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Evaluation and validation of stem volume models for *Quercus glauca* in the subtropical forest of Jeju Island, Korea

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Abstract

This study was conducted to develop stem volume models for the volume estimation of *Quercus glauca* Thunb. in Jeju Island, Republic of Korea. Furthermore, this study validated the developed stem volume models using an independent dataset. A total of 167 trees were measured for their diameter at breast height (DBH), total height and stem volume using non-destructive sampling methods. Eighty percent of the dataset was used for the initial model development while the remaining 20% was used for model validation. The performance of the different models was evaluated using the following fit statistics: standard error of estimate (*SEE*), mean bias ($\bar{E}$), absolute mean deviation (*AMD*), coefficient of determination (R^2), and root mean square error (*RMSE*). The *AMD* of the five models from the different DBH classes were determined using the validation dataset. Model 5 ($V = aD^bH^c$), which estimates volume using DBH and total height as predicting variables, had the best *SEE* (0.02745), *AMD* (0.01538), R^2 (0.97603) and *RMSE* (0.02746). Overall, volume models with two independent variables (DBH and total height) performed better than those with only one (DBH) based on the model evaluation and validation. The models developed in this study can provide forest managers with accurate estimations for the stem volumes of *Quercus glauca* in the subtropical forests of Jeju Island, Korea.

Key words: forest management, gotjawal forest, model evaluation, model validation, Mt. Halla, Sub-tropical forests

INTRODUCTION

Accurately estimating the volume of trees has always been a very important interest for forest managers (Tewari and Kumar 2001). For instance, stem volume estimation for standing trees is essential in the assessment of forest biomass. According to several authors (Fang and Wang 2001, Lehtonen et al. 2004, Vallet et al. 2006, Tobin and Nieuwenhuis 2007), volume estimates can be used to determine the biomass of the whole tree by using stem density and biomass expansion factor. Furthermore, stem volume estimates are required for sustainable forest management (Hofstad 2005, Haywood 2009). They are also essential for sustainable forest resources planning (Zianis et al. 2005), assessment (Guendehou et al. 2012) and environmental studies (Hofstad 2005). Stem volume can be estimated with field measurements of diameter at breast height (DBH) and total height and by allometric equation development (Teshome 2005, Akindele and LeMay 2006, Gonzalez-Benecke et al. 2014). According to Avery and Burkhart (2002), volume equations are used to estimate the average content of standing trees of various sizes and

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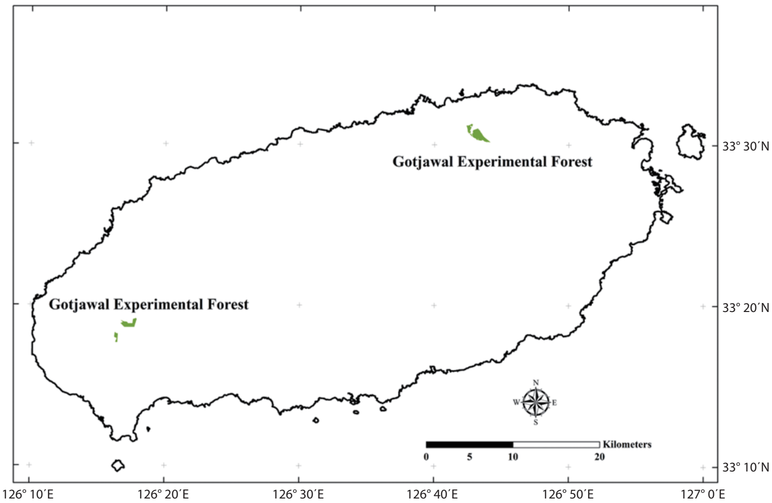

Fig. 1. Geographic location of research sites in Jeju Island, Korea.

species.

Jeju Island has a total land area of 184,840 ha and approximately 88,874 ha (48%) of this island has a forest cover (Korea Forest Service 2012). Jeju Island is internationally recognized for its biodiversity. It was designated as a biosphere reserve by the United Nations Educational, Scientific and Cultural Organization on December 2002 (UNESCO 2014). One of the most important forests in this island is the Gotjawal forest, which is conserved and protected due to its unique ecosystem. One such ecosystem is the Dongbaekdongsan wetland, which is designated as a National Wetland Protected Area by the Ministry of Environment of the Republic of Korea and classified as a Ramsar site (Ramsar Convention 2014). Gotjawal forest has a total land area of 11,000 ha, accounting for 6% of the total land area of Jeju Island (Kang et al. 2013) and is situated on the middle slopes of Mount Halla, the highest mountain in the Republic of Korea. Furthermore, Kang et al. (2013) stated that this forest has very significant roles in establishing biological and cultural diversity while maintaining its ecosystems. One of the most dominant tree species in the forest is *Quercus glauca* Thunb. (Han et al. 2007, Oh 2012, Kang et al. 2013). However, the volume equation for *Quercus glauca* in Jeju Island, which is essential in accurately estimating the biomass and carbon stocks of Gotjawal forest, has not yet been developed. Thus, the objectives of this study were to develop and to validate volume equations for *Quercus glauca* in Jeju Island, Republic of Korea.

MATERIALS AND METHODS

Study site

Jeju Island is located in the southernmost part of the Republic of Korea, between 126°08′43″ to 126°58′20″E and 33°11′27″ to 33°33′50″N (Lee et al. 2009) as shown in Fig. 1. Broadleaved forests comprise the majority of the forestland of Jeju Island with 30,538 ha. The study site is located in the Gotjawal forest, which is classified as a subtropical forest (Korea Forest Research Institute 2014). The elevation of the sampling areas ranges from 86-235 m above sea level. The mean annual temperature (MAT) of the is-

Table 1. Summary of observed statistics of the data used in the development of stem taper models for *Quercus glauca* in Jeju Island, Korea

Statistics	Initial model development (80% data)		Model validation (20% data)	
	DBH (cm)	Height (m)	DBH (cm)	Height (m)
No. of observations	134	134	33	33
Mean	15.45	12.48	16.95	13.05
Minimum	6.20	6.70	6.70	7.10
Maximum	38.40	22.60	36.00	21.40
Standard deviation	6.52	3.22	7.20	3.58

DBH, diameter at breast height.

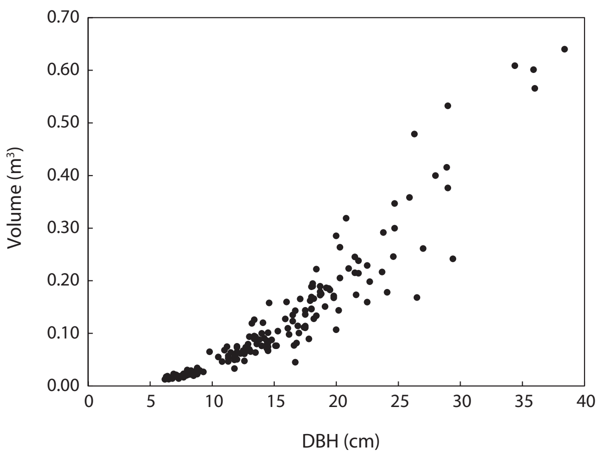

Fig. 2. Scatter plot of diameter at breast height versus volume of the *Quercus glauca* trees in Jeju Island, Korea.

land is 15.80°C. In addition, the minimum MAT is 12.90°C and the maximum MAT is 18.90°C(1981-2010). The mean annual precipitation is 1,497.60 mm (Korea Meteorological Administration 2014).

Data collection and analysis

The DBH (cm) and total height (m) of the 167 sample trees of *Quercus glauca* were measured. The DBH was measured using a standard diameter tape and the total height was measured using a Haglöf Vertex III Transponder and Transponder (Haglöf, Sweden). Because cutting or harvesting of *Quercus glauca* trees is strictly prohibited in Gotjawal forest due to conservation restrictions and destructive sampling of trees is very expensive, labor intensive and time consuming, the diameter outside the bark (DOB, cm) along the stem and the corresponding heights from the ground (m) were measured using the CRITERION400 laser dendrometer (Laser Technology, United States). The DOBs along the stem of each tree were determined starting from 20 cm above the ground and incrementing by 1-2 m. Using the Smalian formula, the volume of the different stem sections were determined. For the last upper stem section, the conical formula was used. The volumes of the different log sections were summed up to calculate the stem volume of each tree. To examine the relationship of DBH - volume of *Quercus glauca*, the stem volume was plotted versus the DBH (Fig. 2). The dataset was randomly split into two subsets. For the initial model development, 80% of the dataset was used while the remaining 20% was used for model validation (Table 1).

Five common volume equation forms used in various forestry literatures (Clutter et al. 1983, Avery and Burkhart 1994, van Laar and Akça 1997) were selected as candidate models to estimate the stem volume outside the bark of *Quercus glauca* in Jeju Island (Table 2). These models have been used in several studies for different species in various countries (Tewari and Kumar 2001, Kozak and Kozak 2003, Tewari and Kumar 2003, Dela Cruz and Bruzon 2004, Segura and Kanninen 2005). The parameters of these models were estimated using the Statistical Analysis System Non-Linear (SAS NLIN) procedure (SAS Institute Inc. 2004). In order to evaluate the performance of these models, the standard error of estimate (*SEE*), mean bias ($\overline{E}$), absolute mean deviation (*AMD*), coefficient of determination (R^2), and root mean square error (*RMSE*), were determined (Table 3). To identify the best models, rank analysis was used. The model with the lowest values for *SEE*, *AMD* and *RMSE* had the best rank. For R^2, the model with a value closest to 1 had the best rank, whereas for $\overline{E}$, a value close to zero was considered best.

Table 2. The five volume equations used in the model development and validation for *Quercus glauca* in Jeju Island, Korea

Model code	Model form*
1	$V = aD + bD^2$
2	$V = a + bD^2$
3	$V = a + bD^2H$
4	$V = D^2/(a + b/H)$
5	$V = aD^bH^c$

*V is the stem volume (m^3); H is the tree total height (m); D is the tree diameter at breast height (cm); a, b and c are the parameters estimated.

Table 3. Fit statistics used to assess the performance of the different volume models

Evaluation statistics	Equations*
Standard error of estimate	$SEE = \sqrt{\dfrac{\sum_{i=1}^{n}(V_i - \hat{V}_i)^2}{n-k}}$
Mean bias	$\overline{E} = \dfrac{\sum_{i=1}^{n}(V_i - \hat{V}_i)}{n}$
Absolute mean deviation	$AMD = \dfrac{\sum_{i=1}^{n}\left\|V_i - \hat{V}_i\right\|}{n}$
Coefficient of determination	$R^2 = 1 - \left[\dfrac{\sum_{i=1}^{n}(V_i - \hat{V}_i)^2}{\sum_{i=1}^{n}(V_i - \overline{V})^2}\right]$
Root mean square error	$RMSE = \sqrt{\sum_{i=1}^{n}(V_i - \hat{V}_i)^2 / n}$

*V_i is the observed volume for the ith tree; $\hat{V}_i$ is the predicted volume for the ith tree; $\overline{V}$ is the observed mean tree volume; k is the number of model parameters; n is the number of observation.

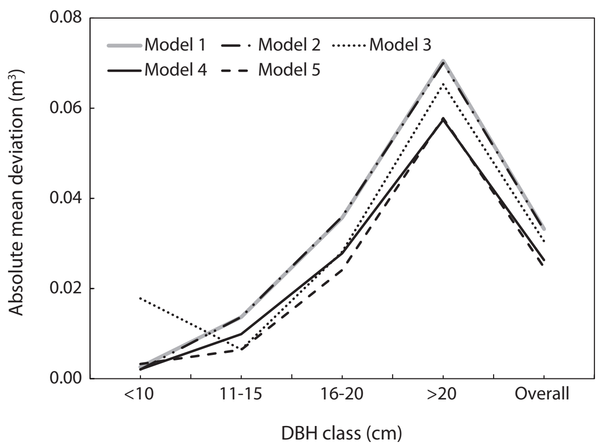

Fig. 3. Absolute mean deviation of the developed volume models in the different diameter at breast height (DBH) classes using the validation dataset of *Quercus glauca* in Jeju Island, Korea.

RESULTS AND DISCUSSION

Initial modeling and validation

Using 80% of the dataset, the initial volume model development was completed with five candidate volume equations. The results of the evaluation showed that the *SEE* ranged from 0.02099 to 0.03240, with model 5 (Schumacher and Hall 1933) having the best value and model 1 the poorest. The *AMD* ranged from 0.01354 m^3 (model 5) to 0.01995 m^3 (model 1), R^2 ranged from 0.92234 (model 2) to 0.98446 (model 5) and *RMSE* ranged from 0.02098 (model 5) to 0.03240 (models 1 and 2). Model 5 had the highest over prediction with $\overline{E}$ value of -0.00112 m^3, while model 4 had the highest under prediction with $\overline{E}$ value of 0.00534 m^3. Based on the evaluation and rank analysis, model 5 was considered the best model for predicting the stem volume of *Quercus glauca* in Jeju Island.

To better determine which model provided the most accurate estimation of stem volume, model validation was conducted. The *AMDs* of the five candidate models in the different DBH classes (5 cm interval) were determined as shown in Fig. 3. The validation results showed that model 5 had the best *AMD* in most of the DBH classes, while models 1 and 2 (with only DBH as predictor) had the poorest performance among the five candidate models.

Table 4. Parameter estimates of the volume models fitted for *Quercus glauca* in Jeju Island, Korea

Model	a	b	c
1	-0.00029	0.00047	
2	-0.00362	0.00047	
3	0.02325	0.00003	
4	1010.90	18174.70	
5	0.00013	1.62510	0.89830

a, *b* and *c* are the parameters estimated.

Final model development

The two datasets were combined for final modeling and evaluation. The parameter estimates of the five candidate models were estimated and are shown in Table 4. Using the five fit statistics, the performance of these models were evaluated as shown in Table 5. Model 5 still provided the best *SEE* with 0.02745, *AMD* with 0.01538 m^3, R^2 with 0.97603 and *RMSE* with 0.02746. For the $\overline{E}$ value, model 4 had the highest under prediction (0.00562 m^3) and model 5 had the highest over prediction (-0.00129 m^3). Models with one predicting variable (DBH) had the poorest performance in most of the fit-statistics. Model 1 had the highest *SEE* with 0.03764, *AMD* with 0.02275 m^3 and *RMSE* with 0.03768, while model 2 had the lowest R^2 with 0.90484. Using rank analysis, the best model was found to be model 5, while model 1 was the poorest.

Kozak and Kozak (2003) recommended using lack-of-fit statistics to determine further which of the candidate models is the most suitable for predicting stem volume. In this evaluation, one or more evaluation statistics must be determined for the various subgroups of the independent variable utilizing the entire dataset. In this study, *SEE*, $\overline{E}$

Table 5. Fit statistics of the different volume models fitted for *Quercus glauca* in Jeju Island, Korea

Model	*SEE*	$\overline{E}$	*AMD*	R^2	*RMSE*	Rank
1	0.03764	-0.00051	0.02275	0.95468	0.03768	5
2	0.03760	0.00000	0.02252	0.90484	0.03755	4
3	0.03092	0.00000	0.01956	0.93566	0.03092	2
4	0.03166	0.00562	0.01816	0.96793	0.03162	3
5	0.02745	-0.00129	0.01538	0.97603	0.02746	1

SEE, standard error of estimate; $\overline{E}$, mean bias; *AMD*, absolute mean deviation; R^2, coefficient of determination; *RMSE*, root mean square error.

and *AMD* in the different DBH classes (5 cm interval) for each model were determined. Results showed that model 5 consistently performed the best among the candidate models, with the best *SEE*, $\overline{E}$ and *AMD* in most of the DBH classes, while model 1 ranked last (Table 6). This evaluation method is important because a single overall value from the fit statistics may not indicate which model is best (Kozak and Smith 1993). For instance, in $\overline{E}$, the negative and positive biases of a model may have a cancelling effect that may produce a better $\overline{E}$ (close to zero) (Berhe and Arnoldsson 2008).

Overall, models with DBH and height as predictors had better performance than the two models with only DBH as a predictor. This result is comparable to other studies (Tewari and Kumar 2001, 2003, Guendehou et al. 2012) which showed that models with two predictors (DBH and height) had better predictive capabilities than those with only one predictor (DBH) based on the fit statistics.

Although models 1 and 2 had lower performance in stem volume prediction, these two models are still effective, especially when the total height of the tree is unavailable. For instance, the Korea Forest Service conducted the 5th National Forest Inventory (NFI) from 2006-2010 in the Republic of Korea and only 10 representative trees in a plot were measured for total height due to the difficulty and high cost of height measurement, whereas the DBH of all of the trees were measured. Furthermore, Segura and Kanninen (2005) recommended developing volume models using only DBH as a predictor because it can be measured easily and accurately in the field, unlike the total height.

CONCLUSIONS

Stem volume models with two predictors, DBH and total height, showed better predictive capability compared to the two models with only one independent variable

Table 6. The lack-of-fit statistics in the different diameter at breast height classes of the candidate models in estimating the total volume of *Quercus glauca* in Jeju Island, Korea

Model	DBH Class (cm)	*N*	*SEE*	*B*	*AMD*	Sum (Rank)
Model 1	< 10	38	0.00679	-0.00358	0.00515	55 (5)
	11-15	52	0.01783	-0.00023	0.01299	
	16-20	43	0.02988	-0.00077	0.02354	
	21-25	21	0.05721	0.00376	0.04526	
	> 25	13	0.09697	0.00128	0.07429	
Model 2	< 10	38	0.00606	-0.00192	0.01004	51 (4)
	11-15	52	0.01783	0.00044	0.01501	
	16-20	43	0.02984	-0.00073	0.02413	
	21-25	21	0.05721	0.00339	0.04527	
	> 25	13	0.09695	0.00078	0.07411	
Model 3	< 10	38	0.01630	-0.01543	0.01549	45 (2)
	11-15	52	0.01213	-0.00016	0.00869	
	16-20	43	0.02672	0.01030	0.01945	
	21-25	21	0.03058	0.01522	0.02464	
	> 25	13	0.09231	-0.01293	0.06708	
Model 4	< 10	38	0.00460	0.00217	0.00305	45 (2)
	11-15	52	0.01605	0.00902	0.01153	
	16-20	43	0.02666	0.01034	0.01951	
	21-25	21	0.03774	0.01021	0.02819	
	> 25	13	0.09320	-0.02089	0.06813	
Model 5	< 10	38	0.00543	-0.00429	0.00432	29 (1)
	11-15	52	0.01089	-0.00188	0.00806	
	16-20	43	0.02373	0.00090	0.01652	
	21-25	21	0.02486	0.00363	0.01863	
	> 25	13	0.08625	-0.00101	0.06819	

DBH, diameter at breast height; *SEE*, standard error of estimate; *B*, mean bias; *AMD*, absolute mean deviation.

(DBH) when estimating the volume outside the bark of *Querucs glauca* in Jeju Island, Korea. Model 5, originally proposed by Schumacher and Hall (1933), is considered as the best based on model evaluation and validation. On the other hand, model 2 is recommended in instances where total height is unavailable. Model 5 also provided a more accurate stem volume prediction than the general volume function in Forest Resource Evaluation and Prediction Program for broadleaf species. It is hoped that the volume models of the present study can help forest managers in sustainably managing the *Quercus glauca* forests in Jeju Island as these models can provide more reliable estimates of the growing stock stem volume.

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