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Allometric relationships between above-ground biomass increment and stand characteristics for crimean pine in Taşköprü, Türkiye

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FOREST ECOLOGY

ABSTRACT

Background: Biomass increment, one of the main components of net primary production (NPP) in forest ecosystems, plays an important role as well as total biomass in the global carbon cycle. In this study, the changes of increments of the above-ground total, stem and branch biomasses depending on stand characteristics (i.e., stand age, stand density, and site index) were investigated, and these relations were modeled for Crimean pine (*Pinus nigra* J.F.Arnold subsp. *pallasiana* (Lamb.) Holmboe) stands in Taşköprü region of Türkiye. Data were obtained from 109 sample trees within 74 sample plots representing the wide range of possible stand characteristics.

Results: The equations developed for above-ground total, stem and branch biomass increments have quite high coefficients of determination (R^2=0.784, 0.684 and 0.780, respectively), whereas low root mean square errors (*RMSE*=0.749, 0.692 and 0.116, respectively). The results indicated that the biomass increment estimates from the allometric equations developed were decreasing with stand age and increasing with stand density and site index and also stand density is the strongest stand characteristic on biomass increment.

Conclusion: The estimates are also consistent with the growth patterns, so the equations can be used for biomass increment estimations and also for carbon storage and NPP projections for Crimean pine stands of the region.

Keywords: Annual increment, stand density, site index, stand age, *Pinus nigra*.

HIGHLIGHTS

Biomass increments were obtained through annual ring analyses on cross-sections taken from the sample trees.
Increments of the above-ground total, stem and branch biomasses changed depending on stand characteristics.
Biomass increments were decreasing with stand age while increasing with stand density and site index.
For all stand density and site classes, as the stand age increased, the ratio of stem biomass increment to above-ground total biomass increment also increased, while the ratio of branch biomass increment decreased.

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INTRODUCTION

Above-ground biomass and also its increment are two main components of the carbon budget of a forest ecosystem (Shibata et al., 2005; Hiura, 2005), and are essential processes that reveal the carbon balance of terrestrial ecosystems (Do et al., 2018). Above-ground biomass increment is the production of forest biomass at certain time intervals. Annual increments in biomass of different forest ecosystems around the world are required to reliably estimate for net primary production, and therefore necessary to estimate carbon sequestration rates of forests (Clark et al., 2001; Djimo et al., 2011; Do et al., 2018; Rawlik and Jagodziński, 2022). Estimating the biomass increment of trees and stands is also an important step to measure and understand forest productivity (Bouriaud et al., 2015). In addition, biomass increment provides valuable information in estimating the oxygen production of the stands (Durkaya et al. 2016). Therefore it is extremely important that the quantification of biomass increment in forests should be estimated for the sustainable management of forest resources, the reliable estimation of carbon content, and to assess the potential of forests to slow down climate change through carbon sequestration.

To estimate the biomass and biomass increment of forests, there are two common approaches among various methods. One of these methods, reliable information on tree growth, which is necessary to estimate the annual increment in biomass, can be obtained by repeated measurements of tree diameter (Lang and Knight, 1983; Lieberman et al., 1985). Otherwise, tree ring analysis is another favour method to determine previous tree diameters instead of repeated measurements (Détienne, 1989; Worbes et al., 2003; Dye et al., 2016). Biomass increment can be determined by taking the differences of biomass values estimated with allometric equations used diameter values obtained from repeated measurements or from tree ring analyzes (Malhi et al., 1998; Dye et al., 2016; Teets et al., 2017). However, repeated measurements on an annual basis or certain time periods are time-, labor- and cost-intensive, and also error-prone (Teets et al., 2017). On the other hand, tree annual ring analysis method is not widely used to determine biomass increment (Dye et al., 2016), although it is a reliable method to estimate biomass increment (Bouriaud et al., 2005).

The NPP of a stand, as well as the biomass increment as its main component, is a function of various stand characteristics, such as stand age, density, and site index as a sign of site productivity (Arp and Oja, 1997). Beside, individual tree biomass is affected by age, species and size of object tree and also by site conditions and management practices of the stand where the object tree is located (Liu, 2009). Therefore, stand age, density, and site index are included as independent variables in biomass increment models as individual tree or stand growth (Avery and Burkhart, 2002).

Crimean pine is economically and ecologically valuable tree species for Turkish forestry with total forest area of about 4.2 million ha (General Directorate of Forestry, 2015). Natural distribution including both pure and mixed stands of the species is in southern Europe, the Balkans, and western Asia. It can survive for several centuries on arid, rocky and poor soils. Crimean pine (*Pinus nigra* J.F.Arnold subsp. *pallasiana* (Lamb.) Holmboe) is one of five subspecies of *Pinus nigra*, and grows naturally in western Black Sea, Anatolian and Mediterranean regions of Türkiye (Akman et al., 2003; Mamıkoğlu, 2007). The fact that Crimean pine stands are prominent in terms of distribution and economically and ecologically important encourages the determination of its biomass and biomass increment.

According to the limited information obtained from the literature, stand characteristics have important effects on biomass increment. In this study carried out to test this hypothesis in Crimean pine stands; it was aimed (i) to investigate the relationships between above-ground biomass increments and stand characteristics, and (ii) to develop allometric equations that model the biomass increment (as above-ground total, stem, and branch level separately) depends on stand age, stand denstiy and site index.

MATERIAL AND METHODS

Study area

This study was conducted for pure and even-aged Crimean pine stands of Taşköprü region, northwest Türkiye (Figure 1). Study area is rich in pure and mixed conifer stands, especially of Crimean pine, which is the most widespread species in the study area. The total study area is 176.648 ha, and 64% of the region covers forested lands.

Elevation of the study area ranges from approximately 800 to 1500 m above sea level with a slope range of 0-40%. Kastamonu-Taşköprü region has an annual average temperature of 10.1 ˚C, and average annual precipitation of 525.3 mm in 1991-2020 period (TSMS, 2022).

Field work

In order to represent the variability of stand conditions (i.e., stand age, site index, and stand density), 74 temporary sample plots distributed available range of ages, sites and densities were measured. Sizes of sample plots were arranged considering stand crown closures to ensure that there are at least 30 trees in the sample plots, and circular sample plots were taken at 800 m^2, 600 m^2 or 400 m^2 in size for stands with 11-40%, 41-70% and more than 70% of crown closure, respectively. In each sample plot, diameters at breast height (*dbh*) and breast hight bark thickness (*b*) of all trees larger than 8 cm (*dbh* ≥ 8 cm) were measured by caliper and bark-gauge, respectively. Trees measured within each sample plot were splitted into 4-cm diameter classes, then 2-3 trees from each diameter class were cored and heights of these trees were determined using Haglof Vertex III hypsometer. To assign stand ages (*T*), ages of 4-5 sample trees with *dbh* close to the mean diameter were determined adding annual ring numbers at the stump height (0.30 m) to average time to reach the stump height. Then, stand ages were calculated by averaging of sample trees' ages for each sample plot. In the sample plots, the ages and heights of 4, 6 or 8 dominant trees considering sample plot size, to ensure 100 trees per hectare approach, were measured to determine site indexes (*SI*) according to the of dynamic site index model developed by Seki and Sakici (2017) for Crimean pine stands in Taşköprü region. The stand density (*SD*, $SD = G / \sqrt{d_q}$, *G: Basal area*, d_q*: the quadratic mean diameter*) was calculated using the relative density formula developed by Curtis et al. (1981).

In order to obtain data for biomass increment calculations, one or two sample trees with the closest *dbh* to the quadratic mean diameter (d_q, $d_q = \sqrt{\sum d_i^2 / n}$, d_i*: diameter at breast height of an individual tree, n: total number of tree*) were felled at stump height in each sample plot. Total number of sample trees felled was 109. From each sample tree, a cross-section was taken at breast height. Ages of sample trees were also calculated.

Above-ground biomass increment calculations

Biomass increment is the change in the amount of biomass between the two time periods and is the main component of NPP (Clark et al., 2001; Foster et al., 2014). There are various *met*hods for estimating the biomass increment. The most reliable method is to use continuous data obtained from permanent inventory (Lang and Knight, 1983; Lieberman et al., 1985). In this study, tree rings analysis method was used due to the lack of continuous data for biomass increment.

To perform tree rings analyzes, firstly, cross-sections taken from sample trees were sanded and polished using fine sandpaper to make them suitable for analysis. On each cross-section, over-bark diameters (*dob*) were measured with two perpendicular angles and averaged, and the bark thicknesses were also measured to calculate under-bark diameters (*dub*). Tree rings analyzes were utilized for 10-year period. The *dob* and *dub* values mentioned above were considered as the end of the period measurements. For the beginning of the period, *dub*s were measured on cross-sections and bark factor (*BF*) was used to convert *dub*s to *dob*s. The *BF* was calculated as 1.186 with the following relationship between *dob* and *dub* of sample trees for cutting year; $BF = \sum dob / \sum dub$ (Loetsch et al., 1973).

In the literature on biomass increment, it is generally assumed that the biomass increment is either estimated as woody biomass increment (Granier et al., 2000; Le Goff et al., 2004; Babst et al., 2014) or as above-ground total biomass increment (Foster et al., 2014; Teets et al., 2017). In this study, both woody biomass and above-ground total biomass increments were examined. For this purpose, over-bark diameters for 10-year period obtained from the tree rings analysis were converted to total above-ground (M_{ag}), stem wood (M_s), bark (M_b) and branch (M_{br}) biomasses by using the single-entry equations developed by Sağlam (2016) for Crimean pine stands at different ages, densities and sites of the study area (Table 1). Stem biomass was obtained as the sum of stem wood and bark biomasses. Then, differences for total above-ground and componential biomasses for 10-year period were calculated and were divided by 10 (length of increment period) to determine annual average biomass increments for each sample tree.

Liu (2009) and Teets et al. (2017) stated that the growth and increment patterns, such as biomass and biomass increment, of a mean tree represent the stand level patterns, and individual tree level estimations could be expanded to stand level. So, biomass increment of stands could be estimated using increment of individual trees, which are mean trees with the closest *dbh* to d_q for each sample plot. Based on this statement, annual biomass increments of sample plots were calculated by multiplying the annual biomass increments of sample trees by number of trees per plot, firstly. Then, sample plot level increments were expanded to hectare level with hectare expansion factor (*k* = 10000/*sample plot size*). Descriptives statistics of biomass increments and stand characteristics (such as stand age, site index and stand density) for 74 sample plots were given in Table 2.

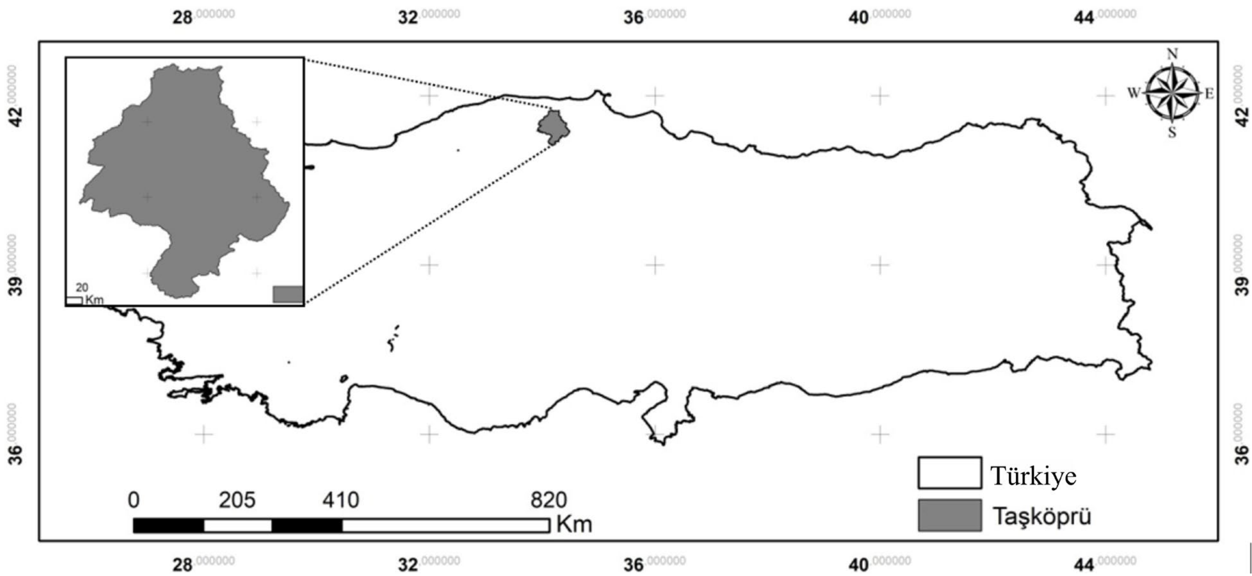

Figure 1: Geographical location of the study area.

Table 1: Allometric equations used for biomass estimations (Sağlam, 2016).

Biomass Component	Equation	R²
Above-ground total biomass	M_{ag} = -2,544 d + 0,455 d^2	0.979
Stem wood biomass	M_s = -2,581 d + 0,332 d^2	0.959
Bark biomass	M_b = -0,039 d^2	0.949
Branch biomass	M_{br} = -0,061 d^2	0.889

Since the increment data were obtained from cross-sections taken from the individaul trees sampled in temporary sample plots, the data about mortality for increment period could not be determined. Therefore, it was assumed that the stands remain stable regard of number of trees, and the effect of mortality on biomass increment was not considered.

Data analysis

The relationships between annual biomass increments and stand age, site index and stand density were investigated using correlation analysis. To achieve the other purpose of the study, i.e. developing regression models to predict biomass increments using stand characteristics, multiple linear regression analysis based on stepwise variable selection method was conducted to fit biomass incement models. The dependent variables in these models were annual total above-ground biomass increment (BI_{ag}), annual stem biomass increment (BI_s) and annual branch biomass increment (BI_{br}), and independent variables stand age (T), site index (SI) and stand density (SD). In addition to the original form of dependent and independent variables, their logarithmic, quadratic and multiplicative inverse transformations were also considered in stepwise selection process. Coefficient of determination (R^2), bias and root mean square error ($RMSE$) were calculated to reveal the prediction success of biomass increment models developed (Equations 1, 2, and 3). Statistical analyzes were carried out using IBM SPSS Statistics 23 software.

The coefficient of determination (R^2):

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{y}_i\right)^2} \quad (1)$$

Root Mean Square Error ($RMSE$):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{n-p}} \quad (2)$$

Bias (B):

$$Bias = \frac{\sum_{i=1}^{n}\hat{y}_i - y_i}{n} \quad (3)$$

where , y_i, and are the estimated, observed, and mean values of the biomass increments, respectively; n is the number of data; p is the number of parameters.

Biomass increments-stand characteristics relationships were demonstrated using scatter plots in addition to the correlation analysis. Observed vs. predicted increment graphs and residual distributions were also created to see the success of the biomass increment models.

RESULTS AND DISCUSSION

According to the Kolmogorov-Smirnov test results, annual biomass increments (BI_{ag}, BI_s and BI_{br}) as well as stand characteristics (T, SI and SD) were normally distributed (p>0.05). Hence, Pearson correlation analysis was applied to detect relationships between annual biomass increments and stand characteristics (Table 3), and the linear relationships between annual biomass increments and stand characteristics were illustrated in Figure 2.

Among stand characteristics, stand density was positively high correlated with all annual biomass increment values, while site index showed relatively weaker positive correlations (p<0.05). The increase in the stand density and thus more trees in the stand lead a decrease in diameter increment in individual trees (Maguire et al. 1990; Kalıpsiz, 1999). However, biomass increments per hectare on a dense stand can be higher than on an open stand because of the higher number of trees on dense stand. Thus, it can be stated that the positive relationship between stand density and biomass increments is due to larger biomass increments at dense stands. Avery and Burkhart (1983) also pointed out that the volume increment is greater at dense stands. On the other hand, positive correlations with site index were explained by the increase of the site index due to the improvement of the conditions of the

Table 2: Descriptive statistics of biomass increments and stand characteristics.

Variables	Min	Max	Mean	Std. Dev.
Annual total above-ground biomass increment (Mg ha^{-1} yr^{-1})	0.83	7.78	3.066	1.621
Annual stem biomass increment (Mg ha^{-1} yr^{-1})	0.66	6.07	2.357	1.240
Annual branch biomass increment (Mg ha^{-1} yr^{-1})	0.13	1.22	0.469	0.249
Stand age	26	153	80.6	26.9
Site index	10.9	36.8	20.67	5.73
Stand density	2.5	12.9	6.12	2.41

site, and thus the larger diameter increment of the trees. Contrary the declared results, stand age had negative correlations with total above-ground and branch biomass increments ($p<0.05$) while non-significant correlation with stem biomass increment ($p>0.05$). The decreasing in stand biomass increment amounts depending on the stand age was a consequence of the lowering of the growth forces and the smaller diameter increments with aging of the trees that forming the stands in accordance with the general model of biomass change (Foster et al. 2014).

According to the multiple linear regression analysis to obtain biomass increment estimates based on three independent variables (stand density, stand age and site index), logarithmic forms of the dependent variables (BI_{ag}, BI_s and BI_{br}) had more successful fitting results than original forms. Baskerville (1972) and Sprugel (1983) suggested use of correction factor (*CF*) when the dependent variable of a regression model has logarithmic transformation. So, all biomass increment models developed in this study required correction factors. Using the equation $CF = Exp(SE^2/2)$, correction factors were calculated as 1.014667, 1.006258 and 1.000336 for total above-ground, stem and branch biomass increments, respectively. As a result, following equations (Eq 4, 5 and 6) were obtained to predict annual biomass increments

Table 3: Correlation analysis between biomass increments and stand characteristics.

Annual biomass increment	Stand age		Site index (m)		Stand density	
	r	p	r	p	r	p
For total above-ground biomass (Mg ha^{-1} yr^{-1})	-0.231^{*}	0.048	0.493^{**}	<0.001	0.649^{**}	<0.001
For stem biomass (Mg ha^{-1} yr^{-1})	-0.205^{ns}	0.080	0.484^{**}	<0.001	0.624^{**}	<0.001
For branch biomass (Mg ha^{-1} yr^{-1})	-0.274^{*}	0.018	0.494^{**}	<0.001	0.653^{**}	<0.001

**Significant at the 0.001 level, *Significant at the 0.05 level, ^{ns}Non-significant.

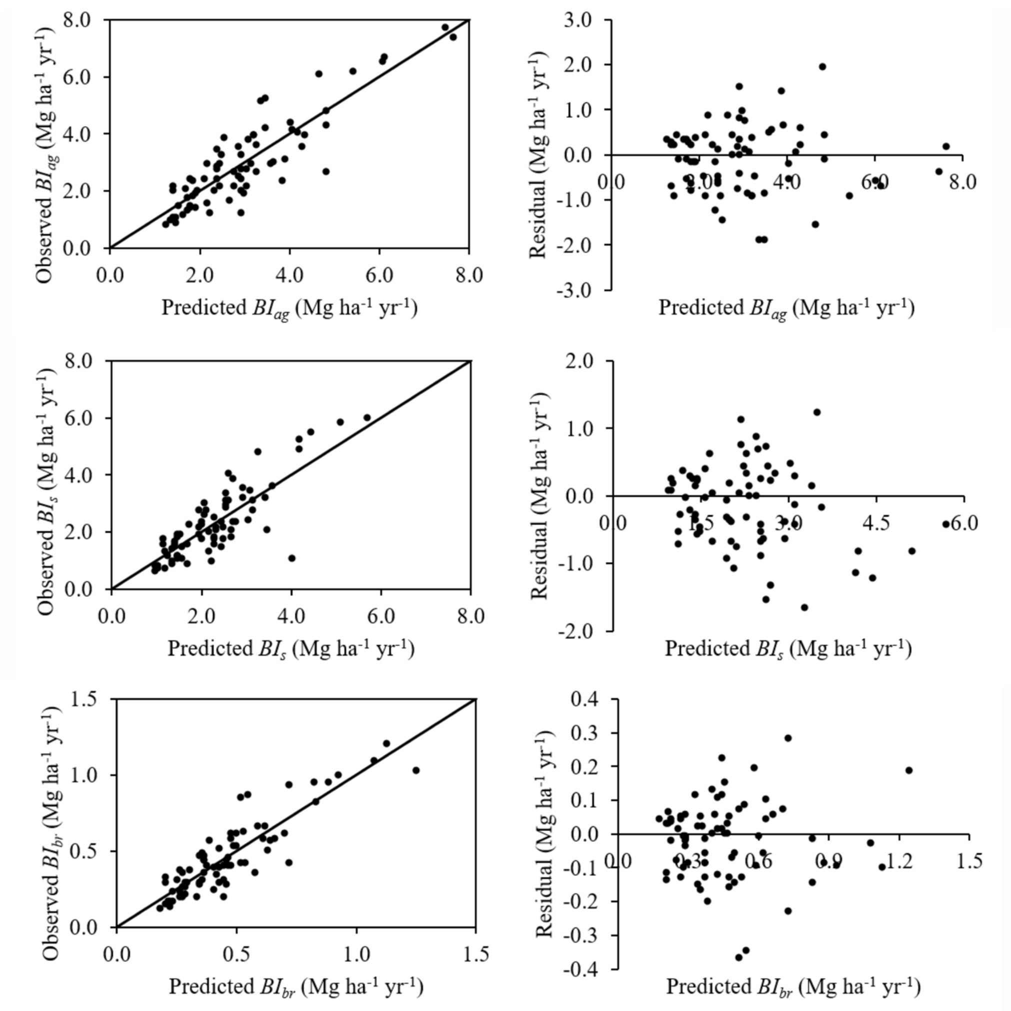

Figure 2: The relationships between biomass increments and stand characteristics.

(BI_{ag}, BI_s and BI_{br}) using stand characteristics (T, SI and SD). All coefficients of the models were significant at 0.05 level.

When the success of biomass increment models are investigated, it is seen that the models for total above-ground and branch biomass increments have high coefficients of determination (R^2) and low bias and root mean square error ($RMSE$) values. Stem biomass increment model has also acceptable goodness-of-fit statistics, although it is not as successful as total above-ground and branch biomass increment models.

$$\ln BI_{ag} = -2.092 + 0.562 \ln SI + 0.163 SD + 28.723 / T \quad (R^2 = 0.784;\ Bias = 0.045;\ RMSE = 0.749) \tag{4}$$

$$\ln BI_{s} = -2.974 + 0.617 \ln SI + 0.871 \ln SD + 24.937 / T \quad (R^2 = 0.684;\ Bias = 0.087;\ RMSE = 0.692) \tag{5}$$

$$\ln BI_{br} = -1.919 - 9.328 / SI + 0.164 SD + 36.541 / T \quad (R^2 = 0.780;\ Bias = 0.013;\ RMSE = 0.116) \tag{6}$$

The observed annual biomass increments against the predictions obtained with regression models and residual distributions were given in Figure 3. As seen on the observed vs. predicted graphs, the differences between the observed and predicted increments have no significant tendency for all three graphs. When the residual graph of the total biomass increment model is examined, the model has smaller residuals for low and high predictions than the predictions ranged from 3 to 5 Mg ha^{-1} yr^{-1}. For stem and branch biomass increment models, the residuals are higher for the predictions between 2-4 Mg ha^{-1} yr^{-1} and 0.4-0.6 Mg ha^{-1} yr^{-1}, respectively.

To detect the change of annual biomass increments regard to site index and stand density, both stand characteristics were grouped in three classes according to data obtained from field inventory. Site classes were 16, 24 and 32 m, and stand density classes were 4.5, 7.5 and 10.5. According to the annual biomass increment prediction results of all SI and SD classes for stand ages ranged from 30 to 150, stand density had greater effect than site index on annual biomass increments (Figure 4).

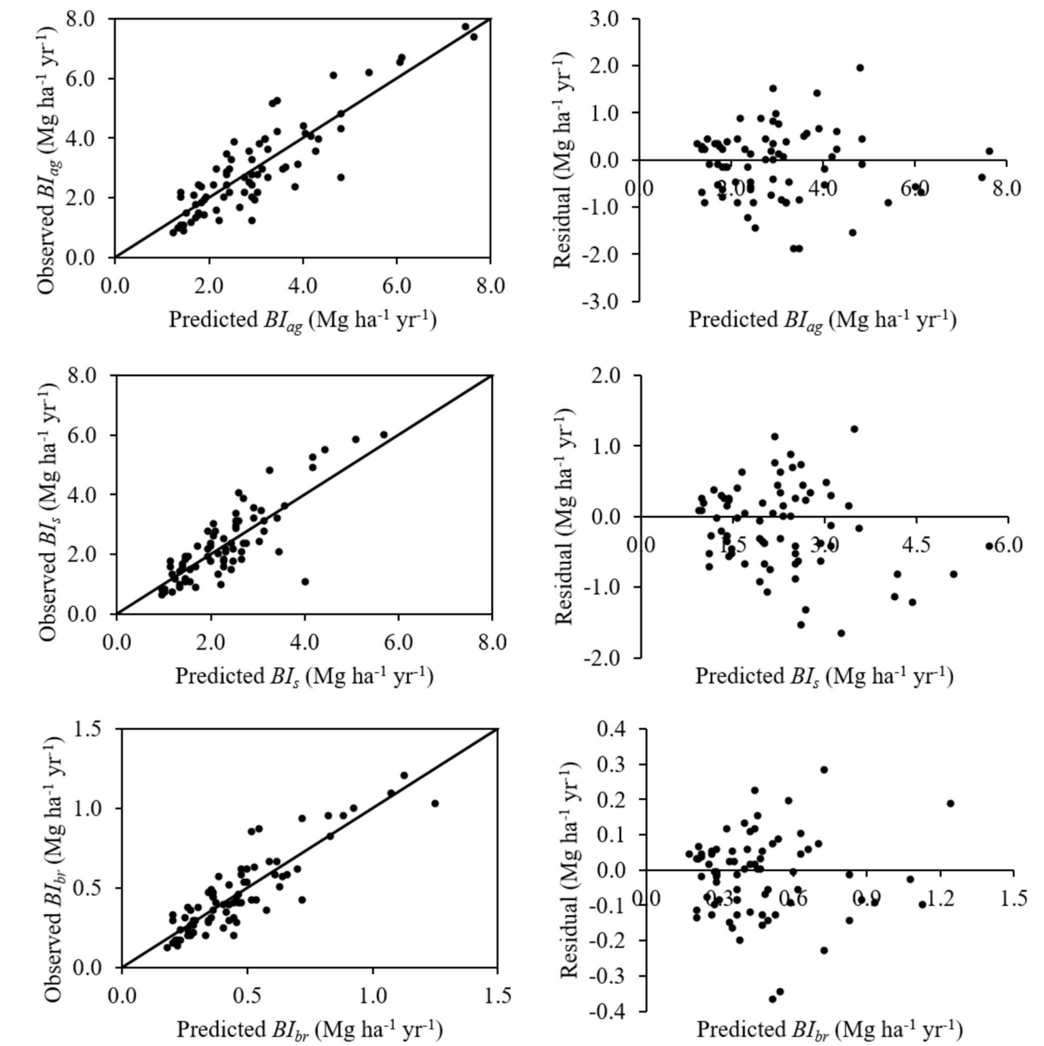

Figure 3: Observed vs. predicted annual biomass increments and residual distributions.

The maximum increments were observed with the highest *SD* class (i.e. 10.5) especially for total above-ground and branch biomass, while the minimum increments with the lowest class (i.e. 4.5) for all biomass values. The effect of site index on annual biomass increments were observed just within *SD* classes. For each *SD* class, the highest increments occurred in *SI*=32 m, while the lowest increments in *SI*=16 m. When Figure 4 is also examined for stand age, it is seen that the biomass increments decreased when the stand age increased with reverse-J shaped distribution. The maximum annual increments of all *SI* and *SD* classes were observed for minimum stand age (*T*=30), and they decreased rapidly till middle ages (nearly 60-70 years). After the middle ages, reductions in the biomass increments were quite slowly. The results of our study on the relationship between biomass increment and stand characteristics are compatible with the literature, since Ren et al. (2016) and Brandl et al. (2019) stated that biomass increments had been affected by stand density, site index and stand age. Similar to our results, they also pointed out that stand density had more effect than others. In addition, Maguire et al. (1990) stated that the biomass increments was positively affected by site index and stand density.

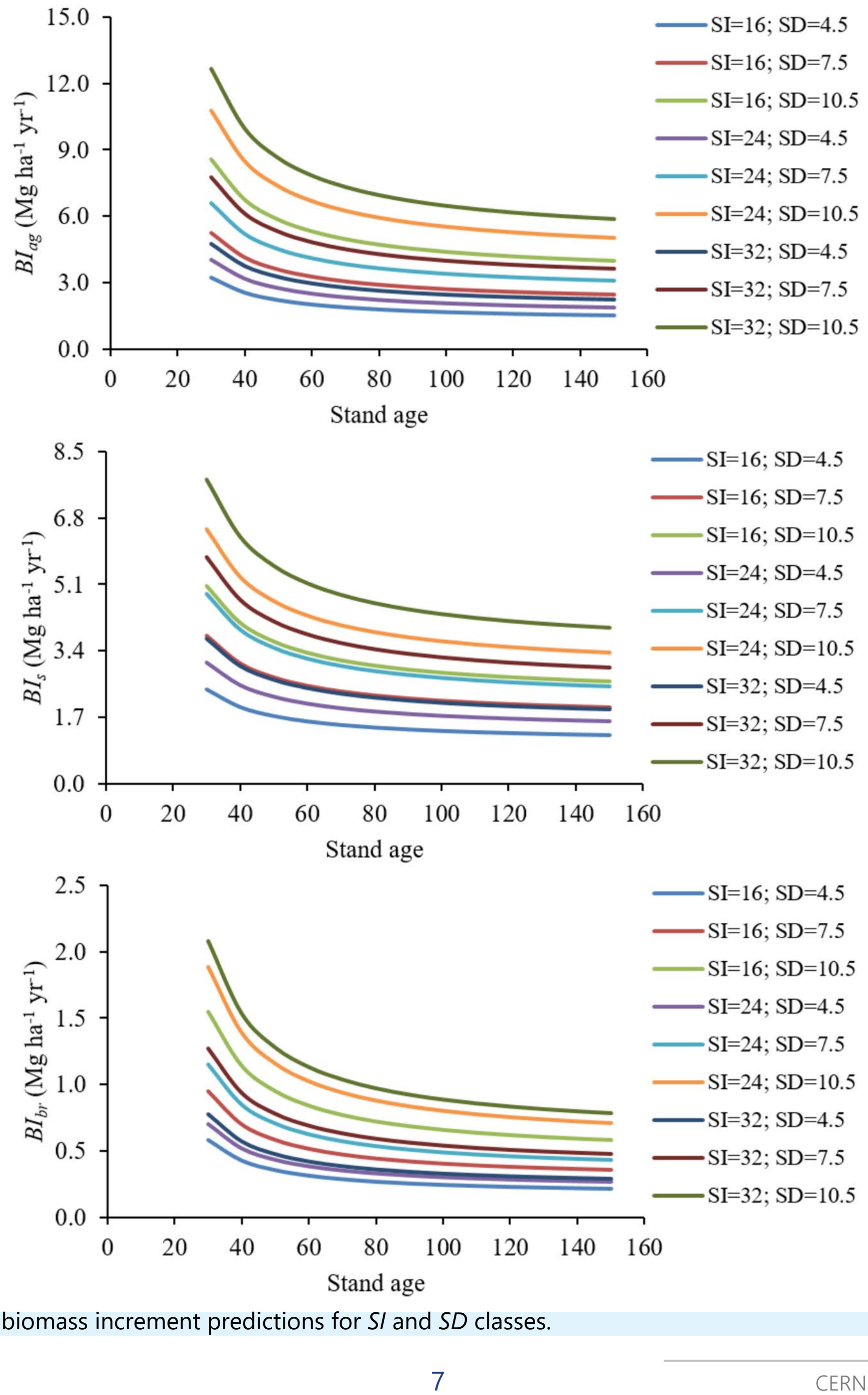

Figure 4: Annual biomass increment predictions for *SI* and *SD* classes.

When the proportion of stem and branch biomass increments in above-ground total biomass increment were compared, the average rate of stem biomass increment in above-ground total biomass increment was approximately 75.4% while of branch biomass increment was 14.9%. As seen on Table 4, for given stand age, when the stand density increased, the ratio of stem biomass increment decreased while branch biomass increment had no remarkable changes for all site classes. However, when the site index increased, the ratio of stem biomass increment also increased while branch biomass increment decreased for all stand density classes. On the other hand, for all stand density and site classes, as the stand age increased, the ratio of stem biomass increment to above-ground total biomass increment also increased (the average is 70.0% for *T*=30 while 77.4% for *T*=150), while the ratio of branch biomass increment decreased (the average is 17.3% for *T*=30 while 14.0% for *T*=150).

To estimate annual biomass increment, reliable data on tree and/or stand growth are required. These data can be obtained from permanent sample plots measured for sequenced periods. If the permanent plots are not available, tree rings analysis is an alternative method to acquire growth rates (Détienne, 1989; Worbes et al., 2003). In this study, the tree-ring analysis method was used due to the lack of sequenced growth data for study area. Djomo et al. (2011) and Babst et al. (2014) were also used this method and had successful results for a tropical forest in south-western Cameroon and for various forest types acroos Europe including five countries (Denmark, Finland, Germany, Belgium and Italy), respectively. Besides, Khan et al. (2009) compared repeated diameter measurements and tree ring analysis for biomass increment estimations and found that the results of both methods were quitly close to each other. Considering the disadvantages of the repeated inventory method in terms of time and cost, tree ring analysis method can also be used reliably in biomass increment estimates.

Table 4: Percentages (%) of stem and branch biomass increments in above-ground total biomass increment.

Stand age		SD=4.5			SD=7.5			SD=10.5			Mean
		SI=16	SI=24	SI=32	SI=16	SI=24	SI=32	SI=16	SI=24	SI=32	
30	Stem	75.0	76.7	77.9	71.8	73.4	74.6	59.0	60.3	61.3	70.0
	Branch	18.0	17.4	16.3	18.0	17.4	16.3	18.1	17.5	16.4	17.3
40	Stem	77.4	79.2	80.4	74.1	75.8	77.0	60.9	62.3	63.3	72.2
	Branch	16.8	16.3	15.3	16.9	16.3	15.3	16.9	16.4	15.3	16.2
50	Stem	78.9	80.7	82.0	75.5	77.2	78.4	62.1	63.5	64.5	73.6
	Branch	16.2	15.6	14.7	16.2	15.7	14.7	16.3	15.7	14.8	15.5
60	Stem	79.9	81.7	83.0	76.5	78.2	79.4	62.9	64.3	65.3	74.6
	Branch	15.8	15.2	14.3	15.8	15.3	14.3	15.9	15.3	14.4	15.1
70	Stem	80.6	82.4	83.8	77.1	78.9	80.1	63.4	64.9	65.9	75.2
	Branch	15.5	15.0	14.0	15.5	15.0	14.1	15.6	15.1	14.1	14.9
80	Stem	81.2	83.0	84.3	77.7	79.4	80.7	63.9	65.3	66.3	75.8
	Branch	15.3	14.8	13.8	15.3	14.8	13.9	15.3	14.8	13.9	14.7
90	Stem	81.6	83.4	84.8	78.1	79.8	81.1	64.2	65.6	66.7	76.2
	Branch	15.1	14.6	13.7	15.1	14.6	13.7	15.2	14.7	13.8	14.5
100	Stem	81.9	83.8	85.1	78.4	80.2	81.5	64.5	65.9	67.0	76.5
	Branch	15.0	14.5	13.6	15.0	14.5	13.6	15.1	14.6	13.6	14.4
110	Stem	82.2	84.1	85.4	78.7	80.5	81.7	64.7	66.1	67.2	76.7
	Branch	14.9	14.4	13.5	14.9	14.4	13.5	14.9	14.5	13.5	14.3
120	Stem	82.5	84.3	85.7	78.9	80.7	82.0	64.9	66.3	67.4	77.0
	Branch	14.8	14.3	13.4	14.8	14.3	13.4	14.9	14.4	13.5	14.2
130	Stem	82.7	84.5	85.9	79.1	80.9	82.2	65.0	66.5	67.6	77.1
	Branch	14.7	14.2	13.3	14.7	14.3	13.4	14.8	14.3	13.4	14.1
140	Stem	82.8	84.7	86.1	79.3	81.1	82.3	65.2	66.6	67.7	77.3
	Branch	14.6	14.1	13.3	14.7	14.2	13.3	14.7	14.2	13.3	14.1
150	Stem	83.0	84.9	86.2	79.4	81.2	82.5	65.3	66.7	67.8	77.4
	Branch	14.6	14.1	13.2	14.6	14.1	13.3	14.7	14.2	13.3	14.0
Mean	Stem	80.7	82.6	83.9	77.3	79.0	80.3	63.5	65.0	66.0	75.4
	Branch	15.5	15.0	14.0	15.5	15.0	14.1	15.6	15.0	14.1	14.9

CONCLUSIONS

In this study, increment models of above-ground total biomass, stem biomass and branch biomass were developed for Crimean pine stands distributed in northern Türkiye. Successful results have been obtained regarding biomass increment estimations. The biomass increments vary depending on the characteristics of various stands, but these characteristics are not considered in most studies. In this study, it was observed that biomass increment decreased with increasing stand age, while increased with increasing site index and stand density. According to the results, stand density is the strongest stand characteristic on biomass increment, although site index and stand age have also important effects. Other stand characteristics (i.e. quadratic mean diameter) may have a significant effect on biomass increment. Considering the stand characteristics in further studies may allow more accurate and reliable predictions.

Although it is one of the main components of net primary production and plays an important role as well as total biomass in the global carbon cycle, the relationships between biomass increment and stand characteristics have not been adequately examined. Researches on biomass increment are very important as well as biomass and carbon sequestration studies for as many species and regions as possible.

AUTHORSHIP CONTRIBUTION

Project idea: FS, OES

Database: FS

Processing: FS

Analysis: FS, OES

Writing: FS, OES

Review: FS, OES

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