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YIELD PREDICTION MODELS FOR *PINUS MERKUSII* PLANTATIONS IN INDONESIA

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ABSTRACT

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Two yield prediction models for *Pinis merkusii* plantations are developed and described in this paper. The first model is formulated as a system of two simultaneous equations involving basal area and yield as two endogenous variables. The system of equations is considered just-identified. Hence, two-stage least squares were used as an estimation procedure. The second model is a single-yield equation whose parameters are estimated by ordinary least squares.

INTRODUCTION

Pinus merkusii Jungh et de Vries is indigenous to Northern Sumatra, Indonesia. In the early 1920s, it was tried in plantations in the islands of Sumatra and Java. Since 1931, it has been planted extensively not only in these islands, but also in Bali and Sulawesi (Ferguson, 1954).

Three previous studies have examined the growth and development of *P. merkusii* in Indonesia. The first is the pioneering work of Ferguson (1954). He used smooth-fitted curves to describe the height of each age class given an average site quality. Other growth curves for other site qualities were developed based on some adjustments from the average site quality.

Sumarna and Sudiono (1972) developed a local volume table for *P. merkusii* plantations at North Bandung (West Java). Later, Suharlan et al. (1976) improved these tables by adding more sample trees. Siahaya (1973) also developed a tree volume table for the same species in West Java, using stem and crown diameters.

Data and study area

The data used in this study were obtained from three plantations located in West, Central and East Java. All these plantations are owned and managed by the government though PERHUTANI, a Forest State Corporation. At West Java, the data were collected from 4- to 34-year-old stands which were planted from 1948 to 1978. At East Java, the data were collected from 11- to 27-year-old stands which were planted from 1955 to 1971. Finally, at Central Java, the stands are 4–19 years of age, and were planted from 1963 to 1978.

From these three sites, 114 permanent sample plots, whose sizes vary from 0.12 to 0.6 ha, were selected. These sample plots were measured and remeasured by the Forest Research Institute (FORI, Bogor) every 2 years since the plantations were about 4 years old. The plots are of various ages. Hence, depending on the age of the plots, two to eight remeasurements were done, so that there were 545 observations taken from these 114 sample plots.

TABLE 1

Distribution of sample plots and number of observations by original stand spacing

Original stand spacing	No. of sample plots/No. of

TABLE 2

Distribution of 545 observations on 114 permanent sample plots by stand age and original stand spacing

Original stand spacing (m×m)	Stand age interval (years)							Total
	0–5	6–10	11–15	16–20	21–25	26–30	31–35	
$1\frac{1}{2}\times1\frac{1}{2}$		2	4	4	2			12
$2\times1\frac{1}{2}$		1	5	4	2			12
2×2		1	2	2	1			6
$3\times1\frac{1}{2}$		6	12	12	6			36
3×2	8	65	103	111	42	2		331
$2\frac{1}{2}\times2\frac{1}{2}$			1	3	1	1	2	8
3×3	8	40	30	16	6			100
4×3	4	7	10	11	8			40
Total	20	122	167	163	68	3	2	545

TABLE 3

Distribution of 545 observations on 114 permanent sample plots by stand age and average total height of dominant trees of the plots

Stand age interval (years)	Average total height interval (m)					
	5.0–10.2	10.3–15.5	15.6–20.8	20.9–26.1	26.2–31.4	31.5–36.7
0– 5	20					
6–10	24	85	13			
11–15		8	108	51		
16–20			8	118	35	2
21–25				6	54	8
26–30					2	1
31–35						2
Total	44	93	129	175	91	13

TABLE 4

These plots were chosen so that stand age, average total height of dominant trees, and site quality are well distributed and represented. Tables 1 to 4 summarize the distribution of the sample plots and the number of observations.

FACTORS AFFECTING YIELD

Clutter et al. (1983) provide a comprehensive review of the development of various types of growth and yield models for different types of forests; the regression models developed in this paper are adaptations of the Shumacher-type yield model described. As pointed out earlier, the primary purpose of the model is to generate expected-yield tables which can be used for growth and yield analysis. Emphasis is given to the effect of thinning on the growth and yield of *P. merkusii* plantations. For this purpose, the regression model includes other factors such as thinning intensity which is based on a thinning guide prescribed by the Forest State Corporation PERHUTANI (1982).

There are several factors that affect the yield of an even-age plantation forst. These include: (1) management regime; (2) genetic variation; (3) stand age; (4) site quality; (5) original spacing; and (6) stand density. In this paper, the genetic variation and management regime (except intermediate cutting or thinning) were held constant and hence they were not considered as primary factors in the model development.

Management regime. In formulating the yield prediction model for *P. merkusii* plantations, the management regime was considered constant because all plantations were managed using the same management guides under the control of FORI and PERHUTANI. However, thinning was considered as a primary factor or variable because the stands were subjected to different levels or intensities of thinning. The thinning intensity was based on the number of trees and average total height of the dominant trees in the stand.

the seeds used for planting came from mother trees of the same variety of *P. merkusii* Jungh et de Vries, and from the same island (i.e., Java). Hence, based on the origin of seeds, it was assumed that the genetic variation among the plantations was not significant.

Site quality. Stand height at a given stand age was used as the index for site quality. Since no site index equation was available for *P. merkusii* plantations in Java, it was necessary to develop one for the study. Based on 545 observations taken from 114 permanent sample plots, a guide equation was used to develop the site index equation.

Original spacing. Results of previous studies in pine plantations (Ware and Staheline, 1948; Bamble et al., 1949; Bennett, 1963; and Pimmanrojnagool, 1979) have used original spacing as primary factor in yield prediction. For the present study, eight types of original spacing were used. Each spacing was expressed as the product of its length and width.

Stand density. For this study, stand density was measured or expressed in terms of basal area per ha.

MODEL FORMULATION AND DEVELOPMENT

Two alternative formulations and estimation procedures were examined in this study. The first formulation involves the use of a single-yield equation whose parameters were estimated by ordinary least squares (OLS). The second formulation adopts the simultaneous-equations approach. In the latter formulation, the model parameters were estimated by two-stage least squares (2 SLS).

The two alternative formulations were examined because previous studies on two other pine species in Southeast Asia, namely *Pinus kesiya* in Thailand (Pimmanrojnagool, 1979) and Benguet pine in the Philippines (Revilla, 1976) have reported satisfactory results using the two formulations.

were specified so that: (1) yield equation is expressed as a function of stand age, site index, original stand spacing, thinning intensity and stand basal area, and (2) other equations were specified in addition to the yield equation.

Single-equation method. Several forms of the single-equation yield prediction model were considered and examined in the study. After careful examination of these various single equation forms, the model described in equation (1) was chosen because it exhibited some desirable statistical properties (e.g. high multiple correlation, R^2, and highly significant regression coefficients), and primarily because it allows direct comparison with the yield equation of the simultaneous equations model. Hence, the single-yield equation is formulated and specified as:

$$\log Y = b_{10} + b_{11}(1/A) + b_{12}(S) + b_{13}(\text{SP}) + b_{14}(\text{TI}) + b_{15}(\log \text{BA}) \tag{1}$$

where Y is stand volume or yield (m^3/ha); A age of stand (years); S site index (m), at base age of 20 years; SP original stand spacing (m^2); TI thinning intensity (%); and BA basal area (m^2/ha); b_{10}, b_{11}, b_{12}, b_{13}, b_{14}, b_{15} are model parameters.

Simultaneous-equation method. The theory of simultaneous-equations in regression analysis and econometrics is described in many books (e.g., Furnival and Wilson, 1970; Kmenta, 1971; Johnston, 1972; Chiswick and Chiswick, 1975) and will not be discussed in detail in this paper. However, some concepts will be briefly presented to highlight the development of the yield prediction model.

In formulating the simultaneous equations, basal area and yield are the two *endogenous* variables. The structural form of the two equations are specified as follows:

$$\log \text{BA} = b_{20} + b_{21}(1/A) + b_{22}(S) + b_{23}(S/A) + b_{24}(\text{SP}) + b_{25}(\text{TI}) \tag{2}$$

$$\log Y = b_{30} + b_{31}(1/A) + b_{32}(S) + b_{33}(\text{SP}) + b_{34}(\text{TI}) + b_{35}(\log \text{BA}) \tag{3}$$

intensity is not included as a distinct explanatory variable, whereas the formulation in equation (3) allows the specification of thinning intensity directly. With the formulations specified in (3), predicted yield tables based on the thinning guides prescribed by PERHUTANI can be generated.

From the above equations, stand age, site index, original stand spacing and thinning intensity are the *exogenous* variables which are determined outside the model. The system of two simultaneous equations consisting of equations (2) and (3) is considered just-identified. Note that the *reduced forms* of the system can be described as follows:

$$\log(\text{BA}) = a_{20} + a_{21}(1/A) + a_{22}(S) + a_{23}(S/A) + a_{24}(\text{SP}) + a_{25}(\text{TI}) \quad (4)$$

$$\log Y = a_{30} + a_{31}(1/A) + a_{32}(S) + a_{33}(S/A) + a_{34}(\text{SP}) + a_{35}(\text{TI}) \quad (5)$$

where

$$\begin{array}{ll} a_{20} = b_{20} & a_{30} = b_{30} + b_{35}b_{20} \\ a_{21} = b_{21} & a_{31} = b_{31} + b_{35}b_{21} \\ a_{22} = b_{22} & a_{32} = b_{32} + b_{35}b_{22} \\ a_{23} = b_{23} & a_{33} = b_{35} + b_{23} \\ a_{24} = b_{24} & a_{34} = b_{33} + b_{35}b_{24} \\ a_{25} = b_{25} & a_{35} = b_{34} + b_{35}b_{25} \end{array} \quad (6)$$

From the reduced form of the two simultaneous equations, it can be observed that the structural parameters (i.e., b_{20}, b_{21}, ..., b_{26}; b_{30}, b_{31}, ..., b_{35}) can be solved from the reduced form parameters (i.e., a_{20}, a_{21}, ..., a_{25}; a_{30}, a_{31}, ..., a_{35}) using the relationships in equation (6). Furthermore, it can be observed from the relationships in (6), that a unique solution for the structural parameters exist given the values of the reduced-form parameters [a]. This condition suggests that the structural equations are just-identified.

Econometric theory has shown that if the system of simultaneous equations is considered *just-identified*, the best estimation procedures are indi-

OLS, except that (log BA) is not in raw form as in equation (1), but in its estimated value obtained from the first step. Hence, the model specification for the simultaneous equation model estimated by 2 SLS is as follows:

— First stage:

$$\log \mathrm{BA} = b_{20} + b_{21}(1/A) + b_{22}(S) + b_{23}(S/A) + b_{24}(\mathrm{SP}) + b_{25}(\mathrm{TI})$$

— Second stage:

$$\log Y = b_{40} + b_{41}(1/A) + b_{42}(S) + b_{43}(\mathrm{SP}) + b_{44}(\mathrm{TI}) + b_{45}(\log \mathrm{BA})$$

where log BA = is the predicted value of log BA obtained from the first stage.

RESULTS AND DISCUSSION

Site index

Techniques for modeling site index are reviewed comprehensively in Clutter (1983). For this study, the guide curve method was adopted in modeling site index. Following this method two forms of the height guide curve and site index equations were formulated and estimated as follows:

— Height guide equations:

$$\log H = 0.323187 + 0.855941(\log A) \tag{7}$$

$$R^2 = 0.94$$

$$\log H = 0.2459 + 0.86426(\log A) + 0.02394(\log E) + 0.000445(\mathrm{SL}) \tag{8}$$

$$R^2 = 0.94$$

— Site index equations:

$$\log S = \log H + 0.855941(\log \mathrm{BAGE} - \log A)$$
$$= 1.1136 + \log H + 0.8559 \log A \tag{9}$$

Site index equations (9) and (10) are guided by (7) and (8), respectively. Equation (7) is based on the model commonly used for height guide curves. However, as described by (7), log A was used instead of the reciprocal of age as originally suggested by Shumacher (1939) because the 545 observations fitted the alternative model better, as shown by the high value of the multiple correlation coefficient, R^2. Between equations (9) and (10), (9) was chosen as the site index equation for the study because the goodness of fit for both height guide curves are almost the same as reflected by their R^2 which are almost equal.

Simultaneous-equations yield model

Solving the parameters of the simultaneous-equations model formulated by equations (2) and (3) by 2 SLS, the following equations were derived:

$$\log \text{BA} = 2.0400 - 1.6610(1/A) - 0.0064(S) + 0.0558(S/A) + 0.0074(\text{SP}) - 0.0201(\text{TI}) \tag{11}$$

$$R^2 = 0.84119; \quad R^2(\text{adjusted}) = 0.83972$$

$$\log Y = 1.7310 - 4.1822(1/A) + 0.0059(S) + 0.00519(\text{SP}) - 0.00678(\text{TI}) + 0.556684(\log \text{BA}) \tag{12}$$

$$R^2 = 0.93322; \quad R^2(\text{adjusted}) = 0.93260$$

Single-equation yield model

Applying OLS directly to equation (1), the following model was derived:

$$\log Y = 1.9244 - 4.1989(1/A) + 0.0057(S) + 0.0059(\text{SP}) - 0.0088(\text{TI}) + 0.4558(\log \text{BA}) \tag{13}$$

$$R^2 = 0.94271; \quad R^2(\text{adjusted}) = 0.94218.$$

Comparison of estimation procedures and results

TABLE 5

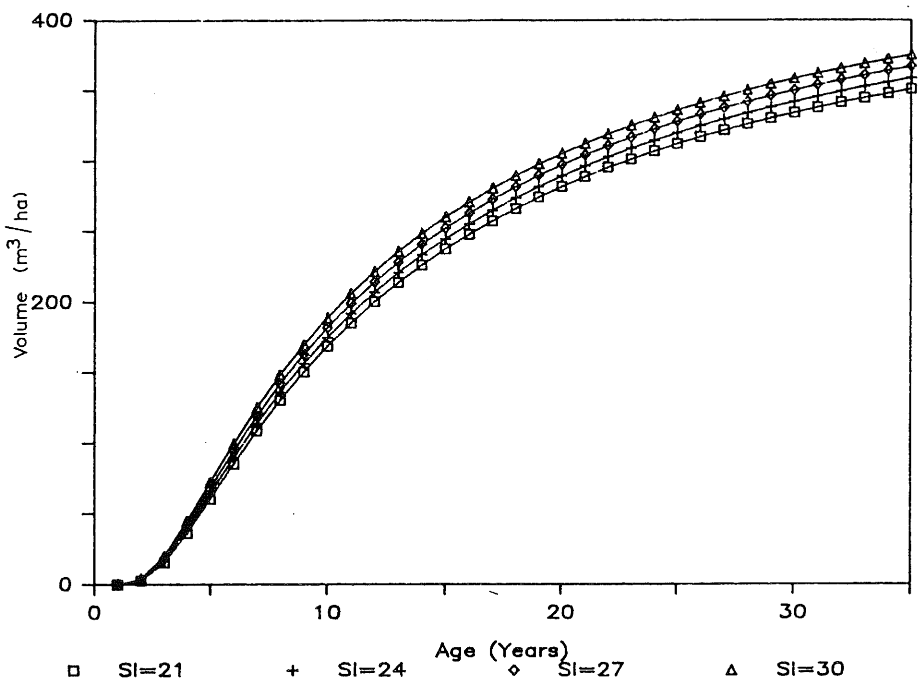
Regression coefficients estimated by OLS and 2 SLS at various sample sizes

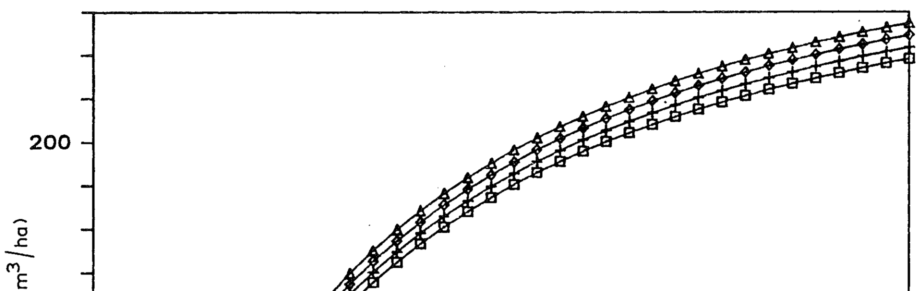
Method	Number of observations	Regression coefficients					
		b_{10}	b_{11}	b_{12}	b_{13}	b_{14}	b_{15}
OLS	300	2.0751	4.2506	0.0065	0.0077	0.0105	0.3615
	400	2.0348	4.2210	0.0068	0.0061	0.0103	0.3840
	500	2.0012	4.2533	0.0064	0.0055	0.0097	0.4092
	545	1.9244	4.1990	0.0058	0.0060	0.0088	0.4559
	Variance of estimates	0.00306	0.000501	0.00000013	0.00000068	0.00000044	0.00122
		b_{30}	b_{31}	b_{32}	b_{33}	b_{34}	b_{35}
2 SLS	300	1.7767	4.2242	0.0067	0.0066	0.0074	0.5172
	400	1.8428	4.1447	0.0059	0.0065	0.0065	0.4896
	500	1.8607	4.1621	0.0062	0.0057	0.0082	0.4798
	545	1.7310	4.1822	0.0059	0.0052	0.0068	0.5567
	Variance of estimates	0.00269	0.00087	0.00000011	0.00000033	0.00000042	0.00088

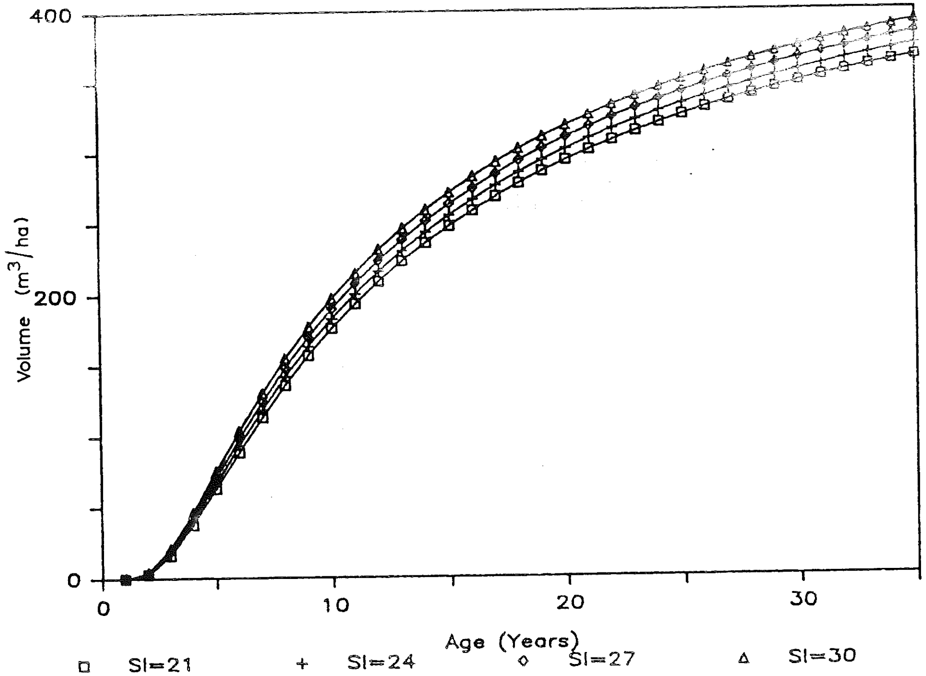
Johnston (1972) has suggested that a sufficient condition for a consistent estimator is that the bias and the variance should approach zero as the sample size increases. To empirically verify whether the two estimation procedures exhibit this property, the regression coefficients were estimated at four different sample sizes. These samples used were randomly chosen from the set of 545 observations. Only sample sizes which are considered large enough (i.e., from 300 to 545) were considered for the analysis. The results are summarized in Table 5.

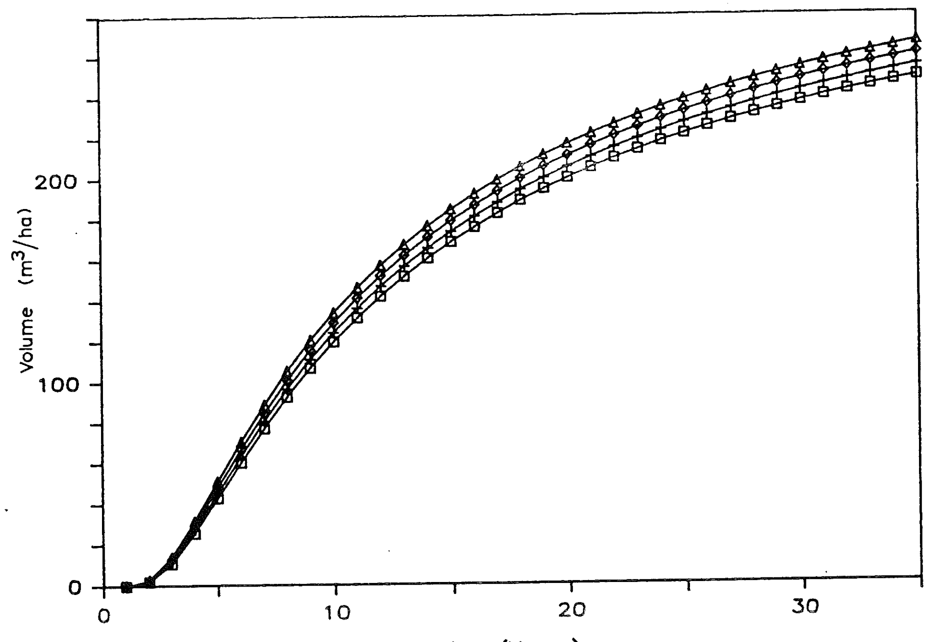
It can be observed from Table 5 that the simple variance of the regression coefficients estimated by 2 SLS is consistently smaller, except for b_{11} and b_{31}. This indicates that the estimated regression coefficients using 2 SLS exhibit less divergence compared to OLS when the sample size is large

In validating the model, two significant aspects were considered: (1) statistical validation, and (2) biological validation. Statistical validation involves the testing of the significance of the regression coefficients and the multiple correlation coefficient. In addition, a simple chi-square test was performed to test how close the predicted yield values are compared to the actual volume measured from 102 observations.






400
200
0
Volume (m3/ha)
0
10
20
30
Age (Years)
SI=21
SI=24
SI=27
SI=30


200
100
0
Volume (m3/ha)
0
10
20
30

Yield tables and curves. As pointed out earlier, the primary purpose of developing the growth and yield prediction models is to generate predicted yield tables for *P. merkusii* plantations based in: (1) original spacing, (2) site quality, and (3) thinning intensity as prescribed by PERHUTANI. To demonstrate the use of the models for growth and yield analysis, yield tables and curves are generated using equations (11) and (12) as shown in Figs. 1 and 2.

SUMMARY AND CONCLUSIONS

This study was conducted to develop a yield prediction model for *Pinus merkusii* Jungh et de Vries in Java, Indonesia. A sample of 545 observations taken from 114 permanent rectangular plots established in West and East Java was used.

Two alternative formulations and estimation procedures were examined. The simultaneous equations formulation was estimated by 2 SLS. On the other hand, OLS was used to estimate the single-yield equation. A simple variance comparison was done to empirically test the consistency of the two estimation procedures. It was observed that the 2 SLS estimates consistently exhibited smaller variance of the estimates when the sample size is large enough (i.e., from 300 to 545). This desirable property is an advantage of 2 SLS over OLS. However, the magnitude of the difference in the variances and the estimates themselves may not be significant enough to favor any one of the two estimation procedures.

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