APPLICATION OF FOREST GROWTH MODELS FOR GROWTH AND YIELD ESTIMATION OF *Tectona grandis* (Linn) STANDS IN NDOKWA WEST LOCAL GOVERNMENT OF DELTA STATE, NIGERIA

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ABSTRACT
This study was carried out to evaluate the performance of growth models on *Tectona grandis* stands in Ndokwa West Local Government Area of Delta State. The Paper described the application of growth models to *Tectona grandis* stands in Ndokwa West Local Government Area of Delta State. Individual growth data were randomly collected from four sample plots of trees. Volume was computed for each stem using Newtons' formular. The data collected were split into two sets in ratio 9:1. The majority of the data (90%) were used for model development while the remaining data (10%) were used for model validation and were fitted in the growth data collected. Model 8 (Patterson equation) and model 14 (Australian equation) for height and volume respectively gave the best results based on the comparison (R^2) and MSE. Yield tables were formulated with the selected models. The models selected were found suitable for growth and yield estimation as well as for the management of *Tectona grandis* in Ndokwa West Local Government Area of Delta State. The Petterson and Australian models were therefore recommended for growth yield estimation in Ndokwa West Local Government Area.

Keywords: Height, Volume, Diameter, Yield Table, Growth and Models.

INTRODUCTION

Individual tree height and diameter are essential forest inventory measurements for estimating timber volume and site index, and are also important variables in growth and yield modeling (Vanclay,2003). Forest resource managers require tree volume information to produce yield estimates for timber inventory and improve forest management decision making (Vanclay, 2003). It is appropriate to up-date inventory on current status, project into the future, determine the outcome to prevent limitation in the future and initiate plans and strategies to realize the objectives and goals of a discipline. Forest growth modeling is no exception; model must be verified to remain relevant (Vanclay, 2003). Lederman (2004) described the impact of individual tree growth model on a multitude of Silvicultural treatment methods and species composition, thus providing detailed information on stand structure development. A great number of growth functions have been developed and used by many people for various tree species in different regions of the world (Zhang and Borders, 2001). Mendoza and Vanclay (2008) also stated that to keep abreast with up-to-date and new development in forest growth modeling, different types of models have been developed and applied to address various issues in Forestry. Comas and Mateu (2007), Rennolls *et al.*, (2007), Scheller and Mlade off (2007) and sun *et al.*, (2007) agreed that models are built on a long tradition of calibrating models against growth observations in existing stands. As with other aspects of models, there is no single optimal approach; the preferred method will depend on the nature of the data available and the purpose to which the model will be used (Mendoza and Vanclay, 2008).

Nichols *et al.*, (2006) and Colak *et al.,* (2003) stated that increasing demands for forest management create new challenges for foresters / modelers to provide growth models with greater capabilities and competition in stands comprising many species and a wide range of tree sizes.

Application and Use of Growth Model in Forestry

Several types of growth models exist with varying degrees of complexity depending on their end use and application. Empirical forest growth models deal with the application of functions fitted to data without considering the physiological process involved in growth and Morphogenesis, and predicting yield and quality of products (Zhang *et al.,* 2008). Mendoza (2005) provides a more comprehensive review of recent empirical growth model. Landsberg *et al.*, (2003) stated that the 3 - PG (Physiological Principles to predict growth) has demonstrated the potential to provide forest growth estimation and has been applied to a wide range of forest species. Yield Tables for forest stands were induced in the 19th century, using stem, height and width data measured over long period of time (Zhang *et al.,* 2008). This study focused on using several growth models to predict growth in the forest using *Tectona grandis* as an example in order to predict the growth rate of teak in the future by formulation ofyield prediction table using best models.The expected output of the growth prediction is to give an insight of what is expected in future which would aid in the management of the plantation. *Tectona grandis* also known as Teak has unique economic importance in the world. The importance includes the use as transmission poles, general purpose and veneer

MATERIALS AND METHODS

Study Area

The study area is Ndokwa West Local Government of Delta State. It is bounded to the North by Aniocha South and Ika South Local Government to the South by Isoko North Local Government Area and to the West by Ethiope East Local Government Area. It lies within Latitude 5° 25' and longittude 6°42' East of the Greenwich Meridian. A stratified random sampling technique was used for collection of tree data. The tree samples differ in terms of age constituting the strata. The strata were between aged 20 and 29. Samples plot 20x20m (0.04ha) were randomly selected from each stratum. Complete enumerations of all trees in the sample plot for all trees were measured. Diameter at breast height (DBH) outside bark at 1.3m above ground and diameter at the base were measured with the aid Diameter girth- tape, total height, merchantable height, diameter at the middle and diameter at the top were all measured with the aid of Spiegel relaskop at a distance of 15m away from the tree and this was used to compute volume. Tree height and diameter data collected were divided into two sets. Ninety percent (90%) of the data were used for model development while the remaining 10 percent were systematically selected across the range of diameter for each species and reserved for model validation.

Models tried

The following growth models were tried in the course of this study.

Models for height

$h = bh + \alpha d/(\beta + d)$	..	equation 1 Bates and Watts (1980), Huang et al., (1992
$h = bh + d^2/(\alpha + \beta d)^2$	..	equation 2 Huang et al., (1992)
$h = bh + \alpha\ (1 + 1/d)^{(-\beta)}$	..	equation 3 Cutis (1967); Huang et al (1992)
$h = bh + \exp\ (\alpha + \beta/d)$	..	equation 4 Schumacher 1939; Arabatzis and Burkhart, 1992
$h = bh + [1n\ (1 + d)]^{\beta}$	..	equation 5 Modified from an equation in Cutis 1967
$h = bh + \alpha\ d^{\beta}$	..	equation 6 Arabatzis and Burkart 1992
$h = bh + (\alpha + \beta/d)^{-8}$	..	equation 7 Modified from Huang et al., 1992
$h = bh + (\alpha + \beta/d)^{-5}$	..	equation 8 Petterson equation (Modification from Schmidt 1967)
$h = bh + \alpha\ [1 - \exp\ (\beta d)]$		equation 9 (Richard's equation) Richards, 1959, Huang et al., 1992; Garman et al, 1995

Where:
H = height of trees in Meters; bh = breast height (1.3m above ground); d = diameter at breast height in Centimeter; αβ = parameters in the equation.

Models for volume

$In\ (V) = a_1 + a_2{*}d$	.. ..	equation 10
$In\ (V) = a_1 + a_2{*}In\ (d)$	....	equation 11
$V = a_1 + a_2 * In\ (d)$	....	equation 12
$V = a_1 + a_2 * d + a_3 * d_2$	.. ..	equation 13
$V = a_1 + a_2 * d_2 + a_3 * h + a_4{*}\ d^2 * h$	..	equation 14 (Australian equation)

Where:
V = Volume; d = Diameter at breast height; a_1, a_2, a_3 and a_4 = Parameters in the equation; h = height

Data Analysis

The fourteen height volume equations (Table 1 and 2) were fitted to data for each stand measurement to select the best models. Data were fitted using linear and nonlinear regression procedure. Models with lowest Mean Square Error (MSE) and highest coefficient of determination (R^2) suggest a best fit. Although the individual MSE and R^2 for each equation vary from stand to stand, a good equation should fit well on average. The average of the mean square errors is used as a measure of overall performance of an equation. The MSE for all equations were compared in the study to select the best equation.

The stem volume was estimated by the use of Newton's formular as used by Husch *et al.,* (1982) and the equation is given as:

$$V = h/6\ (A_b + 4\ Am + A_t)$$

Where:
V = Stem volume (m^3); h = Merchantable height; Ab = Cross sectional Area at the base of tree; Am = Cross sectional area at the middle tree; At = Cross sectional area at the top of tree

RESULTS AND DISCUSSION

Table 1 showed the results of the height models fitted into the data. The height growth estimate had R^2 values which ranged from 0.7332 to 0.9974 with MSE which ranged from 0.5086 to 0.5376.Patterson equation with exponent - 5 (Equation 8) gave the lowest MSE and highest R^2 values respectively. Equation 8 worked best which has an asymptote of 5, the fit was only slightly better than model 9. This agreed with the findings of Wollons (2003) and Zhao *et al*., (2006) that patterson equation gave the best result when they modeled height —Diameter relationships of *Pinus radiate* plantations. The result showed that patterson equation for height was found suitable and could be used to predict height for the management of Teak (Zhao *et al.*, 2006). These ranges indicated that *Tectona grandis* trees in Ndokwa west were doing well.

Table 2 showed the results of volume models fitted into the growth data collected. The volume growth estimate had R^2 values which ranged from 0.8522 to 0.9974 with MSE which ranged from 0.7027 to 0.9231.The Australian equation gave the best fit because it had the height R^2 and lowest MSE values respectively, which were 0.9974 and 0.7027. This fit agreed with that of Brack and Wood, (1996). These ranges indicated that *Tectona grandis* trees in Ndokwa west were doing well. Table 3 showed the yield prediction formulated using the best growth models for height while Table 4 showed the yield prediction for the next 100 years for the volume using the best fitted models. The results showed that as age of the trees increased, the volume also increased.

The yield table will help the forest manager to predict into the future, the future benefits (yield) forecasted from the yield table will motivate the manager into drawing management plans which will help achieve the yield forecasted by the yield table. The result from the yield table will also encourage individuals into establishing teak plantations because of the profit involved in the nearest future.

CONCLUSION

Forest growth models are very useful in forestry for both management and decision making. This study identified the best models for height and volume for plantations in Ndokwa West Local Government Area of Delta State. The Petterson and Australian equation for height and volumes respectively gave the best fit because they had the highest R^2 and lowest MSE values. These models were $h = bh + (\alpha + \beta/d)^{-5}$ and $V = a_1 + a_2 * d^2 + a_3 * h + a_4 * d^2 * h$.These models could be used to forecast forest yield in Ndokwa Local Area of Delta State. The yield forecasted helped the forest manager know what was expected in the future. This would help him draw management plans as well as silvicultural sound management decisions on how the predicted yield could be achieved.

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Table 1: Height models tried on *Tectonagrandis* stands

Models	R^2	MSE	a	B
$h = bh + \alpha d/(\beta + d)$	0.5376	0.7332	-6605.35	156.5841
$h = bh + d^2/(\alpha + \beta d)^2$	0.5532	0.7480	13.9421	13.7734
$h = bh + \alpha (1 + 1/d)^{(-\beta)}$	0.5443	0.7582	16.8332	18.4254
$h = bh + \exp (\alpha + \beta/d)$	0.7548	0.5243	18.9436	20.3648
$h = bh + [1n (1 + d)]^{\beta}$	0.5638	0.6874	18.4938	15.3442
$h = bh + \alpha d^{\beta}$	0.5432	1.2936	25.4836	18.3642
$h = bh + (\alpha + \beta/d)^{-8}$	0.7046	0.5468	18.4953	16.2456
$h = bh + (\alpha + \beta/d)^{-5}$	0.8846	0.5086	15.3248	12.6432
$h = bh + \alpha [1 – \exp (\beta d)]$	0.7648	5.5142	15.1248	17.4268

Table 2: Results of Volume growth models tried in this study

Model	R^2	MSE	ai	a_2	a_3
$In (V) = a_1 + a_2*d$	0.8733	0.9345	4.5118	0.3339	
$In (V) = a_1 + a_2*In (d)$	0.8808	0.9384	-0.7613	1.7620	
$V = a_1 + a_2 * In (d)$	0.8522	0.9231	-3641.80	1083.689	
$V = a_1 + a_2 * d + a_3 * d_2$	0.9221	0.9607	66.1975	-2.7155	0.8159
$V = a_1 + a_2 * d_2 + a_3 * h + a_4* d^2 * h$	0.9974	0.7027	-135.194	0.0524	30.2446

Table 3: Yield prediction tor three heights using best model

Diameter at breast height (cm)	Height (M)
10	8.45
20	9.43
30	10.02
40	10.98
50	11.32
60	1186
70	11.98
80	12.20
90	12.45
100	12.85

Table 4: Yield Prediction for tree volume using Best Model

Age (years)	Volume (cm^3)
10	220.07
20	230.25
30	250.45
40	265.25
50	280.45
60	290.85
70	310.10
80	320.45
90	330.25
100	340.85