Allometric Models for Estimating Growth and Yield of *Eucalyptus grandis* at the Industrial Timber Estate North Sumatera - Indonesia

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Abstract: The suitability of allometric models for tree merchantable volume predictions in stands of *Eucalyptus grandis* at the Industrial Timber Estate North Sumatera, Indonesia was established in this study. Field observation was conducted to gather stands and geographic data from 49 observation of PsP (permanent sample plots) and 52 inventory plots. Multiple linear regression analyses were used to determine the contribution of the predictor parameters to the variation in growth rates. Model 1was found to be more suitable and fit for merchantable volume prediction.

1 INTRODUCTION

Growth and yield prediction models are abstract or simplified representations of some aspect of reality used primarily to estimate the future growth and yield of forest stands (Lucca ,2002). A stand growth model represents an abstraction of the natural dynamics of a forest stand, and depicts growth, mortality and other changes in stand composition and structure. Growth modelling of plantation timber species is a vital tool for the prediction of yield from future harvesting and estimating financial returns (Davis et.al 2001). According Vanclay, 2003 modeling is also good for decision making regarding buying, selling, and trading in forest resources (Vanclay2003).

Forest management implies performing series of treatments in complex productive systems. The purpose of management planning is to provide a basis for the allocation of these treatments so that the desired result can be obtained. In order to do this, management goals must be formulated, effective treatment options capable of producing the desire results must be found and outcome of treatment in the productive system (predicting the result of various management activities) must be described (Mof,2005)

Foresters need to know every detail about the forest they are managing in terms of location, size, quantity and quality of forest resources available and how these resources are changing over time (Medhurst et al.2001). This information can be obtained through proper resource modeling. Growth and yield modeling are very useful tools for managing forest properties either large or small. They are used for operational and strategic planning in nations that own and manage forest lands

2 MATERIAL AND METHOD

2.1 Study Site

The study was conducted in Aek Nauli sector of the Industrial Timber Estate (*Hutan Tanaman Industri* - HTI) North Sumatera, Indonesia, which is geographically situated between 02° 40’00” to 02° 50’00” north latitude and 98° 50’00” to 99° 10’00” east longitude. It is in the territorial jurisdiction of Pores subdistric, Simalungun District, North Sumatera Province, Indonesia

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2.2 Data Collection and Analysis

Data collection for primary data was done through a field survey the primary data and secondary data were digitally encoded. Field observation was conducted to gather stands and geographic data. Stands features referred to diameter, height, merchantable volume, age, species, spacing, site index, basal area, and density of *E. Grandis.* Geographical features referred to slope, elevation, rain fall and soil of the study area The data in this study used 49 observation of PsP (permanent sample plots) and 52 inventory plots. The total area of the plots in this study site is 3.11 ha. Sample plot was located in an area where the stand was of even age, uniformly spaced, and disease free.

Multiple Regression analysis was used for the modeling and analysis of numerical data consisting of values of a dependent variable (response variable) and independent variables (explanatory variables). The dependent variable in the regression equation is modeled as a function of the independent variables, corresponding parameters, and an error term Regression analyses were done to derive the yield equation of Eucalyptus at stand level using SAS.

Generally, yield (V) is considered to be a function of basal area, height, age, site index, stand density, spacing, top soil, rain fall, slope, elevation, , and type of soil. These can be expressed as :

Vi = f (BA, TH, Age, SI, SD, SP, TS, R, SL, E,N, DA, DB, DC, DD) (1)

where :

Vi= merchantable volume of stand for i group species in cubic meter per hectare
BAi= basal area of i group species in square meters per hectare
TH= total height in meter
Age= stand age in years from the year of stand establishment to the year of data measurement
SI = site index in meter
SD= stand density in tree/ha
SP = original spacing in square meters; their values are the products of original spacing (e.g., for a stand of original spacing 3 x 2 m., SP has value of 6)

TS = depth of top soil in centimeter (cm)
R = rain fall monthly (mm)
SL = slope in percent (%)
E = elevation in msal
N = density of upper canopy trees in trees/ha
DA=dummy variable for group of soil dystrandepts, hydrandepts, 1 if type of soil DA, 0 otherwise
DB=dummy variable for group of soil dystropepts, dystrandepts, 1 if type of soil DB, 0 otherwise
DC=dummy variable for group of soil dystropepts, hapludults, 1 if type of soil DC, 0 otherwise
DD= dummy variable for group of soil dystropepts, humitropepts, 1 if type of soil DC, 0 otherwise
bij = regression coefficients

ei= error terms

The volume models were assessed with the view of recommending those with good fit for further uses. The following statistical criteria were used:

a. The largest coefficients of determination (R^2) and coefficients of correlation (r), smallest mean square error (MSE) and values of Mallow's C(p) and Variance Inflation Factor (VIF). VIF (βi) < 4 indicates no multicollinerity, if VIF (βi) > 4 indicates a problem of multicollinearity. There is a possible problem of multicollinearity if VIF (βi) > 15 and there is a serious problem of multicollinearity if VIF (βi) > 30. (Catahan, 2008)
b. Significant F–values as computed in the analysis of variance (ANOVA) that test the overall regression given the intercept term; he critical value of F (i.e., F-tabulated) at p<0.05 level of significance will be compared with the F-ratio (F-calculated). Where the variance ratio (F-calculated) is greater than the critical values (F-tabulated) such equation is therefore significant and can be accepted for prediction
c. Consider the significance of each the independent variables;
d. Randomness of the residual as shown in the graph of the residual error values versus fitted merchantable volume values;

3 RESULT AND DISCUSSION

3.1 Descriptive Statistic of Stand and Geographic Variables

The summary descriptive statistics of the actual stand variables to develop the models are shown in Table 1, while descriptive statistics of geographic are shown in table2. Merchantable volume, basal area, diameter, height averages for *E.grandis*, are 60.965 m^3/ha, 10.076 m^2/ha, 11.213cm;15.5m respectively.

Table 2 indicates that geographic variables were top soil, monthly rainfall, slope, and elevation with average 22.287cm; 201.457mm/month; 15.296% and 1225.52 msl respectively.

Table 1. Descriptive statistics of stand variables *E. grandis*,

Descriptive statistics	Volume (m^3/ha)	Basal area (m^2/ha)	Age (year)	Diameter (cm)	Height (m)	Site index (m)	Density (tree/ha)	Spacing (m^2)
Max	152.307	20.277	6.12	16	25.4	25.004	1280	9
Min	0.3159	0.483	1.08	2.3948	2.619	4.632	575	6.75
Average	60.965	10.076	3.119	11.213	15.514	15.747	925.532	8.928
Variance	0.282	0.067	1.585	12.47	0.047	0.04	0.006	0.158
Standard Deviation	0.531	0.259	1.259	3.531	0.216	0.2	0.079	0.398

Table 2. Descriptive statistics of geographic in studi site

Descriptive statistics	**Top soil (cm)**	**Rain fall (mm/month)**	**Slope (%)**	**Elevation (masl)**
Max	**35**	**361**	**45**	**1400**
Min	**15**	**105**	**4**	**350**
Average	**22.287**	**201.457**	**15.298**	**1225.532**
Variance	**17.669**	**0.029**	**0.098**	**0.016**
Standard Deviation	**4.203**	**0.17**	**0.313**	**0.125**

3.2 Selecting the Best Models

The plot volumes were obtained by adding the volumes of all the trees in the plot (Up) while mean plot volume was obtained by dividing the total plot volume by number of sample plots.

Forest growth models in this study involving the logarithm of merchantable volume are the dependent variable. The use of the logarithm of yield as dependent variable is a convenient way to mathematically express the interaction of the independent variables in their effect on yield.

The assessment criteria revealed that for *E. grandis* model 1was discovered best to have good fit and very suitable for stand volume estimation in the study area. The result suggests that all the models with good fit are suitable for volume estimation within the context of the field data used. Model 1 was selected as the best model for *E.grandis* because it had, R^2 = 0.9830 and r = 0.9915, and the lowest MSE = 0.0341, and C(p) = 2.5881, 4/5 of the independent variables are significant, and not multicollinerity (Table 3). The final model for *E.grandis* is:

$$V = \exp [0.30190 + 1.38912 \ln BA -0.40322 \ln (Age^{-1}) + 0.02682 (SI) -0.00054 (N)] \quad (2)$$

It means that there is an increase in volume by 1.38921 per unit increase in multiple basal area holding other independent variables constant.

There is a decrease in volume by 0.40322 per unit increase in reciprocal age holding other independent variables constant. Villar (2005) studied the yield of Yemane plantation on forest product unit in Bukidnon, Philippines. There was positive correlation between yield of yemane on average age.

Site index is the total height of the dominant trees in a stand at specified ages. There is an increase in volume by 0.02682 per unit increase in site index holding other independent variables constant.

Stand density is a measure of how many trees are growing per unit area. There is a decrease in volume by 0.00054 per unit increase in density of tree holding another independent variables constant. Lu (2000), studied population density of 5.6 years old *Eucalyptus urophylla* plantation. The results showed that the population density remarkably affected DBH, individual standing volume, crown width, live branch height, stand volume and wood fiber width; but did not affect tree height, basic density of wood, and length of wood fibers

Aswandi (2000) reported that the prediction equation for *Eucalyptus grandis* in North Sumatera, Indonesia including age, site index and basal area were fitted. These models fitted were also found to be good enough to predict growth and yield in *E. grandis* in central Western region of Minas Gerais Brazil, (Pereira et al, 2006)

Table 3. Coefficients of determination (R2), coefficients of correlation (r), mean square error (Mse), Mallow's C(p), P-value and Vif using original ages for E.grandis group

Selection Procedure	Model	Model Adequate	Precision	Test of Hypotheses on B's	Multi Collinear (mc)	Selection Procedure	Model
		R^2	r	Mse	C(p)	p-value	Vif
Full model	1	0.9844	0.9922	0.0347	11.9911	significant	not mc
	2	0.9225	0.9605	0.1685	14.0000	significant	not mc
	3	0.9314	0.9651	0.1529	11.9981	significant	not mc
Stepwise	1	0.9830	0.9915	0.0341	2.5881	significant	not mc
selection	2	0.9202	0.9593	0.1617	2.4451	significant	not mc
	3	0.9286	0.9636	0.1464	3.2993	significant	not mc

4 CONCLUSIONS

Regression models for volume estimation was develop and validated for *Eucalyptus grandis* . The stand growth data was collected from permanent sample plot and temporary sample plot in the study area. Based on the evaluation of the models examined in this study model 1can be applied to accurate growth and yield at study site. Dependent variables that significantly affect the volume are basal area, age, site index and stand density.

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