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Volume equations for tree species in the tropical dry forest of East Nusa Tenggara, Indonesia

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ABSTRACT

The aims of this study is to develop and validate tree volume prediction models of tree species in East Nusa Tenggara tropical dry forest, Indonesia. Data collection in this study was conducted by measuring diameter and height of trees. Tree species volume equation is estimated using models of Berkhout, Kopezky-Gehrhardt and Hohenadl-Krenn. Selection of the best models was based on the values of the coefficient of standar deviation (SD), R^2_{adj}, aggregate deviation (AD) and average deviation (AveD), root mean square error (RMSE) and bias. Hohenadl-Krenn and Kopezky-Gehrhardt models were accepted as the best model for tree species in all research sites. The selected volume model for these tree species has Hohenadl-Krenn ($V = 0.572 - 0.033DBH + 0.00106DBH^2$ for Binafun and $V = 0.683 - 0.0366DBH + 0.001278DBH^2$ for Bonmuti) and Kopezky-Gehrhardt models ($V = 0.0502 + 0.000537\ DBH^2$ for Letkole and $V = -0.1776 + 0.000677DBH^2$ for Oelbanu).

Keyword: Volume table, Tropical dry forest, Best models, Selected model.

ABSTRAK

Tujuan penelitian ini adalah untuk membentuk dan melakukan validasi terhadap model prediksi volume pohon hutan kering tropika di Nusa Tenggara Timur, Indonesia. Data dikumpulkan melalui kegiatan penentuan terhadap diameter dan tinggi pohon. Model-model yang digunakan dalam kegiatan penelitian ini adalah Berkhout, Kopezky-Gehrhardt and Hohenadl-Krenn. Penentuan model terbaik berdasarkan pada parameter standar deviasi (SD), R^2_{adj}, deviasi aggregate (AD), deviasi rata-rata (AveD), root mean square error (RMSE) dan bias. Model Hohenadl-Krenn dan Kopezky-Gehrhardt terpilih sebagai model terbaik untuk semua lokasi penelitian. Dimana untuk model Hohenadl-Krenn adalah $V = 0.572 - 0.033Dbh + 0.00106Dbh^2$ pada lokasi penelitian Binafun dan $V = 0.683 - 0.0366DBH + 0.001278DBH^2$ untuk Bonmuti sedangkan model Kopezky-Gehrhardt adalah $V = 0.0502 + 0.000537\ DBH^2$ untuk lokasi penelitian Letkole dan $V = -0.1776 + 0.000677DBH^2$ untuk Oelbanu.

Kata kunci: Tabel volume, Hutan kering tropika, Model terbaik, Model terpilih

INTRODUCTION

For planning conservation strategies, there is a need to determine the few essential measurable properties, that best describe the dry forest vegetation and its environment, and to document quantitative relationships among them (Hutapea and Kuswandi, 2019). The conditions of dry forest show specific in structure, species composition and potential value, as well as variation in stand density, and death and growth rate (Almulqu, 2021). However, generic models are typically allometric equations developed for a group of species, also referred to as multi-species models. In the tropics, they are developed at different scales from (a) local: one or a few sites within a small area with the same climate (Basuki *et al*., 2009; Chidumayo, 2014; Colgan *et al*., 2014; Goussanou *et al*., 2016; Henry *et al*., 2010; Mensah *et al*., 2016; Mugasha et al., 2013; Ryan *et al*., 2011), (b) regional: areas and regions that are large enough to cover significant rainfall and temperature gradients (Kachamba et al., 2016; Mauya et al., 2014; Ngoma et al., 2018; Nott, 2018; Verlinden and Laamanen, 2006; Vieilledent et al., 2012), and (c) pantropical: global zones (Brown, 1997; Chave et al., 2014) in De Cauwer et al., (2020).

Generally, considerable importance has been given to the development of estimation schemes to predict volume for each individual tree and for the whole stand. Economic aspect is the main reason for this effort. Forest industres and other organizations often need periodic inventories to determine the quantity of wood available for utilization. Individual tree based volume measurements are the primary data not only for estimating stand volume per ha. per se for fixed area and for non productive functions, such as protection of soil, water, nutrients, and enhancement of biodiversity (Štícha *et al*., 2019). Tree volume predictions are required for forest stock estimates (Cysneiros *et al*., 2020; Gschwantner et al., 2019). Volume table is a tabular statement showing the volume with respect to diameter of specific area (Shrestha *et al.*, 2018). Volume models are the most important allometric models in forestry (Myllyviita *et al.,* 2021), needed for any tree species and region, as measuring tree volume in the field is usually not possible (Kangas *et al*., 2023).

These tables predict the volume of standing trees of given species, diameters and heights that would be obtained if trees where felled, bucked and scaled as logs (Salih, 2023). A side from providing cubic volume for the entire main stem, the tables also sometimes give either the volume from stump to a given merchantable diameter of the volume of cut lumber obtainable from a tree. The local volume table is prepared based on the limited data set to show the volume. Therefore, such volume tables are applied for the confined areas. In fact, there are several factors that affect precision of the volume table. Some major factors are stand density, site quality, local climate, soil condition, altitudinal gradient, aspect, inter and intraspecific competition (Shrestha *et al.,* 2018).

There are many studies describing tree height estimation and prediction models, mainly using well-known classical modeling techniques, such as non-linear regression models and Bayesian modeling, using in most cases allometric models (Karatepe *et al.,* 2022). The objective of this study is to develop a more ac- curate volume tabel for tree species in tropical dry forest of East Nusa Tenggara, Indonesia. The tree volume equation is formulated by using models of Berkhout ($V = aDb$), Kopezky-Gehrhardt ($V = a + bD^2$) and Hohenadl-Krenn ($V = a + bD + cD^2$). Model equation estimators had the best volume with using a scoring system based on the statistical test criteria in the compilation and validation of the model.

MATERIALS AND METHODS

Research Location

The study was carried out at the Mutis Timau Protected Forest Management Unit (Mutis Timau PFMU) of East Nusa Tenggara Province, Indonesia, which is covered on Kupang District, Timor Tengah Selatan District and Timor Tengah Utara District (Lat. 90 20′ 00″ - 90 45′ 10″ South and long. 123.042′ 30″ - 124.0 20′ 00″ E) (Fig. 1). Data for this study were collected from 4 dry forest study sites named Binafun, Bonmuti, Letkole and Oelbanu, each study site consisting of two 10.000 m² plots.

The research sites represent the dry forests of East Nusa Tenggara, Indonesia, and surrounding areas are the wettest areas on the island of Timor, the rain fell almost every month with the highest frequency of rainfall occurs during November to July, temperatures range between 14-29^{o}C, and in extreme conditions can decrease up to 9^{0}C. High-speed winds occurred in November until March (Almulqu *et al.,* 2018).

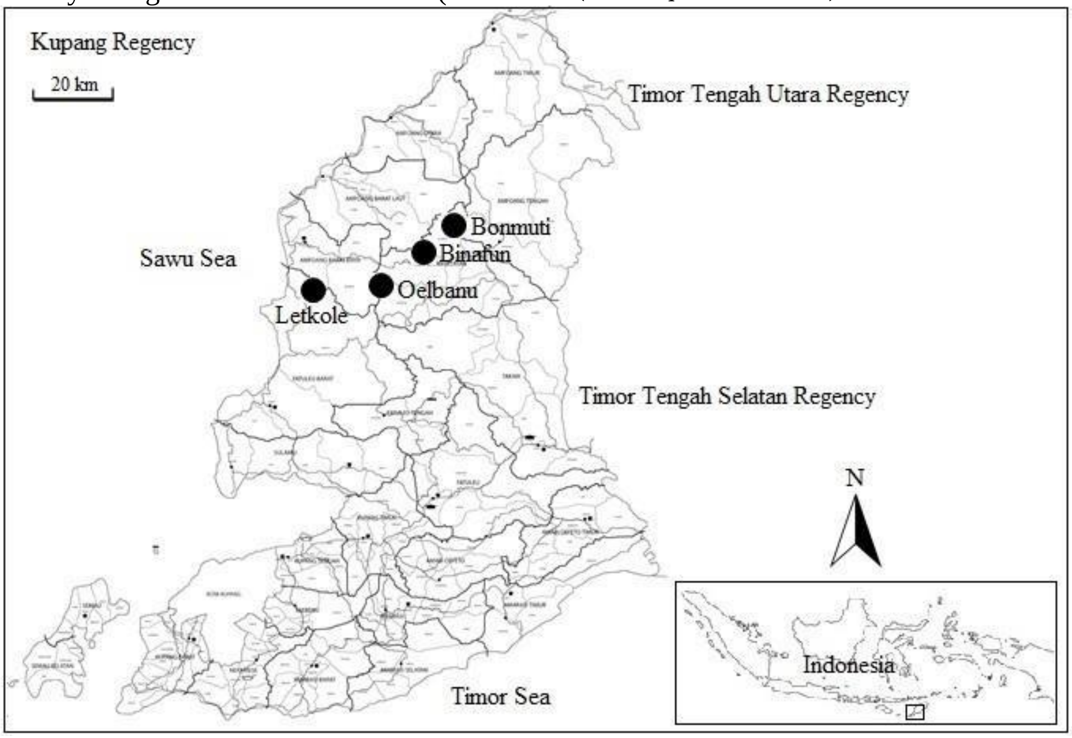

Figure 1: Location of research sites at Mutis Timau PFMU, East Nusa Tenggara Province, Indonesia

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Data Collection

In order to know the potential of tree species, two sample plots (100 m × 100 m) was established in each study area. In each sample plot, it divided into 16 sub-plots (SP) with the size of 25 m × 25 m as shown in Figure 2. In each plot, all tree species were measured for species name, height, and diameter at breast height (DBH) ≥ 20 cm (1.3 meters).

Samples of 516 trees (Binafun=119, Bonmuti=71, Letkole=141 and Oelbanu=185) for developing tree volume model and 372 sample trees (Binafun=98, Bonmuti=45, Letkole=121 and Oelbanu=108) for validating the model were selected randomly from each of the four data sets. The tree volume equation is estimated using models of Berkhout (V = aDb), Kopezky-Gehrhardt (V = a + bDBH^2) and Hohenadl- Krenn (V = a + bDBH +cDBH^2). Where, V= total tree vo- lume (m^3), DBH=Diameter at breast height (cm), a, b, and c=constanta.

Appropriate checks are to be made to assess the ac-curacy of the model. Therefore, I consider the following measures (standar deviation, R^2_{adj}, aggregate deviation and average deviation, root mean square error and bias) (Giri et al., 2021; Hu et al., 2021). The formula for the sample standard deviation is

$$\mathbf{SD} = \sqrt{\frac{\sum_{i=1}^{N}(x_1 - x)^2}{N-1}}$$

Where; s is standard deviation, x1, x2, xn are the ob-served values of the sample items, x is the mean value of these observations, and N is the number of observations in the sample. The formula for the adjusted R2 adj is:

$$\mathbf{R^2_{adj}} = 1 - \left[\frac{(1-R^2)(n-1)}{n-k-1}\right]$$

Where; N is the number of points in your data sam-ple, K is the number of independent regressors, i.e. the number of variables in your model, excluding the constant. The formula for aggregate deviation and average deviation are

$$\mathrm{AD} = \left[\frac{\sum_{i=1}^{n} Vp - \sum_{i=1}^{n} Vob}{\sum_{i=1}^{n} Vp}\right]$$

$$\mathbf{AveD} = \left\{\frac{\left(\sum_{i=1}^{n}\frac{Vp - Vob}{Vp}\right)}{n}\right\} x100\%$$

Where AD is aggregate deviation, AveD is average deviation, Vob is observed tree volume,

Vp is prediction tree volume

$$\mathbf{RMSE}(\%) = 100\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i - \hat{y}_i}{yi}\right)^2}$$

where n is number of trees used for model develop-ment, and yi and y^i are observed and predicted tree volume. The model bias was defined as follows: Bias =(Best- Bobs)/Bobs, where Best=bias estimation of tree volume and Bobs=bias observation of tree volume.

RESULTS AND DISCUSSION

Descriptive of the sampled trees for each Dbh class, research site, equation development plot and validation plot are given in Table 1. Number of sampled tree was different between site and plot. Totally, number of sampled tree is 217 for Binafun, 116 for Bonmuti, 262 for Letkole and 293 for Oelbanu. All site dominated by tree with Dbh class 20 cm - 49 cm and 50 cm -79 cm.

Table 1. Rekapitulasi of tree sample

Location	Dbh class (cm)	Plot for equation development	Validation plot	Total
Binafun	20 - 49	75	71	146
	50 - 79	31	14	45
	80 - 109	9	8	17
	110 - 139	4	1	5
	140 - 169	0	3	3
	170 - 199	0	0	0
	200 - 229	0	0	0
	230 - 259	0	1	1
	Total	**119**	**98**	**217**

Location	Dbh class (cm)	Plot for equation development	Validation plot	Total
Bonmuti	20 - 49	48	40	88
	50 - 79	14	4	18
	80 - 109	6	1	7
	110 - 139	2	0	2
	140 - 169	1	0	1
	170 - 199	0	0	0
	200 - 229	0	0	0
	230 - 259	0	0	0
	Total	**71**	**45**	**116**
Letkole	20 - 49	109	104	213
	50 - 79	22	13	35
	80 - 109	8	3	11
	110 - 139	1	0	1
	140 - 169	0	0	0
	170 - 199	1	1	2
	200 - 229	0	0	0
	230 - 259	0	0	0
	Total	**141**	**121**	**262**
Oelbanu	20 - 49	170	80	250
	50 - 79	12	24	36
	80 - 109	3	3	6
	110 - 139	0	1	1
	140 - 169	0	0	0
	170 - 199	0	0	0
	200 - 229	0	0	0
	230 - 259	0	0	0
	Total	**185**	**108**	**293**

In the present study, analysis of equation develop- ment shows that all values of R^2 and S was in a good range for estimating tree volume (Table 2). In Bon- muti, Berkhout model higher values of R^2 (98.69) and lower values of S (0.051). The estimator is to be unbiased (100% accuracy) if the value is equal to zero for S parameter.

Table 2. Regression models for estimation of tree volume

Site	Model	Equation	S	R^2 (%)	R^2_{adj} (%)
Binafun	Berkhout	$V = 0.000247DBH^{2.243}$	0.077	97.23	97.20
	Kopezky- Gehrhardt	$V = -0.318 + 0.000816\ DBH^2$	0.574	95.70	95.66
	Hohenadl- Krenn	$V = 0.572 - 0.033DBH + 0.00106DBH^2$	0.540	96.22	96.16
Bonmuti	Berkhout	$V = 0.000411DBH^{2.185}$	0.051	98.69	98.68
	Kopezky- Gehrhardt	$V = -0.374 + 0.001037DBH^2$	0.633	97.78	97.74
	Hohenadl- Krenn	$V = 0.683 - 0.0366DBH + 0.001278DBH^2$	0.592	98.08	98.02
Letkole	Berkhout	$V = 0.000383DBH^{2.0924}$	0.116	92.46	92.41

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Site	Model	Equation	S	R^2 (%)	R^2_{adj} (%)
	Kopezky- Gehrhardt	$V = 0.0502 + 0.000537\ Dbh^2$	0.531	91.85	91.79
Oelbanu	Hohenadl- Krenn	$V = -0.145 + 0.00735DBH + 0.000490DBH^2$	0.529	91.94	91.83
	Berkhout	$V = 0.00023DBH^{2.217}$	0.077	94.43	94.40
	Kopezky- Gehrhardt	$V = -0.1776 + 0.000677DBH^2$	0.248	92.60	92.56
	Hohenadl-Krenn	$V = 0.5426 - 0.03518DBH + 0.001019DBH^2$	0.214	94.51	94.45

In the present study, normal assumptions condition are viewed based on residual plot and normal proba-bility plot as shown in Figure 3-6. Generally, the pattern of relationship between the value of residual and normal probability are varies. Model of normali-ty assumption is fulfilled if the values are spread normally. Based on Figure 3-6, we can see plots that follow the linear line, ie, Berkhout, Kopezky-Gehrhardt and Hohenadl-Krenn models, and all plot forming like a S letter. The Kolmogorov-smirnov normality test shows that all models meet the normal assumption because they have P-value> α (0.05). It can be concluded that the normality assumption is fulfilled for all models.

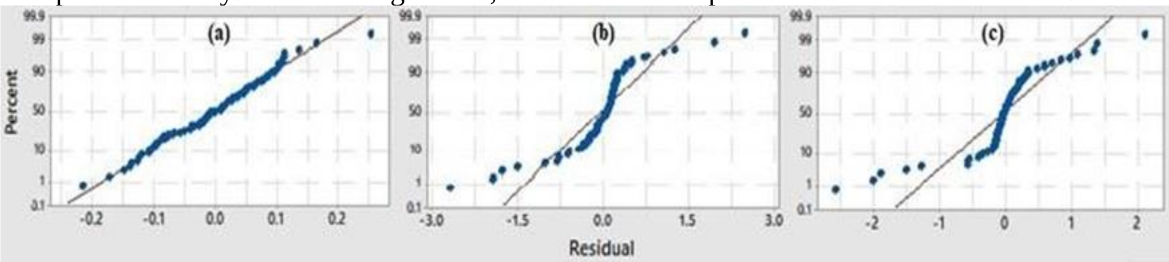

Figure 2. Diagram of normal probability for Binafun tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

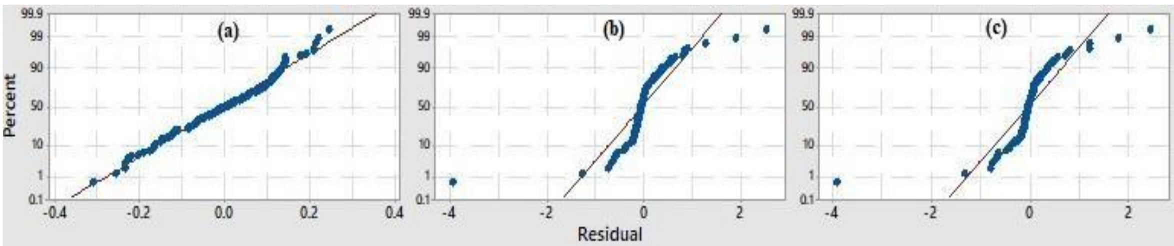

Figure 3. Diagram of normal probability for Bonmuti tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

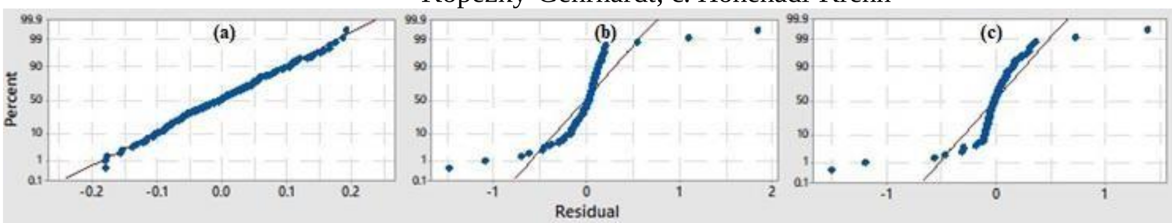

Figure 4. Diagram of normal probability for Letkole tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

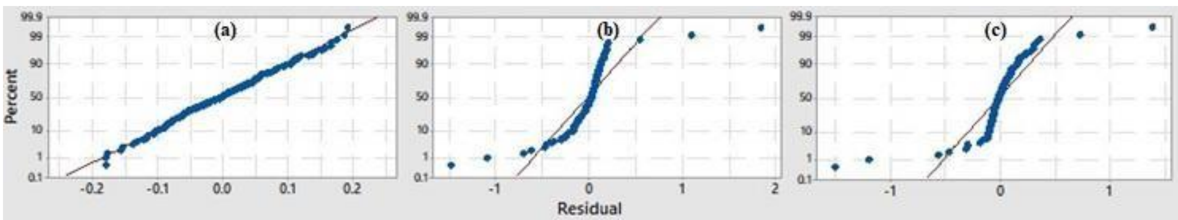

Figure 5. Diagram of normal probability for Oelbanu tree species. a: Berkhout; b: Kopezky-Gehrhardt; c: Hohenadl-Krenn

The result of model validation by using sample data of predefined tree is presented in Table 3. The level of accuracy of tree volume model can be seen from aggregate deviation (SA) and average deviation (SR) values. The range values of SA from -1 to +1 and <10% for SR are a good for volume estimation model. Based on the evidence summarized in Table 3, all model (Berkhout, Kopezky-Gehrhardt and Hohenadl-Krenn) at all sites, fitted with S, SA, SR, RMSE and probability plot. These model also performed well when fitted with optimal scatter plot.

Table 3. Model validation

Model	**Binafun**							
	S	**R^2 adj**	**AD**	**AvD**	**RMSE**	**Bias**	**Xcal**	**Xtable**
Berkhout	0.0778	97.2	-0.039	-0.04	0.383	-0.038	5.58E-06	120.989
Kopezky-Gehrhardt	0.5744	95.66	0.01	0.011	0.11	0.011	4.88E-07	120.989
Hohenadl- Krenn	0.54	96.16	-0.057	-0.06	0.551	-0.055	1.13E-05	120.989
Model	Bonmuti							
	S	R^2 adj	SA	SR	RMSE	Bias	Xcal	Xtable
Berkhout	0.0509	98.68	-0.039	-0.09	0.567	-0.084	2.48E-05	60.48
Kopezky-Gehrhardt	0.633	97.74	0.025	0.056	0.387	0.057	1.23E-05	60.48
Hohenadl- Krenn	0.592	98.02	-0.074	-0.17	1.034	-0.154	7.96E-05	60.48
Model	Letkole							
	S	R^2 adj	SA	SR	RMSE	Bias	Xcal	Xtable
Berkhout	0.116	92.41	-0.175	-0.15	1.359	-0.123	0.0001	146.567
Kopezky-Gehrhardt	0.531	91.79	-0.179	-0.15	1.385	-0.125	0.0001	146.567
Hohenadl- Krenn	0.529	91.83	-0.174	-0.14	1.348	-0.122	0.00017	146.567
	Oelbanu							
Model	S	R^2 adj	SA	SR	RMSE	Bias	Xcal	Xtable
Berkhout	0.077	94.4	0.215	0.199	2.636	0.253	0.0005	132.144
Kopezky-Gehrhardt	0.248	92.56	0.152	0.141	1.736	0.167	0.0002	132.144
Hohenadl- Krenn	0.214	94.45	0.189	0.175	2.244	0.215	0.0004	132.144

** accepted H_0 significance on $\alpha=0.05$*

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Based on the results of Table 4, for Binafun and Bonmuti, model Berkhout and Hohenadl-Krenn should be rejected, because, although is adequately fitted, has low for rangking equation. Also, models Berkhout and Hohenadl-Krenn at Letkole and Oelbanu should be rejected, because, although they have fairly good values for comparison criteria, both for fitting, validation data and their regression coef- ficients is statistically significant at the level p, all of their validation parameter highest than Kopezky-Gehrhardt.

Table 4. Scoring and rangking of equation for tree volume estimating

Model	S	R^2 adj	SA	SR	RMSE	Bias	Xcal	Sum	Rangking
Binafun									
Berkhout	3	1	2	2	2	2	2	14	2
Kopezky-Gehrhardt	1	3	1	1	3	1	3	13	3
Hohenadl-Krenn	2	2	3	3	1	3	1	15	1
Bonmuti									
Model	**S**	**R^2adj**	**SA**	**SR**	**RMSE**	**Bias**	**Xcal**	**Sum**	**Rangking**
Berkhout	3	1	2	3	2	2	2	15	2
Kopezky-Gehrhardt	1	3	1	1	3	1	1	11	3
Hohenadl-Krenn	2	2	3	2	1	3	3	16	1
Letkole									
Model	**S**	**R^2adj**	**SA**	**SR**	**RMSE**	**Bias**	**Xcal**	**Sum**	**Rangking**
Berkhout	3	1	2	3	2	2	3	16	2
Kopezky-Gehrhardt	1	3	3	3	1	3	3	17	1
Hohenadl-Krenn	2	2	1	1	3	1	1	11	3
Oelbanu									
Model	**S**	**R^2adj**	**SA**	**SR**	**RMSE**	**Bias**	**Xcal**	**Sum**	**Rangking**
Berkhout	3	2	1	1	1	1	1	10	3
Kopezky-Gehrhardt	1	3	3	3	3	3	3	19	1
Hohenadl-Krenn	2	1	2	2	2	2	2	13	2

Hohenadl-Krenn model (Binafun and Bonmuti) and Kopezky-Gehrhardt model (Letkole and Oelbanu) performed best in the validation as well as in the fit- ting phases (Tables 3 and 4). And Kopezky- Gehrhardt (Binafun and Bonmuti), Hohenadl-Krenn (Letkole) and Berkhout (Oelbanu) model was placed lowest during fitting and validation analysis. This analysis exemplifies that models can be used with greater confidence.

Table 5. Tree volume equation selected

Study site	Model	Equation
Binafun	Hohenadl-Krenn	$V = 0.572 - 0.033DBH + 0.00106DBH^2$
Bonmuti	Hohenadl-Krenn	$V = 0.683 - 0.0366DBH + 0.001278DBH^2$
Letkole	Kopezky-Gehrhardt	$V = 0.0502 + 0.000537\ DBH^2$
Oelbanu	Kopezky-Gehrhardt	$V = -0.1776 + 0.000677DBH^2$

The developed tree species volume models in this study are based on data from one tropical dry forest site, and we know little about how well these data are representing dry forests elsewhere in Indonesia or other country. However, most of the dryforests in the country, including Mutis Timau where our data were collected, are parts of the Mutis Timau Moun- tains, and similarities regarding growth conditions and allometry are likely present. As long as the al- lometry of the trees obviously is not different from that of Mutis Timau Mountains, we therefore be- lieve that our tree species volume models may be applied for dry forests outside this site. However, further testing of the developed models, if data from other tropical dryforest sites in Indonesia or other countries becomes available, is very recommended. Pitkänen *et al.* (2021) noted the possibility of the observed changes in stem form being due to the differences of the error structure rather than from actual change in time.

CONCLUSION

The present study was the first to develop tree species models for dryforests in Indonesia based on un- destructive sampling. The results showed that large parts of volume variation were explained by the models and that they performed relatively well when tested over different tree size classes. When considering the challenges in height measurements in dry- forests, we in general recommend applying model Hohenadl-Krenn model for Binafun and Bonmuti sites, Kopezky-Gehrhardt model for Letkole and Oelbanu sites with dbh only as independent variable

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