GROWTH AND YIELD PREDICTION MODELS FOR TEAK (*Tectona grandis*) IN IYIOCHA STREAM FOREST RESERVE, DELTA STATE, NIGERIA.

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ABSTRACT
Forest models have been successfully used as research and management tools. The development of effective and accurate models to predict forest growth is essential for forest managers and planners. This study was carried out to develop growth and yield prediction models for the management of *Tectona grandis* in Iyiocha Forest reserve, Delta State. Twenty five (25) temporary sample plots of 20 x 20m were laid in the plantations with age series of 28 and 33years. Complete enumeration and measurement of all trees were carried out in each selected sample plot. The growth data collected include diameter at breast height (cm), total and merchantable height (m), diameter at the base, middle and top (cm) which were used for Volume computation. Six height models, five volume models, three basal area models and three diameter models were fitted in to data collected from the plantations. The data collected were split into two sets in the ratio of 9:l. The majority of the data (90%) were used for model development while the remaining data (10%) were used for model validation. Model 11 for height, Model 3 for volume, model 14 for diameter at breast height and model 17 for basal gave the best fit based on the comparison of their statistical criteria (lowest standard error (SE) and highest coefficient of determination (R^2)). The models with the best fit were found suitable for growth and yield estimation and very adequate for the sustainable management of this speciesin Iyiocha Forest reserve.

Keywords: Height, Volume, Growth, Yield and Models

INTRODUCTION

Foresters have been using various kinds of growth modelsfor at least two hundred years. Vanclay (1994) defined stand growth models as abstractions of the natural dynamics of a forest stand, which encompasses growth, mortality and other changes in stand composition and structure. Therefore, Forest models can be used as very successful research and management tools. The models designed for research require many complicated and not readily available data, whereas the models designed for management use are simpler and depend on more readily accessible data (Johnsen*et al.,* 2001)

Growth can be generally defined as the increase in dimensions of an organism or its fraction (forest stand or individual tree) over time, whereas increment is regarded as the rate of change within a specific period of time (Weiskittel*et al.,* 2011).The sustainable management of forest has become an issue in the past decade, out of concerns of both overexploiting the resource (Robert, 2003), and climate change effects to mankind (Schwalm and Ek, 2001). Sustainable Forest management is difficult to define as reported by Amaranthus, (1997) and, when defined, is hard to measure.

Global Environmental Facility (GEF), (2013), noted that there is no universally agreed- definition for Sustainable Forest Management (SFM). The development of effective and accurate models to predict forest growth and products is essential for forest managers and planners. Growth and yield models, which rely on functions of measurement data from a sample of the forest population of interest, are the tools that have mainly been used to provide decision-support information that meets basic operational needs for evaluating various forest management scenarios (Mohren*et al.,* 1994). Forest is a dynamic biological system that is continuously changing and it is necessary to project these changes to obtain relevant information for prudent decision making. Forestry as a sector depends on other sectors of the economy for factors of production such as capital, land, and labour therefore, if the forestry sector is to continue to enjoy the allocation of these resources, adequate and correct information about the forest is necessary not only to aid management decision but also to show the productive capabilities of the forest.

Reliable inference requires an appropriate user interface, so that users can be confident about using a model correctly, understand the data requirements and the results produced. It also requires that models generate predictions in a convenient form, amenable to further processing or for reporting and presentation. Thus, the utility of a model cannot be gauged without an understanding of who uses the model, what they use it for, and what other systems are involved. Perhaps the most compelling reason for formally constructing a growth model and building a yield prediction system is that it provides an explicit account of the many items and exclusions involved in a yield prediction. Modelsare used by the forest managers and they advise the illiterate forest owners on the application depending on their objectives.

A number of height-diameter models have been developed using only Dbh as a predictor variable for estimating total or merchantable tree height (Quammen, 2012). However, the relationship between the diameter and its height varies among stands (Taylor, 2012) and depends on the growing environment and stand conditions (Taylor, 2012).

Moreover, forestry models play a crucial role in forest management decision making.

Teak's good dimensional stability and aesthetic qualities make it a very profitable option for both public and private forestry schemes (Leverett, 2013).Need for specific information by forest managers and planners are one of the reasons for the increase of the demand for forest models. (Almeida *et al*., 2003). Teak (*Tectona grandis*) is particularly valued for its durability and water resistance, and is used for boat building, exterior construction, veneer, furniture, carving, turnings, and other small wood projects (USDA, 2007). However, this work developed growth and yield prediction models for the management of *Tectona grandis* in Iyiocha Forest Reserve

MATERIALS AND METHODS

The study area is the Iyiocha Stream Forest Reserve in Delta state, Nigeria.

The reserve has a geographic coordinates that lies between latitude $6^o15'$ and $6^o38'$North and longitude $6^o29'$ and $6^o44'$East. The forest reserve was gazetted in 1969 by the then Military Governor of the Mid-Western State of Nigeria under Sub-section (1) of Section 12 of the Forestry Law. It is situated on the right bank of the Iyiwosu Stream at a distance of 1,338feet measured down-stream along the right bank of the Iyiwosu Stream from the point where the right bank of the Iyiwosu Stream is joined by the right bank of the Iyolu Stream. The total area of the forest reserve is 875.416ha (8.754km^2), out of which 167.416ha is a natural forest and 708ha is a plantation of teak (*Tectonagrandis*) and Gmelina (*Gmelina* arborea). The communities within and around the reserve which include: Akwukwu, Ugbolu, Illah, Ani-Okonkwo, Ngegu, Ngene and Aniwalo .

Vegetation and Land Use

The natural vegetation of the area is lowland rainforest with patches of swamp vegetation. The forest consists of three strata of trees. The first and top stratum consist of trees of about a hundred and twenty feet or more high, and is made up of widespread and often isolated crowns while the second or middle stratum is made up of trees of fifty to a hundred and twenty feet high. Trees in this stratum often have smaller crowns. Those in the third stratum or understory consists of trees of about fifty feet high, and forms a rather dense canopy which protect the ground from the direct rays of the sun.

The forest reserve has different land uses which include the natural forest, plantation which comprise of teak (*Tectonagrandis*), Gmelina (*Gmelinaarborea*) and *taungya* farms.

The entire population was first of all divided into strata. Each stratumwas divided into sampling units (plots). The sample trees within each sample plot were then measured. The following variablesweremeasured in each of the stands; Diameter at breast height over bark (cm); this was measured at a standard position of 1.3m above the ground using a Diameter girth tape, Total height (m); this was measured with the aid of a Spiegelrelaskop and a 50m distancetape. Diameter over bark at the base (cm); this was measured with the aid of a Diameter girth tape.Diameter over bark at the top and middle (cm); this was measured with the aid of a Spiegel relaskop. Merchantable height (m); this was measured with the aid of a Spiegel relaskopand 50m distance tape.

The *Tectonagrandis* plantation at Iyiocha stream forest reserve was divided into 5 strata based on age criterion (1984,1985, 1987, 1988, and 1989). The size of the sample plots used was 20m×20m (0.04ha).

Data Analysis

The data collected were subjected to regression analysis in order to select the best models with the highest R^2 values and lowest standard error values. Models were developed for height, volume, height, diameter at breast height and basal area. The basal area of each tree was estimated using the formula below:

$BA= \pi D^2/4$………………..equation 1

Where, BA= Basal Area (m) ^{2}

D =Diameter at breast height (cm)

$\pi= 3.14159$

The stem volume estimation of each tree in each plot were estimated using the Newton's formula as presented by Hustch*et al*, (1982)

V= h/b (Ab+4Am+At)…………equation 2

Where V=Stem volume (m) ^{3}, h = Merchantable height (m), Ab Am and At are cross sectional area at the base, middle and top of the tree respectively

The following models were tested in the course of this study.

Models for Volume

$InV = b_1+ b_3 * d$……………..equation 3

$V = b_1+ b_3 * In (d)$…………equation 4

$V = b_1 + b_3 * d$……………….equation 5

$V = b_1 + b_2 * d^2 * h$…………..equation 6

$V = b_1+ b_2 * d + b_3 * d^2 * h$…… equation 7

Where, V = volume

h = height of trees in meters

d = diameter at breast height

b_1, b_2, b_3 = parameters in the equation.

Models for Height tested in this study

$H= 1.3 + D^2/h (b_0+b_1)^2$…………equation 8

$H= 4.5 + h (1–e–b_0D)$…………..equation 9

$H= b_0+ b_1 \log D$……………….equation 10

$\log H =b_0 +b_1 (\log D)$……….equation 11

$H= 1.3 +b_1D –b_2D^2$…………..equation 12

$H=1–1.3= b_0+b_1 /D$…………equation 13

Where H= height (m)

D= diameter at breast height

e = base of natural logarithm

b_0, b_1, and b_2 = parameters to be estimated.

Diameter At Breast Height Models tested in this study

$D=b_1+b_2H$……………………equation14

$D=b_1+b_2LnH$…………………equation 15

$D=b_1+b_2H+b_3H^2$………………..equation 16

Where

D= Diameter at breast height in cm

H= Height in meters

Basal Area Models tested

$In\ B = b_0 + b_1 (1/A) + b_2 In (H_1) + b_3 In (N) + b_4 (H_{1/A}) + b_5 (N/A)$……………equation 17

$In\ B = In (b_0) + b_1 (1/A) + b_2 (In H_1) + b_3 (In N) + b_4 (H_{1/A})$………..equation 18

$In\ B = b_0 + b_1 (In H_{1/A}) + b_2 In (N)$……equation 19

Where,

B = basal area

A = ages of the different sampling unit constituting the strata

H = height of trees in meters

N = number of trees per hectare (tree/ha)

$b_0, b_1, b_2, b_3, b_4, b_5$ = parameters in the equation

Models used in this study were evaluated in order to select best models based on the highest value of coefficient of determination and lowest standard error.

RESULTS AND DISCUSSION

The tables below show models of best fit based on comparison of lowest standard error(SE) and highest coefficient of determination(R^2)

Table 1: Coefficient of determination and standard error values of height models

MODELS	SE	R^2	bo	b 1	b 2
$H=1.3+D^2/h(b_0+b_1)^2$	2.81	0.56	2.74	6.70	
$H=4.5+h(1-e-b_0D)$	2.77	0.57	2.85		
$H=b_0+b_1 \log D$	2.72	0.62	2.79	6.33	
$\text{Log } H=b_0+b_1(\log D)$	2.60	0.85	2.75	1.95	
$H=1.3+b_1D+b_2D^2$	2.79	0.61		1.07	2.78
$H-1.3=b_0+b_1/D$	2.81	0.60	2.74	2.89	

Six height models where fitted into the growth data. The standard error values ranged from 2.60 to2.81 and R^2 ranged from 0.57 to 0.85. The quality of the model was judged by the highest R^2 value and the smallest standard error. Based on these criteria equation 11 gave the highest R^2 value of 0.85and lowest standard error of 2.60.

Five volume models where fitted into the data to select the model with the best fit. R^2 ranged from 0.64 – 0.89 and standard error ranged from 1.36 to 2.83.The quality of the model was judged by the highest R^2 value and the lowest standard error value. Based on these criteria, equation 3gave the highest R^2 value of 0.89 and lowest standard error of 1.36. The results of the volume models are presented in table 2.

Table 2: Coefficient of determination and standard error of volume models

MODELS	SE	R^2	b_0	b_1	b_2
$InV=b_0+b_1*d$	1.36	0.89	1.07	6.66	
$V=b_0+b_1*In(d)$	2.36	0.69	1.07	4.20	
$V=b_0+b_1*d^2*h$	2.83	0.64	1.07	6.66	
$V=b_0+b_1*lnd^2*h$	2.29	0.86	-1.44	7.41	
$V=b_0+b_1*d+b_2*d^2h$	2.81	0.79	3.08	-8.85	4.49

Results of diameter growth mode

Table 3indicated the Coefficient of determination and standard error of diameter at breast height models with their assessment criteria. Three diameter at breast height models where fitted into the data to get the model of best fit. The standard error ranged from 2.72 - 2.81 and R^2values ranged from 0.61-0.86. Based on these criteria equation 14gave the highest R^2 value and lowest standard error value.

Table 3: coefficient of determination and standard error values for diameter growth models

MODELS	SE	R^2	b_0	b_1	b_2
$D=b_0+b_1H$	2.72	0.86	2.74	2.89	
$D=b_0+b_1LnHT$	2.81	0.61	2.79	1.84	
$D=b_0+b_1H+b_2H^2$	2.81	0.68	2.74	6.70	1.69

Three basal area models were fitted into the data to select the model of best fit. From the data, equation 17 gave the highest R^2 value of 0.86 and leastSE value of 2.81. The R^2 value ranged from 0.75 - 0.86and SE value ranged from 2.81- 3.54. This is shown in the table 4.

Table 4: Coefficient of determination and standard error of basal area models

MODELS	R^2	SE	b_0	b_1	b_2	b_3	b4	b5
$\ln B=b_0+b_1(1/A)+b_2\ln(H_1)+b_3\ln(N)+b_4(H_{1/A})+b_5(N/A)$	0.86	2.81	2.54	3.47	2.35	1.53	3.02	3.02
$\ln B=\ln(b_0)+b_1(1/A)+b_2(\ln H_1)+b_3(\ln N)+b_4(H_{1/A})$	0.78	3.54	4.44	2.95	3.84	4.03	1.84	
$\ln B=b_0+b_1(\ln H_{1/A})+b_2\ln(N)$	0.75	3.82	1.30	3.45	2.40			

DISCUSSION

Six height models, five volume models, three basal area models and three diameter at breast height models were fitted into the data for analysis in order to select the models of best fit. The standard error and the coefficient of determination denoted as SE and R^2 values respectively were used as measure of fit. The lowest SE and highest R^2 value gave the best fit.

Of the six height models, equation 11 gave the best fit having the lowest SE value and 'highest R^2 value. This finding corresponds with that of Pretzsch (2009) who worked on growth and yield; from measurement model in Berlin and Heidelberg where he suggested that a nonlinear regression can conveniently be used to estimate the growth of a forest stand to predict the future growth and yield in forest management.

For this work, the coefficient of determination (R^2) value is 0.85 and when this is expressed in percentage, it shows that 0.85% of the total amount of error has been explained by fitting the regression line and this indicates that the fit of the regression line to the points are good.

Of thefive volume models, equation 4 gave the best fit having the least SE and highest R^2 values. This finding agrees with Shamaki*et al* (2016) who suggested that allometric models be used to estimate stem volume for individual trees in a tropical humid forest comprising of different species. The coefficients of determination (R^2) value for volume are 0.64 and 0.89 which when expressed in percentage means 0.64% to0.89% of the total amount of error has been explained by fitting the regression line and this indicates that the fit of the regression line to the points is good.

For the diameter at breast height models, three equations were fitted to select the best model. Of the three equations, equation 15 gave the best fit having the least SE and R^2 values respectively. Similar findings were observed by Nurudeen,(2011) who made use of the model for predicting the diameter at breast height in his study.

Of the basal area models, equation 19 gave the best fit having the least SE values and R^2 values respectively. And this agrees with the findings of (Leverett, 2013) in management, utilization of plantation and natural stands. The coefficient of determination R^2 value for basal area are 0.75 to 0.86 which when expressed in percentage is 75% and 86% of the total amount of error has been explained by fitting the regression line and this indicates that the fit of the regression line to the point is good.

CONCLUSION

. This work has been able to identify the models of best fit for height,volume, diameter at breast height and basal area respectively that can be applied to the Forest Reserveat IyiochaStreamin order to effectively describe the growth rate and the volume of the timber that can be harvested without violating the sustainability of the Forest Reserve. In other words, models used in the study area for height with R^2 value of 0.85 and SE of 2.60; Volume model with 0.89 and 1.36; Diameter model with 0,86 and 2.72 and Basal Area with 0.86 and 2.81 respectively can guide the forest manager to make good decision on the harvesting schedule and predict into the future the expected height, diameter at breast height, volume and basal area such that sustainability is maintained in the forest.

REFERENCES

Amaranthus, M.R (1997): Forest sustainability: *An approach to definition and assessment.*Gen. Tech. Rep. PNW-GTR-416. Portland OR: USDA Forest Service, Pacific Northwest Research Station. 14-21.

Global Environmental Facility (2013): (www.gef.com/.April, 2015

Husch, B., Charles, I.M and Thomas, W.B. (1982). Forest Measuration. Third Edition- John Wiley and Sons New York 336-342.

Husch, B., T.W. Beers and J.A. Kershaw Jr., (2003): ForestMensuration. 4th Edn. John Wiley and Sons, Inc., New Jersey, USA,840- 949.

Johnsen, K, Samuelson L, Teskey R, McNulty S, Fox T (2001). Process models as tools in forestry and management. *Forest Science* 47: 2-8.

Leverett, Robert T. 2013. Limb Length Using Monocular w/reticle and Rangefinder.March29,2013. http://www.entsbbs.org/viewtopic.php?f=235&t=5216 Accessed March 29, 2013.

Mohren, G.M, Burkhart H.E, Jansen J.J (1994). Contrasts between biologically-based process models and management oriented growth and yield models. *Forest Ecological Management*69: 1-5.

Nurudeen T.A (2011): Nonlinear regression models for volume estimation in *Gmelinaarborea*(Roxb) stands atOluwa forest reserve South western Nigeria. M.sc Thesissubmitted to the Department of Forest ResourceManagement, University of Ibadan, Nigeria 78-102.

Pretzsch H. (2009) Forest dynamic, growth and yields: from measurement to model. Springer Berlin and Heidelberg, Germany; 2009.664.

Quammen,, D.(2012). Scaling a Forest Giant. National Geographic Magazine, Vol. 222, No. 6, December 2012, 28-41.

Robert, A.M. (2003): Evaluating Forest Models in a Sustainable Forest Management Context; FBMIS Volume1; 35-47.

Schwalm, C. and Ek A. R. (2001): Climate change and site: relevant mechanisms and modeling techniques. *Forest Ecology and Management* 150: 241-257.

.

Taylor, Michael. January 11, (2012). Re: 3D surface modeling of a giant redwood trunk. eNTS: The Magazine of the Native Tree Society, Volume 2, Number 01, January 2012, p. 57-59. Native tree society .org/magazine/2012/NTS_January2012.pdf Accessed March 4, 2013.

Vanclay, J.K. (1994). Realizing Opportunities in Forest Growth Modelling.*Canadian Journal of Forestry Research*. 33(3): 536-541

Weiskittel, A.R, Hann D.W, Kershaw Jr J.A, Vanclay J.K (2011). *Forest growth and yield modeling*. John Wiley and Sons, Ltd., Markono Print Media Ltd, Singapore, 415-540