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# DEVELOPMENT OF PARAMETER PREDICTION MODELS FOR PREDICTING THE STAND CHARACTERISTICS OF *ACACIA MANGIUM* PLANTATIONS

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## ABSTRACT

A procedure for predicting diameter distribution of *Acacia mangium* plantations was developed based on the univariate $S_B$ distribution model. In simulation of stand characteristics, equations were developed for predicting average height, basal area per hectare, and number of trees per hectare surviving when age, spacing and number of trees per hectare planted were known. The predicted stand characteristics were then related to the estimated parameters of the Johnson $S_B$ and solving the resulting set of equations for the scale and shape parameters. This study revealed that the parameter prediction method yields reliable prediction equations of the stand characteristics, but the prediction equations of the scale and shape parameters suggested that further research is needed to improve the model.

## INTRODUCTION

It has long been recognized that the extent and distribution of future yields is essential to the successful solution of a broad array of problems associated with sustainable forest management. Determination of raw material values, harvesting costs, product mixes, and forest management planning are activities that emphasize the importance of distribution yield forecasts.

Clutter and Bennett (1965) made a major contribution to structural yield prediction in even-aged forest stands. Their diameter distribution approach gave forest managers the ability to apportion yield to arbitrary size classes based upon whatever diameter class criteria they deemed appropriate, yet provided the customary total stand yield estimates. Additional applications and embellishments by Mc Gee and Della-Bianca (1967), Bennet and Clutter (1968), Burkhart (1971), Lenhart and Clutter (1971), Bailey (1972), Bailey and Dell (1973), Burkhart and Strub (1974), Smalley and Bailey (1974a, 1974b), Lohrey and Bailey (1976), Clutter and Belcher (1978), Dell *et al.,* (1979), and Feducia *et al.,* (1979) served to firmly establish the viability of the diameter distribution method for predicting yields and stand structure in even-aged forest stands (Hyink and Moser, 1983).

The objective of whole stand yield prediction and projection models have attempted to predict stand yields as follows:

(1) Explicitly through multiple regression techniques as a function of easily obtained stand characteristics such as age, a measure of stand density such as basal area or stem per acre, and site index or the

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average height of dominants and codominants (Bennett *et al.*, 1959; Clutter and Jones, 1980); or

(2) Implicitly by prediction of a stand's diameter distribution that is used along with individual tree volume equations to obtain the stand yield (Smalley and Bailey, 1974a; Rennolls *et al.*, 1985).

The second type of model is generally prefered because more detailed information concerning stand structure can be obtained (Borders and Patterson, 1990). This study emphasizes on the development of model based on approach (2) as described above. Attention is focussed upon the development of a parameter prediction model (PPM). A parameter prediction model (PPM) is one which forecasts a future number of trees and the associated values of the parameters of a probability density function (pdf) describing the diameter distribution of those trees.

## MODEL DEVELOPMENT

The use of a pdf to represent stand characteristics involves the estimation of pdf parameters. Estimation of these parameters was first attempted using regression techniques with stand characteristics such as age and site quality as predictor variables (Meyer and Stevenson, 1943; Burk and Newsberry, 1984). Borders and Patterson (1990) stated that relationships among parameters made it very difficult to develope prediction equations that would explain a high percentage of variation in the parameters.

Three of the methods commonly used to predict the pdf parameters are parameter prediction (PPM), parameter recovery (PRM) and percentile prediction (PCPM). This study adopted to PPM in predicting future diameter distributions.

The PPM procedures is as follows:

1) Obtain tree diameters from sample stands of known age, spacing, and number of trees per hectare planted.

2) Select a family of distribution to represent the underlying diameter distributions, $f(x;\theta)$.

3) Estimate the pdf parameters for each sample plot based on diameter distribution.

4) Using regression analysis, develop equations to predict stand level variables (average height, total basal area per hectare, number of trees per hectare surviving) with various combinations of plantation age, average height, spacing, and trees per hectare planted as predictors.

5) And finally, equating the predicted stand level variables to their estimated parameters of the pdf and solving the resulting set of equations for the location, shapes and scale parameters.

Reynolds *et al.* (1988) used the site index as predictor variable, but in Malaysian forestry practices, this is not applicable. Therefore, the spacing measure-ment is used instead as predictor. In a separate study, Kamziah (1998) found that the Johnson $S_B$ distribution is the best distribution to fit diameter data of the *Acacia mangium* plantation in Sandakan, Sabah. The model to be developed uses the Johnson $S_B$ distribution where the $S_B$ parameters will be related to stand variables. This explains step (2) of the PPM. Kamziah *et al.* (1997) indicated that the nonlinear regression is the most powerful estimation technique to estimate the $S_B$ parameters which is the requirement of step (3). These estimated parameters would be related to stand variables for solving the location, shape and scale parameters in step (5).

Several types of equations have been developed in this study to predict stand variables with various combinations of the predictors. The following sets of equations were found to be most suitable for the data.

$$\text{Log}(H) = a_1 \log(S) + \frac{a_2}{A} + a_3$$

$$\text{Ln}(BA) = a_1 + a_2 \ln(H) + \frac{a_3}{A} + a_4 \log(S)$$

$$\text{Ln}(T_S) = a_1 + a_2 \ln(H) + \frac{a_3}{A} + a_4 \log(S) + a_5 (T_p) \log(A)$$

Once a plantation has been generated, the parameters of the assumed underlying Johnson $S_B$ distribution are determined from the following equations.

$$\ln(\hat{\lambda}) = a_1 + a_2 \log(T_s) + \frac{a_3}{A} + \frac{a_4}{S} + \frac{a_5}{BA} + \frac{a_6}{H}$$

$$\hat{\gamma} = a_1 + a_2 \log(T_s) + a_3 \ln(BA) + a_4 \log(H) + a_5 \ln(\lambda)$$

$$\hat{\delta} = a_1 + a_2 \log(T_s) + a_3 \ln(BA) + a_4 \frac{\ln(H)}{A} + a_5 \ln(\lambda) + a_6 \gamma$$

where

$$BA = \sum_{i=1}^{n} \frac{\pi (d_i)^2}{4(10000)} \Big/ \text{area}$$

$$T_p = \left( \frac{100 \times 100}{S^2} \right)$$

$$T_s = \frac{T_{pp}}{\text{area}}$$

and

$H$ = average height (m)

$S$ = spacing (m)

$A$ = age in years

$T_p$ = number of trees per hectare planted

$T_{pp}$ = number of trees per plot planted

$T_s$ = number of trees per hectare surviving

$BA$ = total basal area per hectare ($m^2$/ha)

$d_i$ = diameter at breast height (dbh) for tree i

$n$ = sample size

area = plot size

$a_1, a_2, a_3, a_4, a_5, a_6$ = estimated constants .

## APPLICATIONS

The *Acacia mangium* data gathered from Forest Research Centre, Sabah were used to develop parameter prediction models (PPM). Plots were selected to avoid survival problems and to possess the following characteristics:

1) at least 2 years of age.
2) planted following mechanical site preparation.
3) unthinned, unpruned, and unfertilized.
4) no evidence of excessive insect or disease damage.
5) no evidence of interplanting or excessive numbers of wildrugs.

Permanent plots were remeasured yearly according to the following attributes at each sample plot:

1) plantation age (from planting records)
2) plot dimensions
3) dbh to the nearest 0.25 cm
4) height to the nearest 0.3 m .

Four permanent plots were established for each square spacing (i.e. 2.0 m, 2.8 m, 3.0 m, 3.5 m and 4.0 m). Twenty-five trees were chosen from each plot when the first measurement was taken in 1990 (age 2 years). The summary of the spacing, planting density and plot size is given in Table 1.

**Table 1. Summary of spacing, planting density and permanent sample plot (psp) size for the *Acacia mangium* plantation in Segaliud Lokan Project, Sandakan, Sabah.**

| Plot no. | Spacing (m) | Planting Density Trees/ha | Psp size (ha) | No.of plots |
|---|---|---|---|---|
| A1, A2, A3, A4 | 2.0 x 2.0 | 2500 | 0.010 | 4 |
| B1, B2, B3, B4 | 2.8 x 2.8 | 1275 | 0.020 | 4 |
| C1, C2, C3, C4 | 3.0 x 3.0 | 1111 | 0.023 | 4 |
| D1, D2. D3, D4 | 3.5 x 3.5 | 816 | 0.031 | 4 |
| E1, E2, E3, E4 | 4.0 x 4.0 | 625 | 0.040 | 4 |

This data was used to estimate the parameters of the model discussed in Section 2.0.

## RESULTS AND DISCUSSION

The equation for predicting the stand characteristics along with the root mean square error (RMSE), coefficient of determination ($R^2$), and standard error (SE) of the model coefficients are shown in Table 2. The stand characteristics are then to be regressed on the parameter estimates to develope prediction equations for the scale and shape parameters. These equations along with the RMSE, $R^2$ and SE of the model coefficients are presented in Table 3.

From Table 2, the average height, basal area per hectare and number of trees per hectare surviving can be simulated from age, spacing and number of trees per hectare planted. The $R^2$ for the prediction equations of average height and basal area per hectare exceeds 0.9. The fitted equation for number of trees per hectare surviving yields $R^2$ close to 0.9. The RMSE and SE of the coefficients are reasonably small in all cases. These verify that the parameter prediction method is considerably the appropriate method to generate prediction equations of the stand characteristics.

Table 3 demonstrates the prediction equations for the scale and shape parameters obtained from the stand characteristics. The $R^2$ for the prediction equation of $\hat{\gamma}$ is rather high (0.822) while prediction equations of $\hat{\lambda}$ and $\hat{\delta}$ yield moderate $R^2$ (0.594 and 0.43, respectively). The RMSE and SE of the coefficients are large in many instances. Some factors that influenced the model developed are the relationship among parameters made it very difficult to develop prediction equations that would explain a high percentage of variation in parameters. The small sample size in each plot is also believed to be a contribution factor to the small percentage of variation.

**Table 2. Equations for predicting average height (H), basal area per hectare (BA) and number of trees per hectare surviving ($T_s$) along with the root mean square error (RMSE), coefficient of variation ($R^2$), and standard error (SE) of the model coefficients.**

$$\log(\hat{H}) = 1.401 + 0.1912 \log(S) - 1.5086/A$$

| | | | | | |
|---|---|---|---|---|---|
| SE ($a_1$) | = 0.025 | SE ($a_2$) | = 0.0476 | SE ($a_3$) | = 0.0394 |
| RMSE | = 0.0574 | $R^2$ | = 0.914 | | |

$$\text{Ln}(BA) = -3.102 + 2.367 \ln(H) + 2.211/A - 2.326 \log(S)$$

| | | | | | |
|---|---|---|---|---|---|
| SE ($a_1$) | = 0.45 | SE ($a_2$) | = 0.136 | SE ($a_3$) | = 0.495 |
| SE ($a_4$) | = 0.185 | RMSE | = 0.211 | $R^2$ | = 0.937 |

$$\text{Ln}(T_S) = 7.169 + 0.671 \ln(H) + 2.742/A - 5.387 \log(S) - 0.00034 (T_p) \log(A)$$

| | | | | | |
|---|---|---|---|---|---|
| SE ($a_1$) | = 0.535 | SE ($a_2$) | = 0.106 | SE ($a_3$) | = 0.481 |
| SE ($a_4$) | = 0.347 | SE ($a_4$) | = 0.0000834 | | |
| RMSE | = 0.1428 | $R^2$ | = 0.896 | | |

where

log = logarithm to the base 10

ln = logarithm to the base e

S = spacing (m)

A = age in years

$T_p$ = number of trees per hectare planted

$a_1, a_2, a_3, a_4, a_5$ = estimated constants

**Table 3. Equations for predicting the scale ($\hat{\lambda}$) and shape ($\hat{\gamma}$ and $\hat{\delta}$) parameters from stand characteristics along with the root mean square error (RMSE), coefficient of variation ($R^2$), and standard error (SE) of the model coefficient.**

$$\ln(\hat{\lambda}) = 7.135 - 1.307 \log(T_s) - 2.025/A + 2.037(S) + 0.329/BA - 2.79/H$$

| | | | | | |
|---|---|---|---|---|---|
| SE ($a_1$) | = 0.828 | SE ($a_2$) | = 0.382 | SE ($a_3$) | = 0.897 |
| SE ($a_4$) | = 0.802 | SE ($a_5$) | = 0.303 | SE ($a_6$) | = 2.52 |
| RMSE | = 0.3468 | $R^2$ | = 0.594 | | |

$$\hat{\gamma} = -16.16 + 3.347 \log(T_s) - 1.212 \ln(BA) - 1.02 \log(H) + 3.23 \ln(\hat{\lambda})$$

| | | | | | |
|---|---|---|---|---|---|
| SE ($a_1$) | = 2.14 | SE ($a_2$) | = 0.488 | SE ($a_3$) | = 0.287 |
| SE ($a_4$) | = 1.31 | SE ($a_5$) | = 0.13 | | |
| RMSE | = 0.5864 | $R^2$ | = 0.822 | | |

$$\hat{\delta} = 1.97 - 0.821 \log(T_s) + 0.362 \ln(BA) + 2.499 \ln(H)/A\ 0.157 \ln(\hat{\lambda}) + 0.3536\ \hat{\gamma}$$

| | | | | | |
|---|---|---|---|---|---|
| SE ($a_1$) | = 1.59 | SE ($a_2$) | = 0.376 | SE ($a_3$) | = 0.131 |
| SE ($a_4$) | = 0.429 | SE ($a_5$) | = 0.261 | SE ($a_6$) | = 0.0729 |
| RMSE | = 0.4977 | $R^2$ | = 0.43 | | |

where

log = logarithm of the base 10

ln = logarithm of the base e

S = spacing (m)

A = age in years

$T_p$ = number of trees per hectare planted

$T_s$ = number of trees per hectare surviving

H = average height (m)

BA = total basal area per hectare ($m^2$/ha)

$a_1, a_2, a_3, a_4, a_5, a_6$ = estimated constants

## CONCLUSION

Although the PPM yields very reliable prediction equations for the stands characteristics, the prediction equations of the scale and shape parameters results considerably small percentage of variation in parameters due to the fact that the parameter estimates are highly data specific. Further work is required to improve the predictive ability of the parameter prediction models.

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