanea sativa* Mill. and Quercus spp are found in this region. Regional understory species of *Rhododendron ponticum* L., *Rhododendron* *luteum* L., *Arbutus andrache* L., *Cistus creticus* L., *Ostrya carpiniflora* Scop. are also common in both pure and mixed forms in study area.

Collecting data

Ideally, individual tree growth models can be developed using data from permanent sample plots various geographic and ecological conditions, forest types, site productivity and forest stand structures (Vanclay, 1994). Since permanent plot data are scarce for mixed oriental spruce and oriental beech stands, we based our model on observations from temporary sample plots complemented with tree ring measurements from increment cores. The data were obtained from mixed oriental spruce and beech stands from Artvin province, North-east of Turkey. Data were provided from sampling plots systematically distributed along 300 x 300 m grids along within forest areas located in the Artvin Forest Planning Unit. Starting with more than 550 grid points over the 5000 ha forest area of this planning unit, 86 temporary plots were subjectively selected to develop a distance-independent individual-tree basal area growth for mixed oriental spruce and oriental beech. The criterion for plot selection was that the plots should support a mixture of oriental spruce and oriental beech with at least 10% of stand stocking and these plots represented all degrees of mixture with beech trees. Specifically, the selected plots were all relatively well stocked and covered a variety of stand conditions and degree of mixtures with oriental beech. The selected stands were even-aged and had regenerated naturally. None of the plots showed evidence of intensive thinning or damage from natural causes such as fire or storm. These stands have been managed using standard practices such as relatively moderate thinning without fertilization.

Data were collected in the summer in 2002, from circular sample plots ranging 0.04 - 0.08 ha areas, depending on stand density in order to achieve at least 10% of beech trees in sample plots, defined as stand stocking. Thus, mixed stand structure for developing tree growth modeling were guaranteed by the presence of beech trees among spruce trees. In particular, pure spruce stand structures that included only 2 or 3 beech trees were excluded from this study. All trees greater than 8 cm were numbered and identified by species (spruce or beech tree) and diameters at breast height were measured in millimeters with using diameter tape. Based on diameter class width of 4 cm, 1 spruce tree was occasionally selected at random per each diameter classes and the height and age of this tree were measured. Thus, 8 - 10 height and age measurements were measured in each sample plot. Total height was measured using Blume-Leiss Altimeter with the 0.1 m precision. The spruce trees were bored using a Pressler increment borer to determine both the age at breast height and the periodic annual diameter increment. A total of 802 spruce trees were used in modeling individual tree growth from tree, stand and site characterristics in this study. To avoid measurement errors of annual tree ring widths, we used an annual diameter increment of 5 years and then converted these radial growths from the last 5 years into basal area increments (BAI). Annual diameter increments were translated into annual basal area increments (BAI) using the following equation;

$$BAI = \frac{\pi}{4} \cdot \left(dbh_{end}^{2} - dbh_{initial}^{2} \right)$$

5 year period (cm) and dbh_{end} the diameter at breast height at the5 year period (cm) and dbh_{end} the diameter at breast height at the end of the 5 year period (cm).

In fitting a distance-independent individual-tree model, the logarithm of the basal area increment (BAI) was chosen as the dependent variable. The BAI values were more closely correlated with the tree volume growth than diameter increment (Cole and Stage, 1972; Wykoff, 1990). Furthermore, Bella (1971), Johnson (1973) and West (1980) have observed that using basal area growth as the descriptor variable yielded increases in R^2 values (Vanclay, 1994). The site index of oriental spruce was calculated from the site index curves of height over age developed by Akalp (1978) for oriental spruce. These site index curves developed by Akalp (1978) for oriental spruce are based on the anomorphic guide curve method of site index curve development with a reference age of 100 years. Descriptive statistics including mean, minimum, maximum, standard deviation and the coefficient of variation of the tree and plot characteristics are listed below (Table 1).

Basal area growth model

In this study, the model structure suggested by Sterba et al. (2002), Adreassen and Tomter (2003) and Condés and Sterba (2008) was modified to account for the 5 - year basal area increment of oriental spruce in mixture with oriental beech. In this modeling approach, the general hypothesis that basal area or diameter growth is a function of tree size (SIZE), competition (COMPETITION), and site (SITE) characteristic. The relationships between these growth components and tree growth were separately analyzed. In this study, we designed the basal area growth model in this model structure in order to further explore the relationships of these predictor variables and basal area growth. Thus, the variables could be divided into 4 main groups and the model had the following form:

$$\ln(BAI_5) = a + b_i xSIZE + c_i xCOMPETITION + d_i xSITE + e_i xMIXTURE \quad (1)$$

Where the dependent variable, BAI, is the 5 - year basal area increment (cm^2 per 5 - year increment). The independent variables were grouped and further described by vectors. In the basal area growth model, a represents the intercept and b-e are coefficient vectors.

The vector SIZE is composed of diameter at breast height, dbh (cm) and tree total age (years) and Equation (2) describes SIZE as follows:

$$SIZE = b_1 x \ln(d_{1.3}) + b_2 x d_{1.3}^2 + b_3 x \frac{1}{t} \quad (2)$$

The spatial information for distance-dependent indices was not available for the present study, as for most forest inventories. Thus, the vector COMPETITION was based on distance-independent competition indices, e.g., the Basal-Area-in-Larger Trees, BAL, (cm^2), Basal Area, BA, (m^2 ha^{-1}) per hectare and number of trees per hectare, *N*. The Basal-Area-in-Larger Trees (BAL; Wykoff, 1990), the sum of the basal area of all trees larger in DBH than the subject tree, is the most commonly used distance-independent competition index (Monserud and Sterba, 1996; Sterba et al., 2002). This vector is characterized as:

$$COMPETITION = c_1 xBAL + c_2 x \ln(BA) + c_3 xLn(N) \quad (3)$$

Table 1. Mean standard deviation (S.D.) and range of the main characteristics in the study material.

Variables	Mean	Min.	Max.	S.D.	C.V.
Tree variables					
dbh (cm)	35.2	8.2	76.3	13.9	39.49
Age (years)	75.4	22.6	189.7	30.2	40.05
BAL (m^2ha^{-1})	1.11	0.0	4.12	0.87	78.38
BAI (cm^2 5 yr^{-1})	6.86	0.38	39.76	5.80	84.55
Sample plot variables					
G (m^2 ha^{-1})	41.01	5.14	76.97	15.35	37.43
N (# ha^{-1})	656.8	150	2200	366.7	55.83
S_{100} (m)	21.44	11.64	42.71	5.54	25.84
Altitude (m)	1486	1080	1912	221.86	14.93
Aspect (degree)	73.2	0.0	345	68.3	93.31
BP (%)	43.53	10.4	74.65	14.54	33.40

Min.: minimum; Max.: maximum; S.D.: standard deviation; CV: coefficient of variation; dbh: diameter at breast height BAL the sum of the basal area (m^2/ha) in trees with DBHs larger than the subject tree's DBH:; BAI.: 5 - year basal area increment; G: stand basal area; N: total number of tree per hectare; BP: the proportion of basal area of beech to the total basal area for all species per hectare.

The vector SITE is an indicator of site quality and it defines the productivity of the plot. The SITE is comprised of 3 vectors: SI_{100} is the site index of spruce (m), ALT is the altitude of plots (m) and ASP is the aspect of plots, defined by the azimuth angle to north, with a value of 0 denoting a northern aspect and an angle of 180 indicating southern aspects. Certain ecological variables, including element content of the soil (Ca, Mg, etc) and soil texture (clay, silt, sand) were excluded in SITE vector, since these variables require labor-intensive and costly soil analyses for forest studies. Thus, SITE vector is described as:

$$SITE = d_1 x S_{100} + d_2 x ALT + d_3 x Ln(ASP+1) \quad (4)$$

The vector MIXTURE describes the species composition of beech and is composed of the BP vector. The BP was calculated by the ratio of basal area of beech to the total basal area for all species per hectare. This vector is defined as:

$$MIXTURE = e_1 x \ln(BP+1) \quad (5)$$

A multiple least-square regression technique was used to model the relationship between basal area growth (BAI for 5 - year, cm^2) and tree, stand, mixture variables for mixed oriental spruce and beech stands in Equation (1). In fitting this model, several selection circumstances were considered:

(i) Desired variables, including tree size, competition, site index and stand descriptions.
(ii) Reasonable variables with reasonable sign of the estimates.
(iii) Available variables in common forest applications (Andreasen and Tomter, 2003).

These predictor variables, along with their various transformations, interactions and combinations, were tested in a multiple linear regression model with a significance level of α = 0.05. The parameters of the model were determined using stepwise regression in the SPSS REG-procedure (SPSS Institute Inc., 2004).

Model evaluation

To further evaluate the quality of the model fit and the parameter estimates, we used the magnitude and distribution of residuals for the basal area growth model. We identified any obvious dependencies or patterns representing systematic discrepancies and a breakdown of assumptions of multiple least-square regressions (Trasobares and Pukkala, 2004). While there are many assumptions in this model, the essential multiple least-square regression assumptions are that the residuals should have the normal distribution with mean zero and that the variance of these residuals should be constant. These normality assumptions were tested with W tests (Shapiro and Wilk, 1965). We further used t-tests to evaluate the null hypothesis that the mean prediction residuals equal zero.

The unequal residual variances (heteroscedasticity) were analyzed visually since non-normality of the studentised residuals made the use of statistical tests impractical (White, 1980). The presence of heteroscedasticity associated with the error term of the models was checked by plotting the standardized residuals against the predicted values. The presence of heteroscedasticity showed increasing error variation with increasing predicted values. However, the zero-studentized residuals crossing the center of the data points show equal residual variance, homoscedasticity (White, 1980). Furthermore, the presence and severity of multicollinearity was defined by values of the variance inflation factors (VIFs), with values greater than 10 taken to indicate the presence of multicollinearity (Myers, 1986).

To determine the accuracy of model predictions, the absolute and relative biases and the root mean square error (RMSE and RMSE %) were calculated for the models as follows (Vanclay, 1994; Gadow and Hui, 1998) :

$$bias = \frac{\sum (y_i - \hat{y}_i)}{n} \quad (6)$$

Table 2. Parameter estimation and related statistics for individual periodic basal area growth for five-year (cm^2) model in Equation (1).

Parameters	Coefficient	Standard error	t statistics	VIF value
intercept	4.292043	0.724	4.123*	
$Ln(d_{1.3})$	0.000915	0.142	- 10.32***	3.321
$d^2_{1.30}$	0.000221	0.221	- 3.321**	4.213
1/t	51.53221	2.542	6.231***	3.779
BAL	- 0.000017	6.432	- 4.431**	4.541
Ln(BA)	- 0.434002	0.123	- 3.782**	4.351
Ln(N)	- 0.319036	0.201	- 4.021**	1.651
S_{100}	0.010472	3.321	3.532**	1.266
ALT	- 0.000619	9.412	- 2.983*	4.462
Ln(ASP + 1)	- 0.095520	0.621	- 3.012*	2.432
Ln(BP + 1)	0.195957	0.503	3.832**	1.234
R^2_{adj}	0.624			
S.E.E.	0.8360			
RMSE	0.8234			
RMSE%	33.39			
Bias	0.00823			
Bias%	0.1353			

The dependent variable is the natural logarithm of periodic basal area growth increment in cm^2 per 5 - year for oriental spruce, $d_{1.3}$ the diameter at breast height, t tree age, BAL the Basal-Area-in-Larger Trees, BA Basal Area per hectare, N number of trees per hectare, S_{100} is the site index of spruce (m), ALT the altitude of plots, ASP the aspect of plots, BP ratio of basal area of beech to the total basal area for all species per hectare R^2_{adj} adjusted coefficient of determination, S.E.E. standard error of estimate, RMSE root mean square error, t the t-statistics for the hypothesis of β = 0 and VIF the variance inflation factor. *Significant at a level of 0.05., **significant at a level of 0.01., ***significant at a level of 0.001.

$$bias\% = 100\frac{\sum(y_i - \hat{y}_i)/n}{\sum \hat{y}_i / n} \quad (7)$$

$$RMSE = \sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{n-1}} \quad (8)$$

$$RMSE\% = 100\frac{\sqrt{\sum(y_i - \hat{y}_i)^2 /(n-1)}}{\sum \hat{y}_i / n} \quad (9)$$

where n is the number of observations, and y_i and $\hat{y}_i$ are observed and predicted values of 5 - year tree basal area growth from developed model.

In addition, the model's results were further evaluated by graphical comparisons with the 3 - dimensional graphs which plotted predicted 5 - year basal area growth against to predictor variables, e.g. dbh, age, the BAL, SI_{100} and BP of beech trees. Thus, the basal area growth model was examined for relationships predicted 5 - year basal area growth and predictor variables with reasonable sign of the estimates of model.

RESULTS

The distance-independent individual-tree basal area growth model for mixed oriental spruce and oriental beech stands was developed by estimating multiple regression from tree, stand and site variables. Parameter estimates for the individual-tree basal area growth model (Equation 1) are given in Table 2 and each of these parameters is logical and significant at the probability level of 0.05. The model shows relatively good performance in explaining the variation in basal area growth of spruce, with an adjusted coefficient of determination (R^2_{adj}) of 0.624 and a standard error of estimate (S.E.E) of 0.836.

The normal distribution of residuals was tested using Shapiro-Wilk tests (Shapiro and Wilk, 1965) and the critical

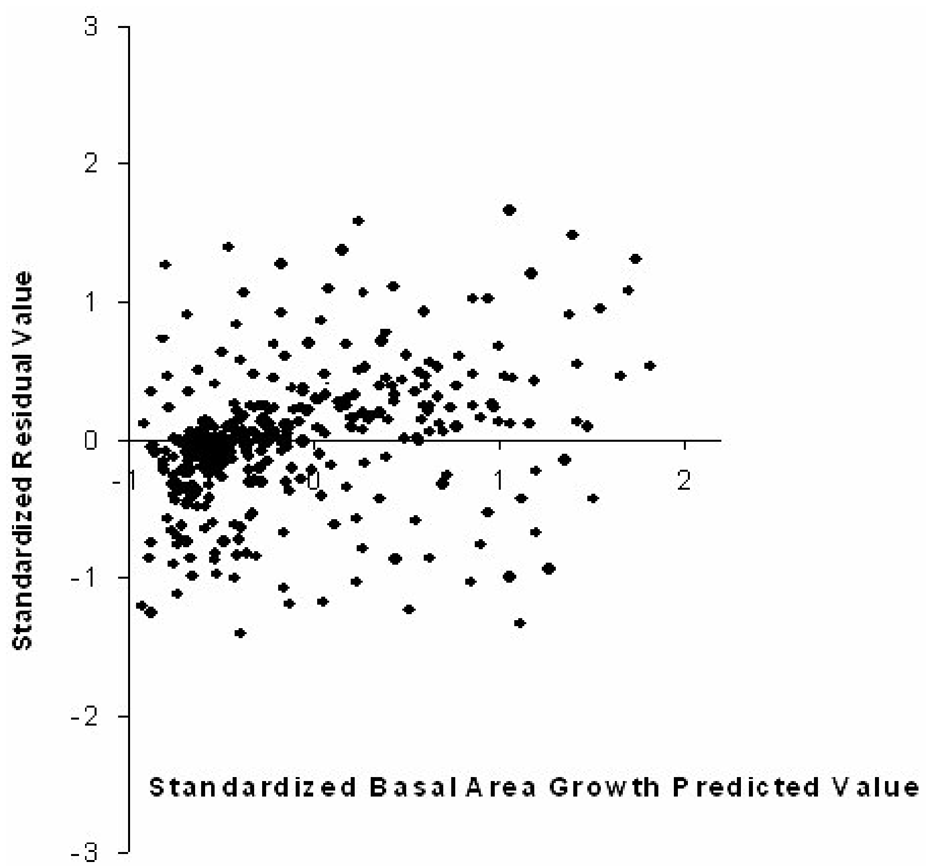

Figure 1. The standardized residuals versus standardized basal area growth predicted values of individual growth model.

critical value for the Shapiro-Wilk test was 0.957, p = 0.354, demonstrating the normal distribution of the residuals. The null hypothesis that the mean prediction residuals would be equal to zero was tested by t-test, which revealed that the null hypothesis could not be rejected and statistically significantly different from zero (t value = - 4.813, p = 0.412). The standardized residuals versus fitted (predicted) values for the growth model are given in Figure 1. These residuals of this growth model indicate that there are no observable patterns in Figure 1 and thus, there are no serious violations of the assumption of constant variance, such as homoscedasticity. The values of VIFs calculated for each predictor of growth model indicate that there is no multicolllinearity in these basal area growth models since each of these values is less than 10 (Table 2).The absolute and relative (%) biases and the root mean square error (RMSE and RMSE%; equations 2 - 5) of the basal area growth model were 0.00823, 0.1353 and 0.8234, 33.39%, respectively. After obtaining the parameters fitted to the 5 - year basal area growth data, the bias was analyzed with respect to the considered regression variables, including dbh, age, G, BAL, S_{100} and the BP variables in Figure 2. These graphical analyses of model biases revealed no meaningful and evident trend of bias values along with these predictor variables (Figure 2). However, the differences between observed and estimated basal area growth in younger trees were found to be larger than older trees in mature stands (Figures 2a, b). This trend was probably due to the nature of the basal area growth of the spruce trees, which caused the variation in the basal areas of spruce trees to be higher in mature stand than in immature stands.

The performance and behavior of the model in predicting 5 - basal area growth were analyzed by 3 – dimensional graphs showing the combined effects of 2 independent variables on basal area growth (Jõgiste, 2000; Lee et. al., 2004). In spite of being much 2 - way interactions between independent variables, 5 - basal area growth as a function of age and dbh of tree (Figure 3a), age and total basal area of sample plot (Figure 3b), age and the BAL of tree (Figure 3c), age and S_{100} of plot (Figure 3d), age and the basal area proportion (BP) for beech trees (Figure 3e), were illustrated with the 3 -

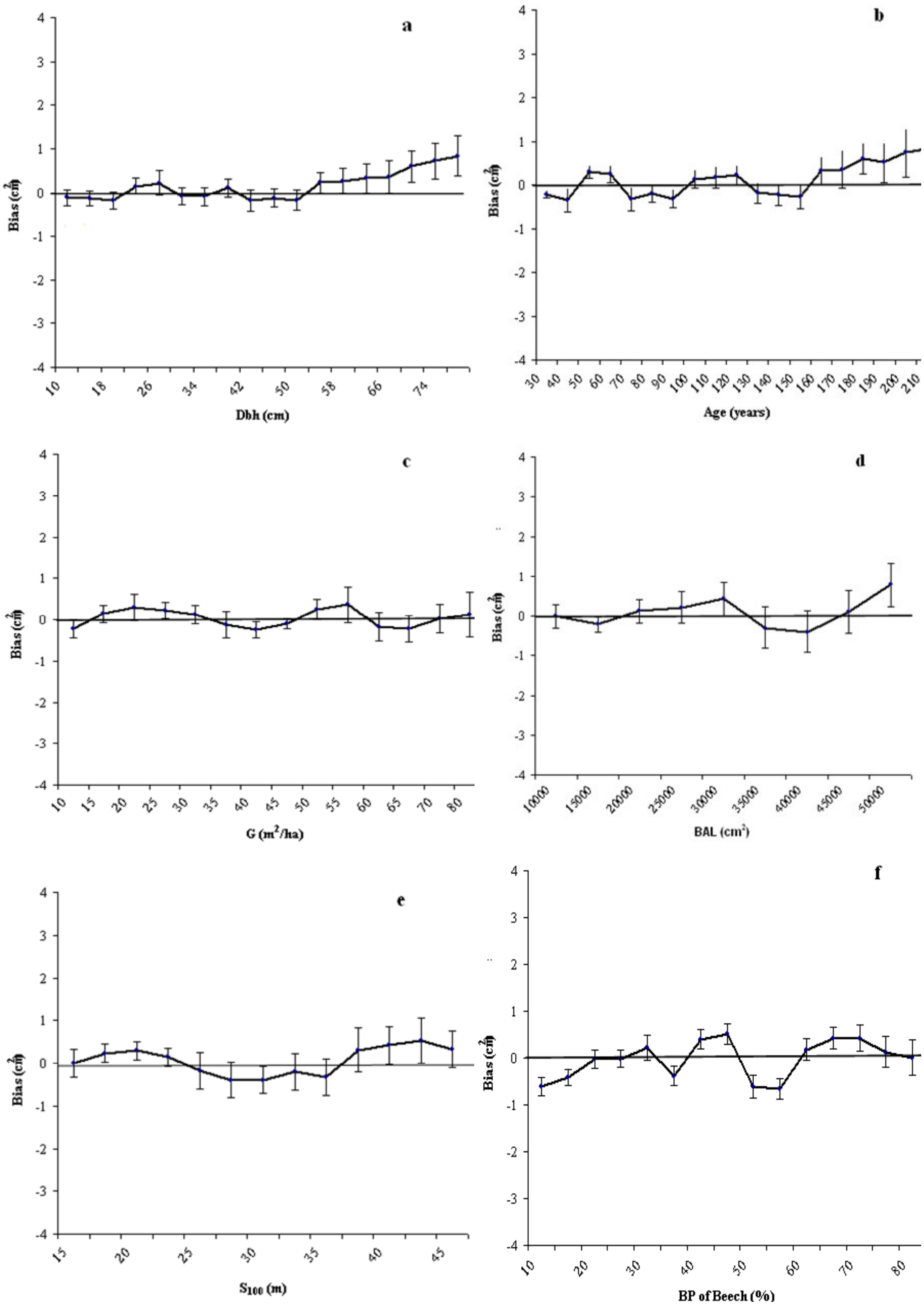

Figure 2. Biases (means ± Standard deviations) of basal area growth for 5 year with respect to dbh (2a), age (2b), BA (2c), *BAL* (2d), S_{100} (2e), BP of beech trees (2f).

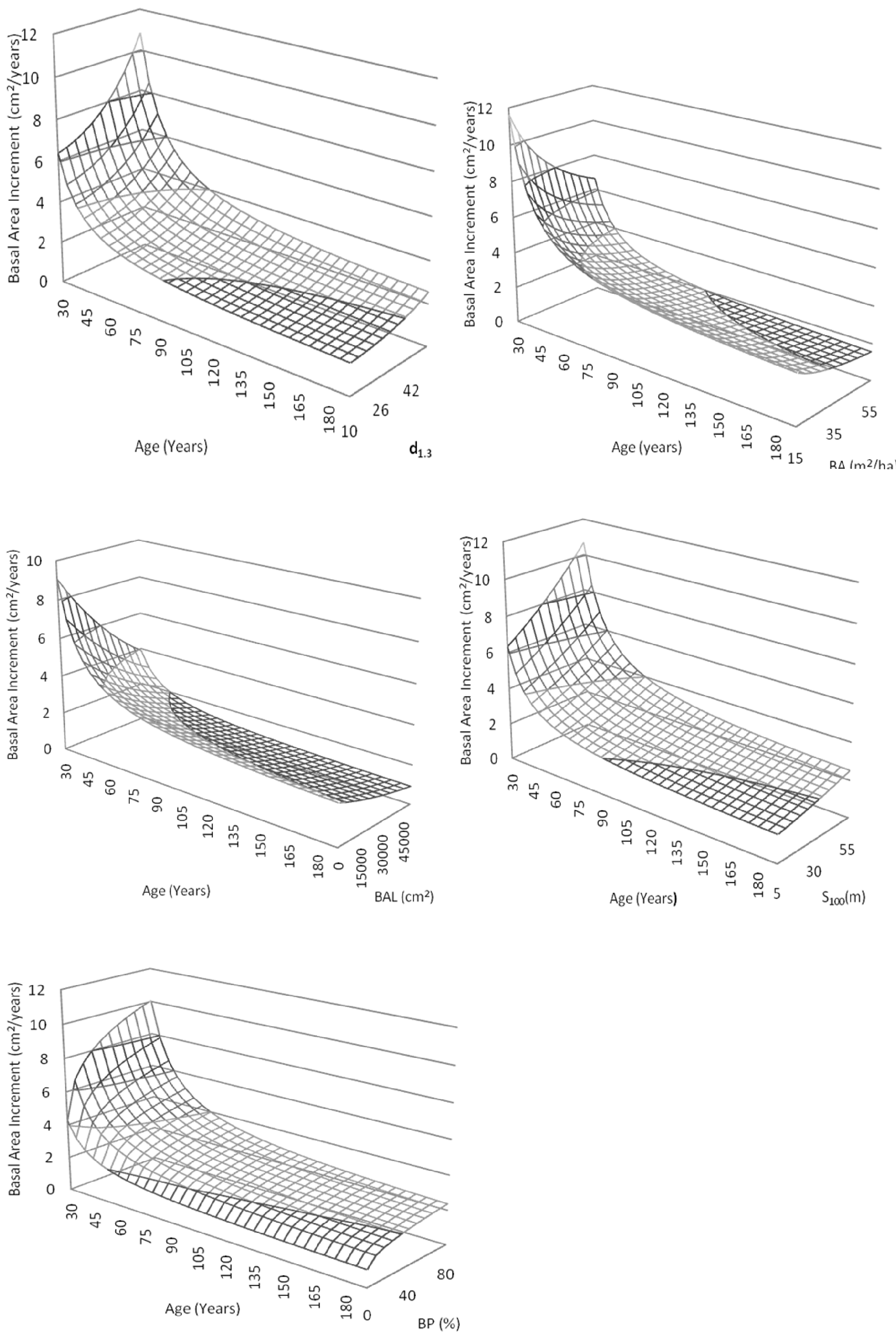

Figure 3. The performance and behavior of the model in predicting basal area increment for five years by dbh (3a), basal area of sample plot (3b), the BAL of trees (3c), S_{100} of sample plot (3d), Basal area percent of beech trees in sample plots (3e). Other variables were kept constant in each appertaining model predictions: the BAL is 11042 cm^2, N 656.8 ha^{-1}, G 41.1 ha^{-1}, SI_{100} 24.5 m, ALT 1146 m, ASP 74°, and BP of the beech trees 18.53%.

dimensional graphs to test the behavior of basal area growth and other variables have been kept constant: the BAL is 11042 cm^2, N 656.8 ha^{-1}, 41.1 ha^{-1}, SI_{100} 24.5 m, ALT 1146 m, ASP 74°, and BP of the beech trees 18.53%.

DISCUSSION

This study presents a distance-independent individual-tree basal area growth model for oriental spruce growing in mixture with oriental beech. This deterministic growth model predicts the 5 - year basal area increment (cm^2) of individual oriental spruce trees through multiple least-square regression from given tree, stand and site variables. The predictor variables in this model are individual tree growth models, including those proposed by Jogiste (2000), Sterba et al. (2002), Andreassen and Tomter (2003), Trasobares and Pukkala (2004), Zhang et al. (2004), and Zhao et al. (2004). These variables can be divided into 4 main vector groups, namely, SIZE, COMPETITION, SITE and MIXTURE vectors. Thus, different variables affecting basal area growth were included in the model and we were able to further analyze and evaluate the effects of these variables on tree growth. These variables were tested through both statistical and biological properties. In particular, the estimate of each parameter for variables of these regression models should be statistically significant at 95% probability levels. All of these variables are biologically and ecologically reasonable and meaningful.

Within the SIZE model component, sign of the parameter for dbh and the inverse of the tree age ($1/t$) was found to be was positive (Table 2). Thus, dbh was positively correlated with BAI, while age of trees was negatively correlated with BAI. The positive effect of dbh on BAI can be explained by the effects of past competition and/or vigor on tree growth, and we found a negative relationship between dbh and age with BAI in this model (Lee et al., 2004). This result is consistent with general experience and previous studies (Jõgiste, 2000; Sterba et al., 2002).The BAI decreases with increasing age, the older tree the tree, the less its growth, which is consistent with general experience and previous studies (Jogiste, 2000; Lee et al., 2004).

The Basal-Area-in-Larger trees (BAL), Basal Area (BA) per hectare and number of trees per hectare predictor in the COMPETITION model component had a markedly negative effect on BAI. In particular, a suppressed tree (with larger BAL, BA and N) would have less basal area growth than that of a dominant tree (smaller BAL, BA and N) in the same stand. The negative effect of competition on tree growth has been confirmed by previous growth studies (Biging and Dobbertin, 1992; Jogiste, 2000; Sterba et al., 2002).

In the SITE model component, SI_{100}, the site index of spruce (m), had a significantly positive effect on BAI, but ALT, the altitude of plots (in m), and ASP, the aspect of plots, were both negatively related to BAI. The SI_{100} is a very commonly used measure of site productivity, as well as a quantitative measure of all the effective factors of the site, which include climatic, biotic, physiographic and edaphic factors (Wang, 1998). In particular, forest areas of high site quality with higher site index values are more favorable areas for growth of this species, and, therefore, the positive relationship between site index and BAI of spruce is consistent with general experience. The ALT showed a negative relationship with BAI, since the altitude had negative effect on physical and chemical attributes of the soil, possibly decreasing the growth period, affecting surface flow of precipitation waters, decreasing the depth of the soil and also higher soil skeleton content, the aggravations of nutrient and water budget in forest sites (Cepel et al., 1977). Furthermore, *ASP* was negatively correlated with BAI, caused by the fact that Northern regions are cooler and experience more precipitation with less evaporation and more soil moisture than southern aspect with the increasing azimuth in the Northern Hemisphere. Thus, the significant negative relationship between azimuth angles and BAI was consistent with ecological perspectives such as those by Eruz (1984) and Dasdemir (1992).

In the MIXTURE model component, the parameter's sign of the mixture proportion (BP) was positive. The BAI of spruce trees was found to increase with increasing BP values and increasing beech mixture proportion. This positive relationship between the proportion of beech trees and BAI of spruce trees may have been due to a facilitation process in mixed stands with beech trees. Some studies, including Sariyildiz et al. (2005), Elmer et al. (2004) and Rothe et al. (2002), show that litter fall from beech trees in mixed stands exerts positive effects on soil structure, soil decomposition processes, soil chemical properties, soil pH values and abiotic and microbial soil factors. Sariyildiz et al. (2005) studied decomposition rates of beech and spruce litter in pure and mixed stands of both species in Artvin. This study shows that abiotic and microbial factors in mixed stands may be better than those in pure stands of spruce or beech and thus mixed stands have superior conditions of litter decomposition rates than do pure stands. Elmer et al. (2004) concluded that the addition of beech to spruce forests could produce favorable growing conditions due to a higher decomposition potential of soils. Rothe et al. (2002) reveal that the admixture of beech trees positively influences humus thickness, soil acidity and soil solution chemistry for mixed stands. As documented in previous studies, beech admixture has a positive effect on forest site conditions, especially soil decomposition process, soil fertility and soil nutrient cycling. Beech trees are often called the 'mother of the forests' in popular worldwide forest writing, due to their ability to improve site and soil quality by a mixture of beech. Also, Kennel (1965) and Rothe and Kreutzer (1998) state that spruce trees use their space more efficiently in mixture with beech than in pure stand and spruce trees growing in admixture with beech grew more rapidly than those growing in pure spruce stands. This facilitation pattern of beech trees in mixed spruce stands suggests some opportunities to improve poor or degraded forest sites by introducing beech trees to forest areas in this region. However, this facilitation effect of beech trees on improving forest sites conditions requires further study and comparison with pure stands.

The developed individual tree model explained 62.4% of all BAI variation in oriental spruce and also, SE was 0.836 cm^2 and RMSE was 0.8234 cm^2. The predictive performance of this basal area growth model was remarkable satisfactory compared to previous individual tree growth models. Jogiste (2000) developed a model that predicted 60% of basal area increment variation with SE of 0.702 - 0.722 cm^2 in Norway spruce [*Picea abies* (L.) Karst] in mixed stands of spruce and birch in Estonia. Sterba et al. (2002) studied a re-parameterising PROG-NAUS model for 2 Austrian growth district and developed a basal area growth model with R^2 of 0.567 - 0.571 cm and SE of 0.702 - 0.722 cm for Norway spruce (*Picea abies* L. Karst.) growing in mixed stands with European beech (*Fagus sylvatica* L.). Andreassen and Tomter (2003) developed a distance-independent individual tree growth model predicting 26 - 55% of basal area growth variation with SE of 0.73 - 0.88 cm^2 for Norway spruce, Scots pine, birch and other broadleaves in Norway. Condés and Sterba (2008) developed an in-dividual tree basal area increment model with R^2 of 0.36 - 0.48cm^2 and bias of 5.95 - 6.56 cm^2 for *Pinus halepensis* Mill. These differences in predictive performances of basal area growth models may be explained through the use of different predictor variables, as well as the stand and site variables used to model growth, along with the interaction of these factors and they may also reflect the differences between studied species and study areas. Even though individual tree growth model explained 62.4% of variation in basal area growth, 37.6% of the variation in the site index remains unexplained. It is per-haps impossible to perfectly predict the total variance in tree growth, since not all factors affecting growth can be measured and factors such as tree vigor, natural genetic variation, micro site differences and measurement errors will remain unaccounted for (Nyström and Kexi, 1997).

The data sets used in this study were based on temporary sample plots complemented with tree ring measurements from increment cores. This available data may cause slightly problem in the modeling process and may affect the model predictions. However, we believed that this data limitation does not significantly or meaningfully affect the model prediction for BAI because important predictor variables affecting BAI were included in our individual tree growth model. Furthermore, model results concerning relationships between predictor variables and BAI with model predictive performance were entirely reasonable when compared with previous growth models (Sterba et al., 2002; Trasobares and Pukkala, 2004; Zhang et al., 2004; Zhao et al., 2004). In addition, data based on temporary sample plots with tree ring measurements have been commonly successfully used in forest studies when no permanent sample plots are available (Jogiste, 2000; Schröder et al., 2002; Lee et al., 2004; Huuskonen and Miina, 2007; Kangur et al., 2007). Ideally, permanent sample plots would certainly improve the model predictions and applicability of this model; however the developed BAI models based on temporary sample plots can be satisfactory in model results and feasibility and they are particularly relevant for partial short forest applications and management practices. In particular, oriental spruce forests have been managed in Turkey with tactical management plans for 10 - year intervals. Thus, the individual tree BAI model presented in this study may be a valuable management tool for these oriental spruce forests.

In the evaluation process, we observed that bias had no meaningful or evident trend along with regressor variables (e.g., dbh, age, BAL, G, S_{100}, BP) in the model (Figure 2). These bias plots emphasized the fact that the model provides accurate predictions of BAI with respect to tree, stand and site predictor variables. However, the differences between observed and estimated basal area growth in younger trees were also found to be larger than older trees in mature stands (Figures 2a, b). This trend was probably due to the nature of basal area growth of the spruce trees, with the variation of basal area higher in mature stands than in immature stands. Since trees with a variety of dbh measurements exist in mature stands, this variability in dbh values may be caused by larger variations in basal area growth. The larger variation of basal area growth in mature stands than immature stands is always present and inevitable phenomenon in forest populations due to itself nature of the growth process. Other tree growth modeling studies, including Adreassen and Tomter (2003), Mabvurira and Miina (2002), Zhang et al. (2004), Hynynen et al. (1998), and Trasobares and Pukkala (2004), observed no constant variance of residuals, an inevitable phenomenon for forest populations due to the nature of the growth process. We found an identical bias trend in predicting tree growth, but these previous studies and present paper did not use weighted least regression (WLS) to model BAI, because a problem occurs if the degree of variation is high enough and evident in predicting estimates of basal area growth. However, this bias trend was not meaningful or evident for heteroscedastic problems for estimates of BAI in developed 5 - year basal area growth.

In biological and ecological evaluations, 3 - dimensional graphs were used to evaluate the combine effects of independent variables on basal area growth of oriental spruce (Figure 3). This evaluation suggest that the fitted basal area growth model posses desirable statistical properties and are biologically reasonable when also these variable's parameters were considered, especially is consistent with general growth trend experience and with the known rules about forest growth modeling. The behavior of basal area growth model in respect to independent variables illustrated in these 3 - dimensional graphs (Figures 3a, b, c, d, e) was consistent with general experience and with the known rules about basal area growth, for example; basal area growth decreases with increasing age and dbh of tree and increasing with site index values.

This study presents a distance-independent individual-tree basal area growth model for oriental spruce growing in mixture with oriental beech. This growth model is the first one on individual tree growth prediction systems for mixed oriental spruce and beech stands. This individual tree growth model has commonly practicability for predicting future yields, making forest management decisions and updating inventories. Furthermore, this model provides important information for the management of mixed stands. These types of distance-independent tree models have been used widely for growth and yield predictions and because this model is distance-independent tree model, it will be applicable even when spatial information from mapped tree locations is not available for most forest inventories. However, this model will be improved by the addition of permanent sample plots comparing alternative silvicultural treatments and alternatives. Furthermore, this individual tree growth model presents a clear understanding about the presence of beech species in basal area growth of oriental spruce with mixed stands. Previous studies, including Kennel (1965) and Rothe and Kreutzer (1998), Elmer et al. (2004) and Rothe et al. (2002), focused on mixed Norway spruce (*Picea abies L.)* and beech (*Fagus sylvatica*), but the present paper details the relationships between tree growth and admixture for oriental spruce (*P. orientalis* (L.) Link) and oriental beech (*F. orientalis* Lipsky) species. Consequently, these findings for oriental spruce and beech were added to the international scientific knowledge base regarding mixed stands. However, these results should be extrapolated to outside the studied forest area was further analyzed and evaluated at other forest sites since the results of this tree growth model are specific to this species and the type of forest structure that was studied.

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