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Height−diameter relationships in Brutian pine stands in Kurşunlu Waterfall Nature Park

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Abstract

In the scope of this study, the aim was to develop height−diameter models for Brutian pine forests located within the boundaries of Kurşunlu Waterfall Nature Park in Aksu district of Antalya province. For this purpose, height−diameter data for 516 sample trees were randomly divided into model (422 trees) and control (94 trees) groups. Using height−diameter values obtained from 422 sample trees, parameter estimates were made for three models that are commonly used in the literature and successfully reflect height−diameter relationships. The best model was evaluated based on four success criteria: Coefficient of Determination (R^2), Root Mean Square Error (*RMSE*), Mean Absolute Error (*MSE*), and Akaike Information Criterion (*AIC*). The results of the evaluation indicated that the M2 (Meyer) model, which exhibited the lowest ranking value, was the most effective model. The observed and predicted height values of the trees in the independent data group were compared using the Student's *t*−test. The results of the test indicated that the observed and predicted height values were statistically indistinguishable (p>0.05). The height−diameter model developed as a result of the study will serve as a significant tool for biomass and carbon stock estimation.

Keywords: *Pinus brutia* Ten., Height-diameter models, Tree height, Diameter at breast height

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1. Introduction

The diameter and height of trees represent fundamental measurements in forest inventory studies. The measurement of diameter and height of trees is employed as a fundamental variable in numerous applications within the field of forestry. These include the estimation of tree and stand volume, the development of growth models, the analysis of stand structural diversity and the estimation of biomass and carbon stock. The diameter at breast height of trees can be readily and precisely quantified to facilitate these estimations, whereas the measurement of tree height is more challenging and time−consuming. In this context, height−diameter models are of significant importance in the present era (Arabatzis & Burkhart, 1992; Huang et al., 2000; Sharma & Parton 2007; Meng et al., 2009; Diamantopoulou & Özçelik, 2012; Ercanlı, 2015).

A positive curvilinear relationship between height and diameter is observed in general. In order to model this relationship, both linear and non−linear regression models have been employed. Non−linear regression models are more flexible than linear regression models and provide ease of application to data. Consequently, they are employed with greater frequency (Larsen & Hann, 1987; Wang & Hann, 1988; Arabatzis & Burkhart, 1992). One of the models that form the basis for the growth and yield models required for ecosystem−based functional forest management planning used in Türkiye is the height−diameter model. Studies on these models are of great importance (Özçelik & Çapar, 2014).

When analyzing studies on height-diameter models in Türkiye, the following are observed Sönmez (2009), Mısır (2010), Özçelik et al. (2013), Özçelik and Çapar (2014), Ercanlı (2015), Çatal and Carus (2018), Özçelik et al. (2018), Ercanlı and Eyüboğlu (2019), Ercanlı (2020a, 2020b), Seki and Sakici (2022). Among these studies, the study conducted by Özçelik and Çapar (2014) was carried out in Antalya province.

It provides valuable predictions regarding stand structure, volume estimations for individual trees and stands, individual tree growth models, biomass and carbon estimations by modeling the relationships between diameter and height variables. *Pinus brutia*, the most widely distributed coniferous species in Türkiye, especially in Antalya province, offers numerous economic and ecological benefits. Consequently, height-diameter models developed for this species and region are of significant importance. In protected areas, the relationships between the diameter and height values of trees are of particular significance with regard to biomass and carbon estimation. The aim of this study is to develop height−diameter models for Brutian pine stands in the Kurşunlu Waterfall Nature Park.

2. Material and Methods

The General Directorate of Nature Conservation and National Parks is responsible for the operation of Nature Parks. Consequently, the natural structure of forest areas should be preserved. The Kurşunlu Waterfall, which has been designated a Nature Park, is protected in accordance with the provisions of the National Parks Law. The Kurşunlu Waterfall Nature Park is situated within the country coordinate system at latitudes 37° 00' 48" to 37° 00' 63" North and longitudes 30° 81' 00" to 30° 84' 05" East, in the Aksu district of Antalya province, Türkiye (Figure 1).

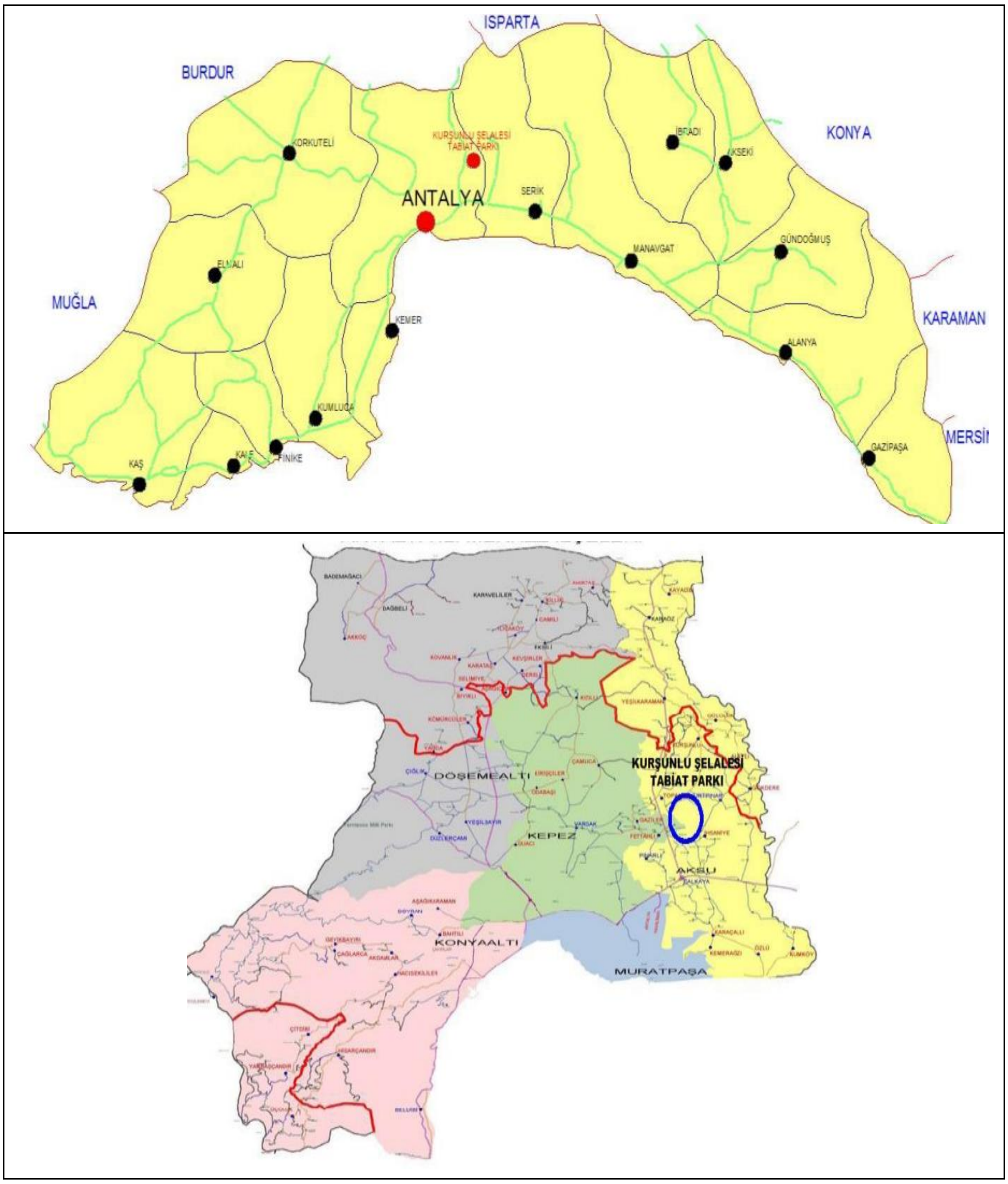

Figure 1. Study area (UDGP, 2011)

The Kurşunlu Waterfall Nature Park is located in a transitional zone between the Mediterranean climate and the terrestrial climate of Central Anatolia. The climate of the Park is generally characterized by hot and dry summers, and mild and rainy winters. In terms of temperature values in Türkiye, Antalya has a temperature above the average (UDGP, 2011).

The tree communities found in the Kurşunlu Waterfall Nature Park are mainly composed of Brutian pine (*Pinus brutia* Ten.), which is the dominant species in the Mediterranean region. In the scope of the study, height−diameter data obtained from 516 sample trees were used to develop height−diameter models for Brutian pine. These data were randomly divided into 2 groups (model and control) and the data from 422 sample trees were used to develop the models, while the data from 94 sample trees were used for the validation of the developed models (Figure 2). Non−linear regression analysis was used to estimate model parameters based on data from 422 trees. All parameters of the height−diameter models that were found to be statistically significant were subjected to a relative ranking based on various statistical criteria, and the best non−linear height−diameter model was determined.

In this study, three different basic non−linear height−diameter models were used, utilizing models used in the modelling of height−diameter relationships by various researchers. The height−diameter model structures for which parameter estimation was performed, together with the references used, are listed in Table 1.

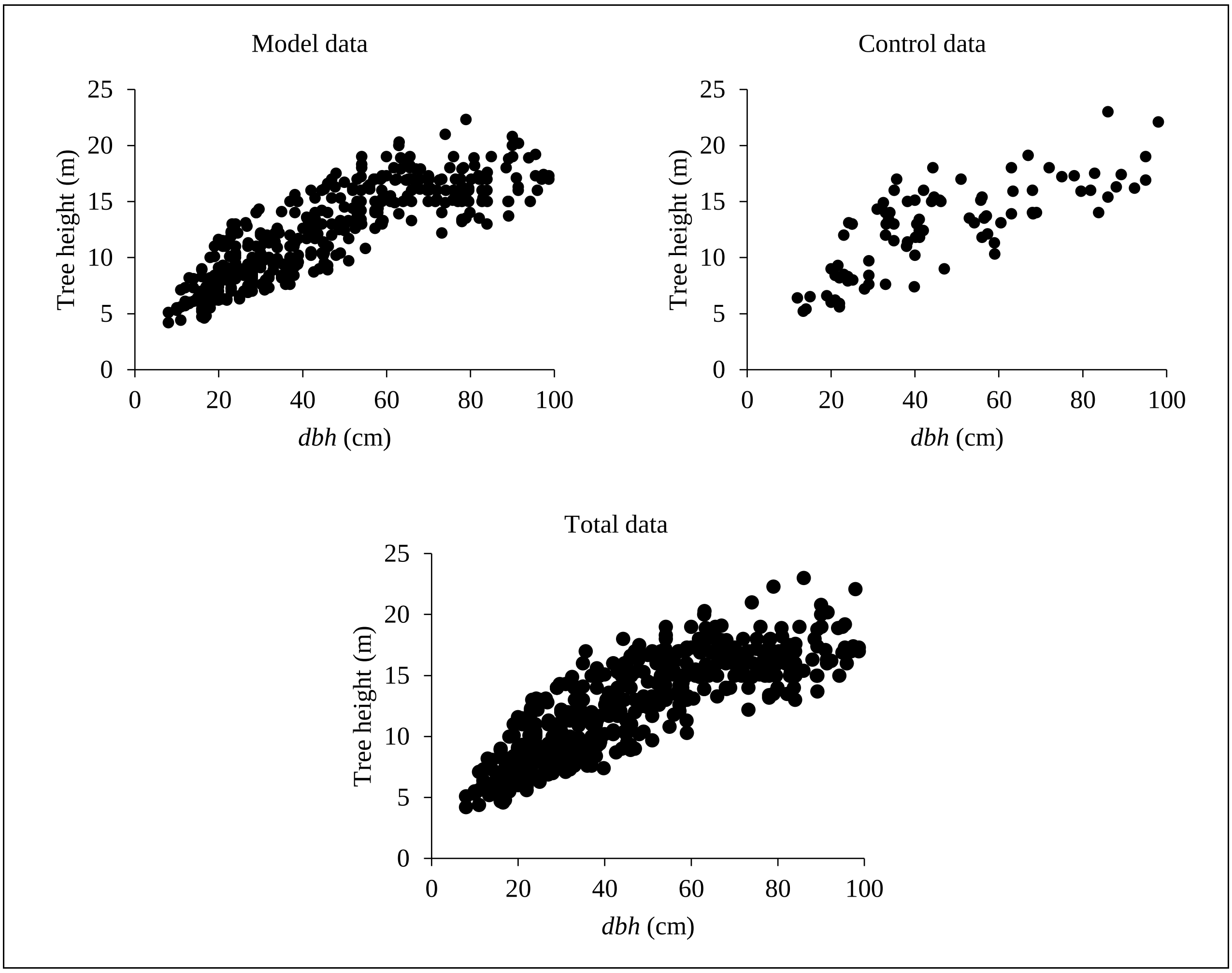

Figure 2. Height−diameter distributions for model, control and total data

Table 1. Models used to develop height−diameter models

Model	Model Form	References
M1	$h_{ij} = 1.3 + a * \left(1 - e^{(-b*dbh)^{c}}\right)$	Chapman-Richards (1959)
M2	$h_{ij} = 1.3 + a * \left(1 - e^{(-b*dbh)}\right)$	Meyer (1940)
M3	$h_{ij} = 1.3 + a * dbh^{b}$	Power function

h=tree height (m), *dbh* =diameter at breast height (cm) and *a*,*b*,*c*=model parameters

In this study, the height−diameter models were compared based on qualitative and quantitative evaluations. After parameter estimation of the models, the coefficient of determination (R^2) and various error statistics (Root Mean Square Error, *RMSE*; Mean Absolute Error, *MAE*; Akaike Information Criterion, *AIC*) were calculated for these models. After selecting the best height-diameter model according to statistical criteria and all parameters were significant, the model validity was tested. For this purpose, the observed height values of the trees of the independent data (control group) and the height values predicted from the best model were compared by Student's *t*−test.

The evaluation of the constructed models was based on four different statistical criteria. These statistical criteria are:

Coefficient of Determination:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(yi - \hat{y}i)^2}{\sum_{i=1}^{n}(yi - \bar{y}i)^2}$$

Root Mean Square Error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(yi - \hat{y}i)^2}{n - p}}$$

Mean Absolute Error:

$$MAE = \frac{\sum_{i=1}^{n}|\hat{y}i - yi|}{n}$$

Akaike Information Criterion:

$$AIC = n\, ln(HKOK) + 2p$$

where yi, $\hat{y}i$, $\bar{y}i$ are the observed, predicted and average values of the dependent variable, respectively, n is the number of observations, and p is the number of model parameters. Subsequently, the error distributions were analyzed visually. Graphical representations were used to show deviations and systematic errors.

3. Results

Within the scope of the study, model parameters, various statistical criteria and performance rankings of 3 non−linear models, for which parameter estimations were made using data obtained from 422 sample trees, are presented in Table 2 and Table 3.

When examining Table 2, which shows the model parameters and statistical criteria, all parameters of the models were found to be significant at the $p<0.05$ level. Upon examination of Table 3 and Figure 3, it is observed that although the statistical criteria for the models have similar values, M2 stands out in the ranking.

To validate the model, the height predictions of the trees in the independent data subset (control groups; 94 trees) were made using the height−diameter model (M2). The observed heights of the trees in the independent data subset were compared with the predicted heights using Student's t−test, and the test results indicated that the observed and predicted heights were statistically indistinguishable ($p>0.05$).

The prediction and bias values for the developed height−diameter model were presented in Figure 4 for the model, the control and total data set. When Figure 4 is analyzed, it is observed that the bias values associated with predictions made by the height−diameter model exhibit a random distribution and do not have any trend. It is understood that the observed height values and the height values predicted by the M2 model are close to each other. As a result of these evaluations, it is ensured that the assumptions regarding regression analysis, such as bias being randomly distributed and having no trend, are met. Satisfying these assumptions is also an important result for the success of the model.

Table 2. Statistical criteria and parameter estimations for the models

Model	R^2	*RMSE*	*MAE*	*AIC*	Parameters		
					a	b	c
M1	0.765	2.015	1.612	301.686	19.692	0.019	0.940
M2	0.764	2.013	1.608	299.287	19.130	0.021	
M3	0.752	2.065	1.669	309.920	1.280	0.570	

Table 3. Success ranking of the models

Model	R^2	*RMSE*	*MAE*	*AIC*	Rank (R^2)	Rank (*RMSE*)	Rank (*MAE*)	Rank (*AIC*)	Total Rank
M1	0.765	2.015	1.612	301.686	1.0	2.0	2.0	2.0	7.0
M2	0.764	2.013	1.608	299.287	2.0	1.0	1.0	1.0	5.0
M3	0.752	2.065	1.669	309.920	3.0	3.0	3.0	3.0	12.0

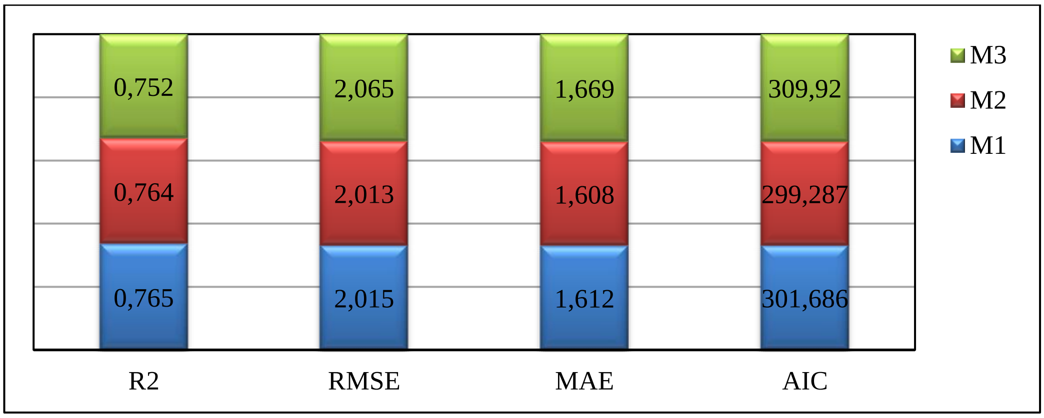

Figure 3. Statistical criteria for the models

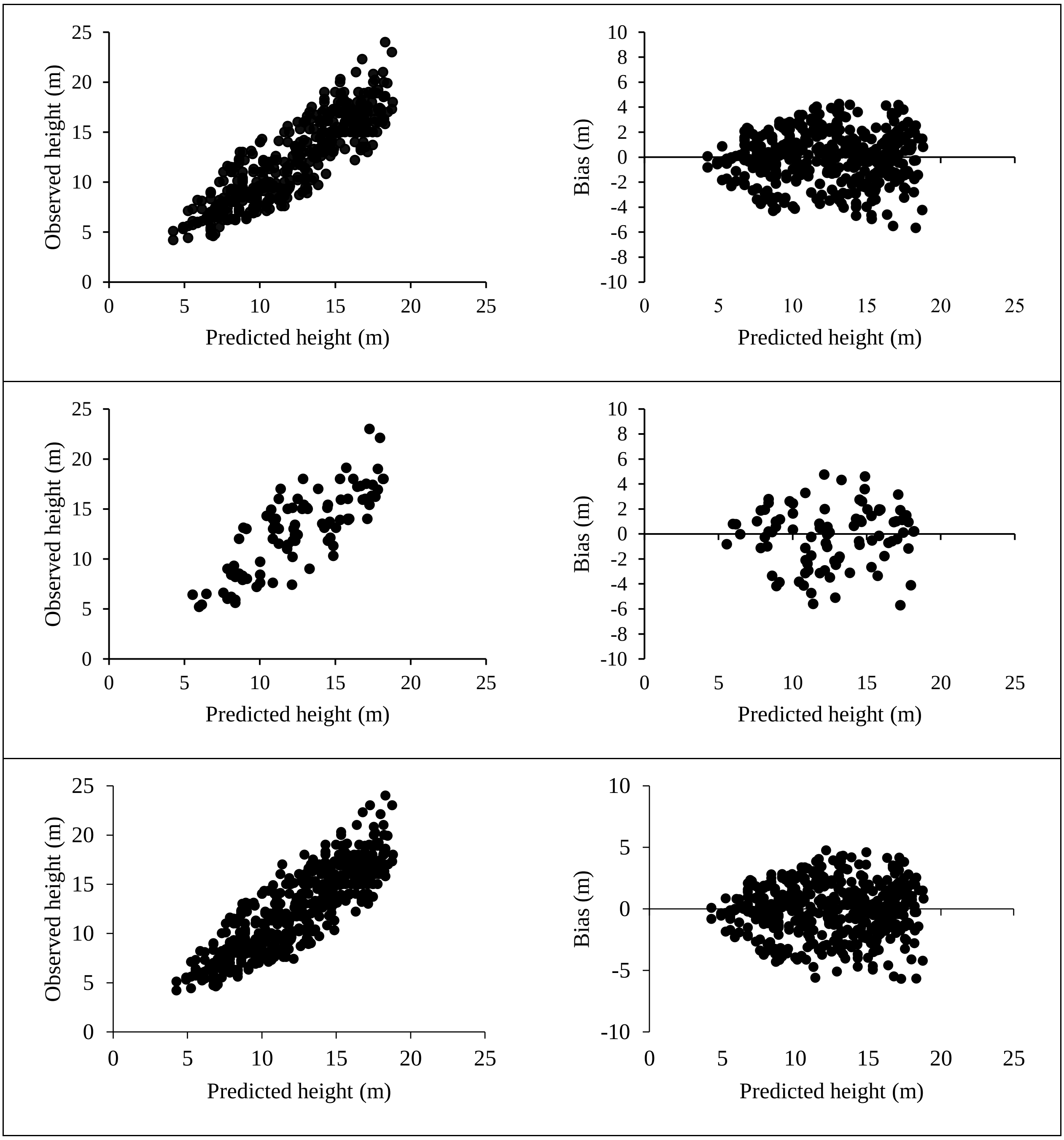

Figure 4. Prediction and bias plots of M2 for the model (top), control (middle) and total (bottom) data

In Türkiye, height–diameter relationships were studied by Sönmez (2009), Mısır (2010), Özçelik et al. (2013), Özçelik and Çapar (2014), Ercanlı (2015), Çatal and Carus (2018), Özçelik et al. (2018), Ercanlı and Eyüboğlu (2019), Ercanlı (2020a, 2020b), and Seki and Sakici (2022). Among these studies, the study conducted by Özçelik and Çapar (2014) was conducted in the Antalya province. Since the developed height-diameter model is a generalized height-diameter model, the predictions of the models were not compared. Height–diameter models are important because they serve as the basis for many other models. For this reason, studies on this topic are crucial. The height–diameter model developed for Brutian pine stands in the Kurşunlu Waterfall Nature Park stands out as a study that enables biomass estimation and carbon balance estimation in protected areas.

4. Conclusion

The statistical analyses were carried out for the development of height–diameter models for Brutian pine stands in the Kurşunlu Waterfall region in Aksu distirct of Antalya province within the scope of the study. Height–diameter measurements from 512 sample trees were used to develop the models. In the development of the models, three different height–diameter models were used, which are frequently preferred in the literature for modeling height–diameter relationships and give successful results. Four statistical criteria (R^2, *RMSE*, *MAE*, *AIC*) were used to determine the best model. Among the models evaluated, the two-parameter M2 model (Meyer, 1940) has been identified as the best model. After deciding on the best model, the validity of the model was tested using Student's *t*–test with an independent set of data, and as a result of this test, it was determined that the model provided unbiased predictions with 95% confidence. The height–diameter model developed for Brutian pine stands in the study area stands out as a study that allows biomass estimation and carbon stock estimation in protected areas. For this reason, it is an important study in terms of enabling carbon balance assessments for protected areas.

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Conflict of interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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