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BIOMASS EQUATIONS IN NATURAL BLACK PINES

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ABSTRACT

Since the black pine is one of the most common pine species in Turkey, the present study was carried out and the belowground and aboveground biomass developments of natural black pine individuals was modeled because there is no reliable model for estimating especially the belowground biomass for the natural stands. Moreover, the biomass expansion factors (BEF) and biomass conversion and expansion factors (BCEFs) were calculated for the black pine components. In addition, by the diameter groups, the leaf dry matter contents (LDMC) and root/shoot ratios were determined. Totally 34 sample trees were measured in various diameter and height groups in Kızılcahamam Forest Enterprise. The models utilizing DBH (diameter at breast height) and H (tree height) as independent variable yielded stronger relationships than the models, which use DBH as independent variable, did. LDMC values show linear increase from the small diameter groups towards the large diameter groups. BCEF values changed from 0.063 to 0.825. Mean root/shoot ratio was calculated to be 0.137±0.016.

KEYWORDS:
Pinus nigra (Arnold), biomass, BCEF, LDMC

INTRODUCTION

Forest ecosystems play significant role in the global cycle of carbon, which is believed to be the most important greenhouse gas having effect on the climate change. The aboveground and belowground biomasses of ecosystems are the important components of terrestrial carbon stocks. The most important carbon stocks in forest ecosystems consist of the mass of woody plants. The aboveground woody biomass determination methodology offers sufficiently advanced and reliable data, whereas the belowground woody biomass determination methodology still has certain difficulties [1,2].

Decreasing the uncertainties in determining the amount of carbon stored in biomass and the change in amount of carbon is important not only for understanding the long-term relationships in global carbon change [3] but also for the obligations from the United Nations Framework Convention on Climate Change (UNFCCC) and implementation compulsions of the Kyoto Protocol [4]. The UNFCCC obliges all parties having signs under the convention to prepare, publish, and update the inventories for gas emissions and removals from land-use change and forestry by using comparable methods [5].

In determining the calculation method for woody biomass, there are 2 generally accepted approaches. First of them is the allometric equation enabling the estimation of wood biomass by using the easy-to-measure wood characteristics, whereas the second one is the use of biomass expansion factors (BEFs) or biomass conversion and expansion factors (BCEFs) in determining the biomass amount [6,7]. The biomass regression equations are used for direct biomass calculation [8]. Even though the allometric equations are more useful in determining the tree-level biomass at high accuracy levels, the use of BEF and BCEFs in large areas based on the forest inventory comes to the forefront. The lower accuracy level of this method is its disadvantage over the allometric equations, whereas the disadvantage of allometric equations is that data collection operation required large amount of labor and time and thus money [7,9]. Moreover, in making nationwide evaluations by using BEF and BCEFs, the coefficients should be determined based on the site and stand conditions in order to not cause any error [10, 11].

45% of Turkey's forestlands are covered with 3 pine species. Among these species, the second rank belongs to the black pine with 4,693,060ha of forestland area [12]. The black pine, which is very important for Turkey, has been examined in various biomass studies. For the natural black pine individuals, Durkaya et al. [13,14] carried out 2 different aboveground biomass studies. Again, Güner and Çömez [15] carried out a study on the belowground and aboveground biomass in the black pine plantations. But, there is no reliable study on the belowground biomass development of natural black pine individuals in Turkey.

In the present study, the aboveground and belowground growths of natural black pine individuals were modeled. BEF and BCEF coefficients were calculated for the black pine individuals in the study area. Moreover, the leaf dry matter contents

(LDMC) and root/shoot ratios were determined for the diameter groups.

MATERIALS AND METHODS

Study Area: The study area was chosen within the borders of Kızılcahamam Forest Enterprise located between 40º 58' 14''-32º 96' 26''E and 40º 35' 13''-32º 26' 40'W. Kızılcahamam Forest Enterprise Directorate is located in the Central Anatolian climate zone. The annual mean temperature of region is 10.4 ˚C. The annual mean precipitation is 550mm, whereas the summers and draught and softly rainy and the winters are cold and rainy. The mean temperature in January, which is the coldest month, is -0.4 ˚C, whereas the mean temperature in August with is 20.1 ˚C. The study area can be seen in figure 1.

Experimental data: Single trees from pure *Pinus nigra* Arn. stands in different development phases were analyzed in order to determine aboveground and belowground biomass development. Totally 34 sample trees were measured in various diameter and height groups.

The trees, diameters of which were measured, were cut at the point closest to soil, and then the height of tree was measured. Then, the branches of sample trees were removed from the stem and divided into groups as thinner than 4 cm (no commercial value) and thick (commercially valuable) branches and then weighed. And then, the samples were taken from both of the groups. The stem was divided into 2.05m sections, and the bottom diameter and length of the tip part and the diameters at the ends of the sections were measured in order to determine the stem volume. Each section was weighed and 5cm-thick stem samples were taken from the middle of these sections. Then, the areas represented by each of trees were determined and excavated to the root depth with a digger. The roots were cleaned from soil, and the amount of coarse root (> 2 mm) was determined. Nothing was done about the amount of fine root. The roots were divided into stumps (thicker than 4 cm and thinner than 4 cm), and then weighed. Samples were taken from both groups. All of the samples were labeled and then preserved in plastic bags. Samples were brought to the laboratory; needles were removed from the shoots, then the barks were separated from wood and fresh weights were determined. After air-drying, the samples were oven-dried at 65 ± 3 ˚C until the weight stabilized and the final dry weights were determined.

Data evaluation: The present study tested different models for determining biomass as a function of DBH (diameter at breast height) or DBH and H (tree height). The appropriate functions were chosen and used in the estimation of biomass. During determining the most appropriate functions, the coefficient of determination (R^2), standard error of estimate (S_e), total error (TE(%)), mean deviation ($\bar{D}$), and absolute mean deviation ($|\bar{D}|$) were utilized. The models, average absolute difference, standard error, total error and average absolute error values were small and coefficient of determination value were large, were selected as best-fit models. Models were given in Table 2.

And then, wood density, root/shoot ratio, BEF and BCEF were calculated through the following equations for natural *Pinus nigra* Arn. stands [15,16,17]. Also leaf dry matter contents (LDMC) were calculated (Zang et al., 2017).

$$WD = \frac{SB_{Barked}}{SV_{Barked}} \quad (1)$$

$$R/S = \frac{B_{Root}}{B_{Aboveground}} \quad (2)$$

Here, WD refers to wood density (t/m^3), B to biomass (kg/tree), SB to stem biomass (kg/tree), and SV to stem volume (m^3/tree).

To convert stem volume to dry biomass, the following equation was used for calculating BEF. In this study, it was determined separately for $BEF_{Aboveground}$ and BEF_{Total}. $BEF_{Aboveground}$ was calculated by using the ratio of total aboveground biomass to stem biomass (Eq.3). Besides that, BEF_{Total} was calculated by using the ratio of whole tree biomass stem biomass (Eq.4) [4,16,18]. BCEF is a value that converts stem volume directly to whole tree biomass. BCEF can be calculated separately for tree components (i.e. needles, branches, stem and roots), and it is a value that converts stem volume directly to whole tree biomass [15,17,19, 20, 21]. BCEF was calculated by using the ratio of tree components biomass stem volumes (Eq.5). The leaf dry mater content (LDMC) was calculated as the ratio of needle dry mass to fresh mass (Eq.6). LDMC is important property in plant ecology, because it is reflect survival and a speedy biomass production like specific leaf area [22, 23, 24, 25]

$$BEF_{Aboweground} = \frac{B_{Aboveground}}{B_{Stem}} \quad (3)$$

$$BEF_{Total} = \frac{B_{Whole\ tree}}{B_{Stem}} \quad (4)$$

$$BCEF_i = \frac{B_i}{SV} \quad (5)$$

$$LDMC = \frac{B_{dry\ needle}}{B_{green\ needle}} \quad (6)$$

where, BEF refers to biomass expansion factor (tons/tons), BCEF to biomass conversion expansion factor (tons/m^3), r/s to root to shoot ratio, and LDMC to leaf dry matter.

RESULTS AND DISCUSSION

For natural black pine, the models make it possible to estimate the biomass values of aboveground and belowground tree components from the diameter at breast height (DBH) ($d_{1,3}$) and independent variables of diameter at breast height ($d_{1,3}$)

– tree height (h). The models found to be suitable for estimating the biomass development from diameter at breast height ($d_{1.3}$) of natural black pine stands are presented in Table 1. Moreover, the models found to be suitable for estimating the biomass development from DBH ($d_{1,3}$) and tree height (h) of natural black pine stands as independent variables are presented in Table 2.

TABLE 1
Models using DBH ($d_{1.30}$) as an Independent Variable

Single-Tree Biomass Equations:	R^2	F	S_e	TE(%)	$\overline{D}$	$\lvert\overline{D}\rvert$	f	
ABOVEGROUND								
$S = -21.9123+(1.8311 d_{1,30})+(0.1788\ d_{1.30}^2)$	0.92	175	49	-0.004	-0.007	34.29		1
$SB = 3.9654+(0.0332 d_{1.30}^2)$	0.91	318	8	-0.006	-0.002	6.11		2
$CB = 29.4194+(-5.4799\ d_{1.30})+(0.1771\ d_{1.30}^2)$	0.60	14	32	0.0003	0.03	37.35		3
$CBB = 12.9122+(-1.6785\ d_{1.30})+(00476_{1.30}^2)$	0.67	19	13	-0.188	-0.03	7.26		4
$ln\ NB = -5.9140+2.5585\ ln d_{1.30}$	0.85	185	0.58	16.05	3.78	15.75	1.48	5
$ln\ NBB = -6.6574+2.5066\ ln d_{1.30}$	0.84	163	0.61	19.19	1.79	6.38	1.53	6
$N = 4.1387+(-0.6455 d1.30)+0.0423 d_{1.30}^2)$	0.80	62	12	0.109	0.027	7.02		7
$lnTC = -6.1514+3.0477\ ln d1.30$	0.91	311	0.53	8.51	9.52	57.23	1.39	8
$TA = 25.2346+(-5.8687 d_{1.30})+(0.5188 d_{1.30}^2)$	0.86	93	137	-0.002	-0.007	78.16		9
BELOWGROUND								
$SW = 16.0672+(-1.6804\ d_{1.30})+(0{,}0537\ d_{1.30}^2)$	0.82	68	10	0.20	0.03	6.61		10
$lnSB = -5.8571+(1.9787\ ln d_{1.30})$	0.89	248	0.39	10.10	0.27	1.05	1.19	11
$RW_{thick} = -1.3280+(0.0118\ d_{1.30}^2)$	0.61	41	7.25	0.47	0.052	4.44		12
$lnRB_{thick} = -7.6246+(2.3389\ ln d_{1,30})$	0.78	97	0.49	-0.16	-0.0037	0.81	1.32	13
$RW_{thin} = 0.1419+(0.002 d_{1.30}^2)$	0.55	38	1.41	0.97	0.018	0.84		14
$RB_{thin} = -0.3295+(0.0444 d_{1.30})$	0.38	19	0.74	0.45	0.004	0.42		15
$lnTB = -4.0720+(2.2100\ ln d_{1.30})$	0.90	300	0.39	9.50	3.41	10.39	1.19	16

(S: Stem biomass, SB: Stem bark biomass, CB: Commercial branch biomass, CBB: Commercial branch bark biomass, NB: Non-commercial branch biomass, NBB: Non-commercial branch bark biomass, N: Needle biomass, TC: Total crown biomass, TA: Total aboveground biomass; SW: Stump wood biomass; SB: Stump bark biomass; RW_{thick}: Root wood (> 4cm) biomass ; RB_{thick}: Root bark (> 4cm) biomass ; RW_{thin}: Root wood (< 4cm) biomass ; RB_{thin}: Root bark (< 4cm) biomass ; TB: Total belowground biomass).

TABLE 2
Models using DBH ($d_{1.30}$) and tree height (h) as independent variables

	R^2	F	S_e	TE(%)	$\overline{D}$	$\lvert\overline{D}\rvert$	f	
ABOVEGROUND								
$S=34.545-3.6148 d_{1.30}-6.7528h+0.2544\ d_{1.30}^2+0{,}5636h^2$	0.93	101	46	-0.014	-0.027	28.76		17
$SB=-2.0274-0.7265 d_{1.30}-1.0497h+0.0207\ d_{1.30}^2+0{,}058h^2$	0.92	85	8	-0.10	-0.03	5.17		18
$CB = 255.5218-5.6471 d_{1.30}-31.9573h+0.1822\ d_{1.30}^2+1.1011h^2$	0.61	6.6	65	0.071	0.04	38.26		19
$ln\ CBB = -10.8522+4.9231\ ln d_{1.30}-1.6933\ ln h$	0.69	9	19	0.40	0.065	7.66	1.0	20
$NB=19.4032+0.6955 d_{1.30}-4.9045h+0.0235\ d_{1.30}^2+0{,}1558h^2$	0.43	55	30	-0.06	-0.014	15.20		21
$NBB = 3.3242+0.182 d_{1.30}-0.8906h+0.0107\ d_{1.30}^2+0{,}0183h^2$	0.44	5	11	0.15	0.014	5.83		22
$N = 2.9398-0.949 d_{1.30}+0.4765h+0.0465\ d_{1.30}^2-0{,}0049h^2$	0.80	29	13	0.14	0.03	6.81		23
$TC = -86.3031-16.3546 d_{1.30}+0.3757h+0.5458\ d_{1.30}^2-0.0127h^2$	0.65	13	111	0.14	0.15	55.83		24
$TA=106.6611-11.5098 d_{1.30}-11.481h+0.5972 d_{1.30}^2+0{,}7758h^2$	0.86	45	139	-.0024	-0.008	74.15		25
BELOWGROUND								
$lnSW=13.4008-5.978 ln d_{1.30}+1.2256 ln d_{1.30}^2+17.4151 ln h-3.4007\ ln h^2$	0.90	63	0.38	8.77	0.24	0.98	1.18	26
$lnSB=-6.4736-1.7942 ln d_{1.30}+0.5914 ln d_{1.30}^2+5.1045 ln h-0.993 ln h^2$	0.90	63	0.38	8.77	0.24	0.98	1.18	27
$RW_{thick} = 0.8366-0.555 d_{1.30}+0.027 d_{1.30}h+0.246 d_{1.30}^2-0.0007 d_{1.30}^2h$	0.61	9	7.67	0.42	0.04	4.39		28
$RB_{thick}=9.492-0865 d_{1,30}+0.064 d_{1.30}h+0.023 d_{1.30}^2-0.745h-0.0014\ d_{1.30}^2h$	0.69	13	1.33	-21.76	-0.50	0.87		29
$RW_{thin}=-0.9945+0.3759 d_{1.30}^2-0.0203 d_{1.30}h-0.0113\ d_{1.30}^2+0.0008\ d_{1.30}^2h$	0.59	10	1.41	-3.12	-0.06	1.04		30
$lnRB_{thin}=-14.5055+2.587 ln h-0.1611 ln d_{1.30}^2+6.912 ln h-1.5431 ln h^2$	0.70	16	0.58	24.35	0.21	0.51	1.48	31
$lnTB=-10.8345-2.557 ln d_{1.30}+0.7068 ln d_{1.30}^2+11.4013 ln h-2.1988 ln h^2$	0.92	85	0.37	10.15	3.64	9.70	1.17	32

Stem wood density is a ratio of oven dry weight of timber to its volume [4, 26, 27]. The volume was measured using Smalian's formula. The mean stem wood density was calculated to be 0.622±0.020 for natural black pine. Root/shoot ratios (R) are commonly used in converting standing volumes of timber into total carbon stocks, for the purpose of national inventories of greenhouse gas emissions and sequestration like BEF and BCEF [1,18] Mean root/shoot ratios were calculated to be 0.137 ±0.016 for natural black pine trees. Figure 1a shows root/shoot ratios of sample trees according to DBH and also the root-shoot biomass relationship can be seen in Figure 1 b with a significant slope. In this study an improved model was offered for relating root biomass (y) to shoot biomass (x) for natural black pine stands (y=0.1063x-0.0007).

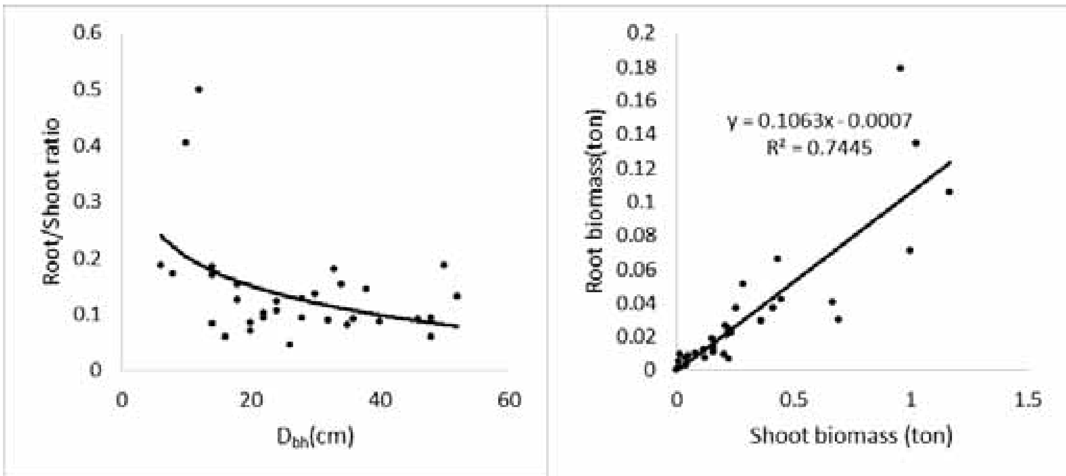
BEFs were calculated for the belowground, aboveground, and total values, whereas the BCEFs were calculated for stem, branch, needle, aboveground, and belowground components. BCEF values varied between 0.063 and 0.825 (Table 3).

TABLE 3
Changes in BEF's and BCEF's with respect to components (Mean±SE)

	(Mean±SE)
$BEF_{Aboveground}$	1.343±0.047
$BEF_{Belowground}$	0.175±0.018
BEF_{Total}	1.518±0.051
$BCEF_{Stem}$	0.622±0.020
$BCEF_{Branch}$	0.139±0.025
$BCEF_{Needle}$	0.063±0.005
$BCEF_{Aboveground}$	0.825±0.040
$BCEF_{Belowground}$	0.124±0.021

(SE: Standart error)

The changes of leaf dry matter content were examined for 5 different diameter groups. Mean LDMC was determined to be 0.437±0.017 for natural black pine stands. According to the diameter groups, LDMC's and their standard errors are shown in Figure 2.



a b

FIGURE 1
Root/shoot ratios relationships (a) and improved model (b)

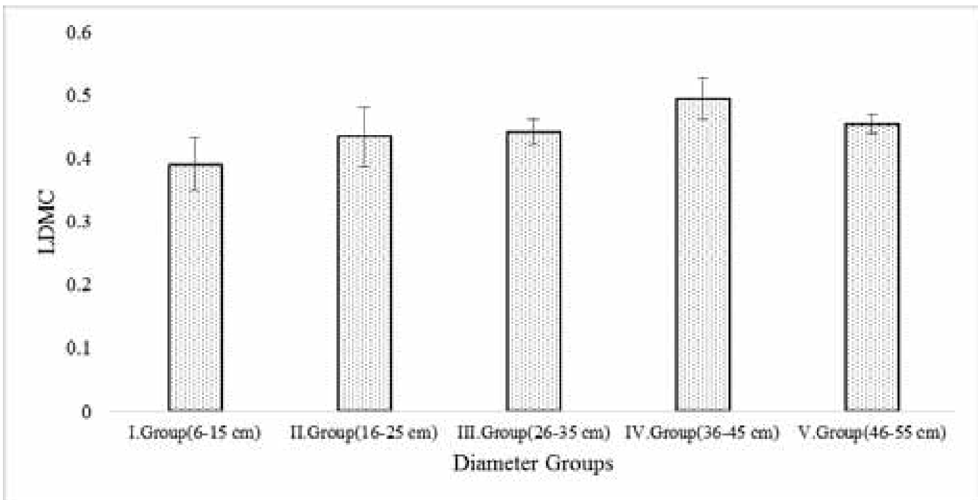


FIGURE 2
LDMC and standard errors by diameter groups of sample trees

Although the most accurate method of determining the biomass of a tree is to directly weigh it by harvesting in the field, it might sometimes be a time-consuming and destructive practice [28]. The use of allometric relationships instead of the direct harvesting in determining the biomass is frequently preferred as a non-destructive and indirect measurement method. Moreover, it is less time-consuming and more affordable [30]. In the present study, it was aimed to determine the aboveground and belowground biomass of natural *Pinus nigra* (Arnold). The analyses were performed using the data collected from 34 different sample trees that had different diameters. The biomass amounts by the tree components from sample trees were modeled via allometric relationships. Furthermore, the root/shoot ratios, BEF, BCEF, and LDMC values were calculated.

In Turkey, as in rest of the world, the forest inventory generally focuses on the wood volume because of the economic reasons, and it doesn't include the data related with determining the biomass [29]. Thus, making use of biomass and carbon models with reference to the tree diameter or tree diameter-length is very difficult when it is performed by using only the data in management plan. Moreover, it also requires making new calculations. In the present study, using the planted stem volume values that are the most useful factor in the management plans made it possible to reliably determine the biomass values by making use of BEFs and BCEFs without needing any extra calculation. As it can be seen in Tables 1 and 2, the models using DBH and H as independent variables showed stronger relationships when compared to the models using DBH as independent variable. BCFs and BCEFs are presented in Table 3 as mean values.

The comparisons made between the results obtained from previous natural black pine aboveground biomass [13] and planted black pine belowground and aboveground biomass [15] studies are presented in Figure 3.

As seen in the Figure (a, d), the forestation areas have more needle and belowground biomass, whereas the natural stands with same size have higher stem weight values (b). The total aboveground biomass values (c) up to 30cm DBH are close to each other. At higher diameter levels, the model of Güner-Çömez [15] yields higher values, although this result is understood to originate from the fact that there was no individuals having larger diameters in the forestation areas. The remarkable similarity between these results and those obtained in a study carried out on the natural and forestation young yellow pines [31] is that the forestation areas have more needle biomass but the natural stands involve more stem biomass.

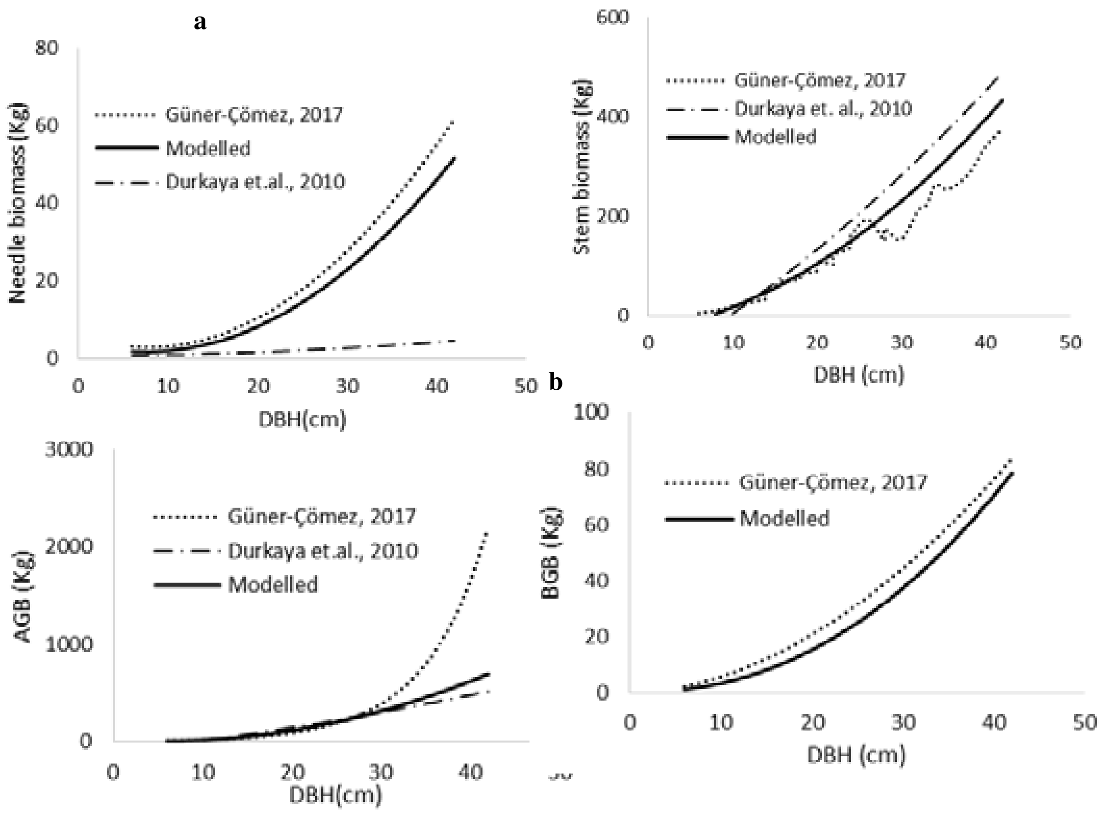


FIGURE 3
Comparison of equations developed for natural and planted black pines

TABLE 4
Change of the tree components' ratio by the diameter groups

	Stem (%)	Branch (%)	Needle (%)	Belowground (%)
Group I (6-15.9 cm)	66.8	8.1	6.4	18.6
Group II (16-25.9 cm)	74.2	9.3	7.4	9.2
Group III (26-35.9 cm)	71.6	11.9	6.5	10.0
Group IV (36-45.9 cm)	59.1	24.6	7.4	8.9
Group V (46-55 cm)	53.6	29.5	6.9	10.0

By the diameter groups, the changes in the ratios of tree components are presented in Table 4.

The stem biomass reaches at the highest level among all the tree biomass in Group II, whereas it starts decreasing from this point. Being inversely proportional to the stem biomass, the branch biomass exhibits a trend increasing gradually towards the larger diameter value groups. Needle biomasses show no remarkable change among the diameter groups. The belowground biomass has the highest level in Group I, whereas it reaches a plateau in following groups. Helmisaari et al. [32] determined the distribution of biomass ratios among the tree components for 3 different development groups (young, middle-aged, and old) of natural yellow pine stands. In their study, they reported an increase in stem ratio and a decrease in branch ratio from young to old in comparison with whole tree biomass and an increase in needle ratio and a decrease in total belowground biomass ratio from middle-aged to old ones. When compared to our results, these results have significant differences in stem ratio. This difference can be explained with possible strong branching of natural black pine stands together with the increasing diameter. As expected, the root/shoot ratios decreased as the diameters increased (figure 1a). Similarly, as it can also be seen in table, the increase in diameter also increases the aboveground biomass.

Except for the Group V, the mean LDMCs showed linear increase from smaller diameter groups towards the larger ones (Figure 2). Together with the increase in diameter, also the leaf dry matter contents were observed to increase.

CONCLUSION

Even though the *Pinus nigra* is one of the most common pine species in Turkey, there is no reliable data that allows estimating especially the belowground biomass values of this species' natural stands. In this study, the belowground and aboveground biomass developments of natural black pine individuals were modeled and this deficiency was significantly made up. Moreover, the BEF and BCEF values of the black pine components were calculated. By the diameter groups, the leaf dry matter contents (LDMC) and root/shoot ratios were calculated.

In order to accurately determine the biomass stored in the forests, it would be a better approach to perform separate studies for each species instead of starting from the general principles. But, as it can be seen above, significant variances might be seen even within the same species grown in different silvicultural regimes and different habitats. There are differences between the biomass values of individuals taken from natural and forestation stands of black pine species. Although the total biomass values were close to each other, there also are differences in the distribution of biomass among the tree components. The differences between the biomass contents of same species' individuals grown under different silvicultural conditions suggest that, rather than the general methods, the local models should be developed in order to accurately and precisely determine the amounts and changes of biomasses stored in forest ecosystems.

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