DEVELOPMENT OF VOLUME MODELS FOR TECTONAGRANDIS (LINN F.) STANDS IN OGWASHI-UKWU FOREST RESERVE, DELTA STATE, NIGERIA.

[1]Aigbe H. I[*]. and [2]Ogu C. I.
[1]Department of Forestry and Wildlife Technology, School of Agriculture and Agricultural Technology,Federal University of Technology, Owerri
[2]Department of Forestry and Environment, Faculty of Agriculture, River State University, River State
E mail: igaigbe@yahoo.com

Abstract
This study is based on the relationship between tree volumes (V), diameter at breast height (Dbh) and stump diameter (Dst). Empirical equations were developed for estimating tree volumes of *Tectona grandis* from dbh and Dst The purpose is to develop a volume model for *Tectona grandis* stands in Ogwashi - Ukwu Forest Reserve and to adopt it for sustainable forest management. Systemic sampling technique (systemic line transect) was employed for laying of plots. Two transects with a distance of 500 m between them were laid and sample plots of size, 20m x 20m (0.04 ha) were laid in alternate direction along each transect at 250 m interval and thus summing up to 4 sample plots per transect and a total of 8 sample plots. A series of regression equations were all fitted to the data generated and analyzed using Microsoft Excel and SPSSsoftware computer package. The regression equations were fitted for choosing the best model. The following equations were adjudged the best out of the several regression equations fitted. The equations were $V = 0.02 + 7.36\, x\, 10^{-5} Dbh^2 H_T$;$lnV = -11.10 + 0.00 D_{st}{}^2 + 1.70\, x\, 10^{-5} D_{st}{}^2 H_T + 1.082 lnD_{st} H_T$;$V = 0.006 + 7.4\, x\, 10^{-5} Dbh^2 H_m$ and $V = -0.63 + 6.36\, x\, 10^{-5} Dst^2 H_m$. This indicates the significant status of the model for predictive purpose. Residual analysis showed conformity with the assumption of independence of errors in regression analysis and that error is normally distributed. The result of data validation between predicted and observed values using paired t-test showed no significant difference (P>0.05). The study showed thatstump diameter is appropriate for tree volume estimation, especially when Dbh is unavailable and that linear regression equations may not be appropriate in fitting individual tree volume equations for the forestreserve under investigation, which made data transformation necessary and needed.

Keywords: *Tectona grandis*, tree volume, stump diameter, diameter at breast height, modelling, Ogwashi - Ukwu.

Introduction

Tectona grandis (Teak) is a genus of tropical hardwood trees in the family Vabenaceae, native of the South and South-East Asia, and commonly found as a component of monsoon forest vegetation (Robertson, 2002). They are large trees growing up to 30-40 m tall which is deciduous in the dry season (Robertson, 2002). Teak is one of the most valuable timbers in the world on account of its outstanding properties. The sapwood is white to pale yellow-brown narrow to moderately wide. The hard wood is dark golden brown, sometimes with darker markings (Hart, 1973).
The tropical ecosystem is the most diverse of all terrestrial ecosystems, containing more plants and animal species than any other biome (Turner, 2001).The need to sustainably manage this rich ecosystem is imperative.However, Ogwashi – Ukwu Forest Reserve have not been sustainably managed due to inadequate management tools. With the rate Nigeria forest is being depleted at alarming rate and the poor management techniques put in place, there is need to adopt sound management programme to revive the dwindling forest resources. Global forest resources assessment revealed that Nigeria is one of the five countries in the world with the highest annual rate of deforestation for the period 2000 – 2010 (FRA, 2010). Between 1990 and 2000, Nigeria lost about 2.7% of its forests to deforestation which increased to about 18.56% (about 2.06 million ha) between 2000 and 2010 (FRA, 2010; FAO, 2011). Lack of modelling tools for sustainable and adequate estimates of growing stocks within the forest plantation is also a challenge. Such information guides forest managers in timber valuation and proper management prescriptions (Akinsanmi, 1999). According to Avery and Burkhart (2002), volume equations are used to estimate average content of standing tree of various sizes and species. Where unapproved logging operation exists, the plantationsupervisor is still interested in knowing the volume of trees illegally removed and even when trees are legally removed, the stump can still serves as reference were diameter at breast height (Dbh) and tree height measurement cannot be made(Aigbe *et al.*,2012). Thus, volume equation that has diameter at breast height (Dbh) as predictor variable only cannot be used directly (Aigbe *et al.*, 2012).

Therefore, this study was conducted to developed tree volume equations for *Tectona grandis* stands in Ogwashi – Ukwu Forest Reserve, Delta State, Nigeria from diameter at breast height and stump diameter.

Materials and Method

This study was conducted in Ogwashi-Ukwu Forest Reserve in Aniocha South Local Government Area of Delta State, Nigeria. The geographic limits are set by latitude 6°00º - 6º 25ºN and longitude 6º 5º- 6º 25º E. It occupies a total area of 258 ha, with less than 27 ha (10.5%) occupied by natural lowland rainforest while the deforested areas have been regenerated with exotic tree species (FORMECU, 2000). The rainfall pattern is bimodal, with peak periods in July and September, and an annual average between 1600 – 2000mm. The average rainfall is about 266.5mm in the coastal areas and 1905mm in the extreme north. Mean annual temperatures are between 25 – 29°C and a relative humidity of 75% (Metrological Service Station, 2013). The terrain is rough and elevation rises from the river valleys up to 1000m above sea level in mountainous area (Bush, 2003). The entire region built up by the sedimentation of the Niger Delta and consists of the delta in various stages of development. Geology of study area is overlaid by various degrees of granites, genesis, shits and isolated deposition of amphibolite (Perekeme, 2000).

Methods of Data Collection
Sampling Technique

Systemic sampling technique (systemic line transect) was employed for laying of plots. Two transects with a distance of 500 m between them were laid at the centre of *Tectona grandis* stands. Sample plots of size, 20m x 20m (0.04 ha) were laid in alternate direction along each transect at 250 m interval and thus summing up to 4 sample plots per transect and a total of 8 sample plots. In each plot, the outside bark stump diameter (Dst) of the tree were measured at 5cm above ground (since all timber exploitation done in the plantation shows that trees were cut at this point), Diameter at breast height (Dbh) (taken at 1.3m from ground), merchantable tree height (taken at point between ground level and point of the first surviving whorl of branch), total tree height, outside bark diameter at base, middle and top position were all measured. Individual tree volume were calculated using the Newton's formula (Husch,*et al*, 1982).

Data Analysis
Preliminary Data Analysis

The preliminary analysis of the plantation data enabled computation of individual tree volume and per-hectare estimates of stand variables from the raw data. The procedure used at this stage is the mean tree method used by Abayomi (1984) and Akindele (1989, 1992). The calculation also included the range of value (minimum and maximum). The procedures include the following steps:

(1) Estimation of minimum, maximum and mean basal areas per hectare from dbh using the formula:

BA $= \pi D^2/4$………… equation 1

Where:

BA	=	basal area (m^2)
π	=	3.142 (a constant)
D	=	Dbh (m)

(2) Calculation of tree volume for each of the trees in each plot, using Newton's formula (Husch *et al*. 1982).

$V = {}^{h}\!/_{6}\left(A_b + 4A_m + A_t\right)$........ equation (2)

Where:

V = tree volume (m^3)
h = tree height (m)
A_b = Cross –sectional area at the base (m^2)
A_t = Cross –sectional area at the top (m^2)
A_m = Cross –sectional area at the middle (m^2)

(3) Estimation of stand variables on a per-hectare basis

The variables estimated on per-hectare basis were basal area and volume. Total parameters per plot were obtained by adding the parameters of all individual trees within the plot. Mean plot parameters were then computed by summing the total parameters of all the sample plots and dividing by the number of sample plots selected in the stands. Parameters per hectare were obtained by multiplying the mean plot parameters by the number of sample plots per hectare.

Model Development

The preliminary data results were the basis for the statistical data analysis investigation of the relationships between the variables which were analyzed using Microsoft Excel and SPSS software computer package. A series of regression equations were fitted to the data. The equations were assessed and compared on the basis of coefficient of determination, variance ratio and overall standard error estimated. Some of the regression equations tried were:

$V = b_1D$……………… equation 3
$V = a + b_1 D$…….. … equation 4
$V = aD + b_1D^2$………... equation 5
$V = a + b_1D + b_2D^2$……. equation 6
$V = a + b_1D^2$…………... equation 7
$\text{In } V = a+b_1\text{In}D$……... equation 8

Where a is regression constant and b_1 and b_2 are regression coefficients
V = Volume of tree in m^3
D = stump diameter/Dbh in m
The relationships between variables were analyzed using correlation and graphs.

Model Validation

The validation data (i.e. the one tenth of the data observed value) set aside for model validation and not use for model calibration were used for this purpose. The validation was done by testing for significant difference between the predicted value and the actual (observed) value using paired t- test. If there is no significant difference ($P < 0.005$) between the observed and predicated values, then it means the model is acceptable. (Aigbe *et al*, 2013).

Results and Discussion

TREE GROWTH ATTRIBUTE

A total of 177individual trees were measured in eight temporary sample plots from the*Tectona grandis*stands.The results as shown in Table 1 indicated that the mean Dbh and stump diameter were 34.38 cm and 40.00 cm respectively, while the mean total tree and merchantable height were 5.09 m and 12.42 m respectively.*Tectona grandis* shows variation in growth attribute contrary to expectation as shown in Table 1. The variation could be due to lack of maintenance of the plantation since the time of establishment.Large gaps exist between some trees, suggesting that there was no beating up at the early stage of plantation establishment.

Themean value for total treevolume per hectare and merchantable volume per hectare were674.74$m^3ha^{-1}$and 279.44 m^3ha^{-1}respectively. The mean volume per hectare recorded in this study are higher than the values reported for tropical rainforest ecosystems in Nigeria by previous researches (e.g. Adekunle *et al.,* 2004 who reported 181.36 m^3/ha in Shasa Forest Reserve; 227 m^3/ha in Ala Forest Reserve; 91.71 in Omo Forest Reserve; and Adekunle and Olagoke, 2008 who reported 262.36m^3/ha). The higher values obtained in this study is an indication that Ogwashi – Ukwu Forest Reserve is rich in timber resources.

The mean basalarea per hectare was47.23 m^2ha^{-1} (Table 1).The value of the mean basal areaper hectare (47.23 m^2) could be attributed to the density of trees in the Forest Reserve. The implication for the value of mean basal area per hectare is that the forest is well stocked when compared proportionally with report of Alder and Abayomi (1994), which stated that for a well-stocked rainforest in Nigeria, the mean basal area is 15m^2. The value of mean basal area per hectare obtained in the forest reserve was higher than what was reported byAdekunle *et al*, (2004) and Onyekwelu *et al.* (2008) for some tropical forests in southwestern Nigeria; Aigbe and Oyebade (2014) for *Terminalia ivorensis* in Sokponba Forest Reserve.

Table 1: Summary Statistics of *Tectona grandis* in Ogwashi – Ukwu Forest Reserve

Variable	Minimum	Maximum	Mean ± SE
Diameter at breast height (cm)	17.80	72.10	34.38 ± 0.73
Stump diameter (cm)	24.00	78.50	40.00 ± 0.73
Merchantable height (m)	3.00	7.00	5.09 ± 0.065
Total height (m)	9.40	14.60	12.42 ± 0.075
Basal area per hectare (m^2/ha)	30.69	68.79	47.23 ± 5.33
Merchantable volume per hectare (m^3/ha)	170.65	403.49	279.44 ± 1.39
Total volume per hectare (m^3/ha)	403.40	1021.00	674.74 ± 39.07

DEVELOPMENT OF MODEL

The correlation coefficients between the various individual tree growth parameters are presented on Table 2. The Table shows thatDbh and stump diameter hadstrongest linear relationship (r = 0.986) follow by Dbh/BA (r = 0.983) and BA/total volume (r = 0.982) respectively. Merchantable height and basal area had the weakest linear relationship (r = 0.380) (Table 2).The high correlation coefficients between stump diameter and diameter at breast height(r = 0.986) suggests that the stump diameter could serve as substitute to diameter at breast height in tree volume estimation.This particular relationship between stump diameter and volume will be very useful to forest manager in quantifying the trees illegally removed from the forest, thereby increasing surveillance activities against illegal activities. By implication, tree stump diameter – volume model will be a good management tool for the forest reserves under study since it can be used to estimate the volume of trees removed from the forests if the stump diameter is known. Similar results have been reported for pines and oaks (Bylin, 1982), teak (Osho, 1983), Bald cypress (Parresol, 1998) and Gmelina (Akindele, 2003).

Table 2: Correlation Matrix for the Tree Growth of*Tectona grandis* in Ogwashi – Ukwu Forest Reserve

	Dbh(cm)	*THT(m)*	*MHT(m)*	*D_s(cm)*	*BA/m2*	*Mvol/m3*	*Tvol/m3*
Dbh(cm)	1						
THT(m)	0.657	1					
MHT(m)	0.422	0.625	1				
D_s(cm)	0.986	0.677	0.454	1			
BA/m2	0.983	0.590	0.380	0.971	1		
Mvol/m3	0.937	0.625	0.554	0.957	0.957	1	
Tvol/m3	0.962	0.638	0.420	0.977	0.982	0.977	1

Dbh-Diameter at breast height; THT- Total tree height; MHT- Merchantable height; D_s-Stump diameter; BA-basal area; Mvol- Merchantable volume; Tvol- Total volume

The scatter diagram of the dependent and predictor variables are shown in figures 1a –d. It is evident from the scatter plots of the relationships between tree variables (Figures 1a – d) that none of the predictor variableshad perfectly linear relationship with tree volume. This shows that linear regression equations may not be appropriate in fitting individual tree volume equations for the forest reserve under investigation, which made some data transformations necessary

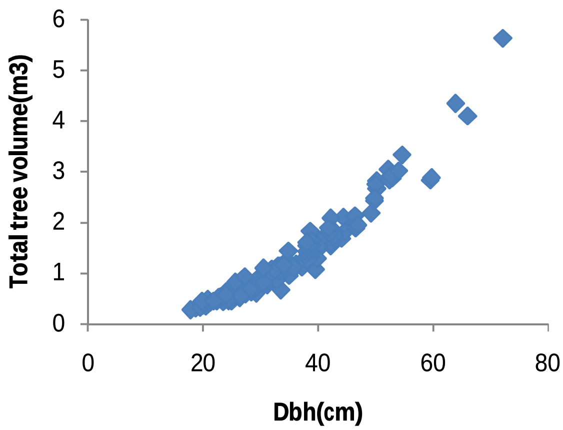

Figure 1a: Relationship between total tree volume and Dbh

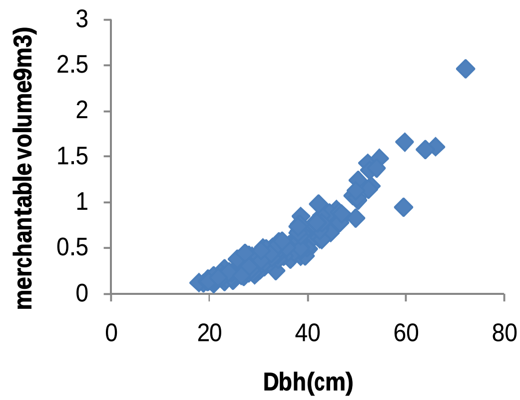

Figure 1b: Relationship between Merchantable volume and Dbh

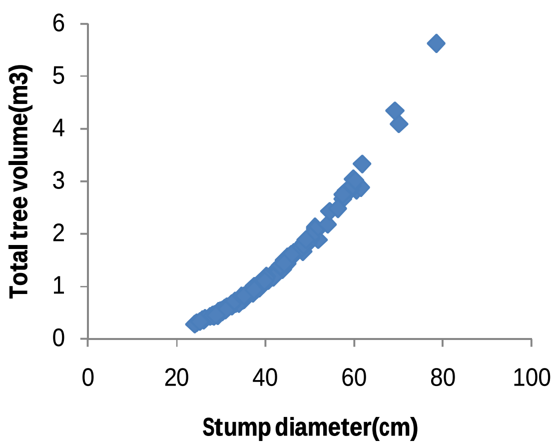

Figure 1c: Relationship between Total tree volume and Stump diameter

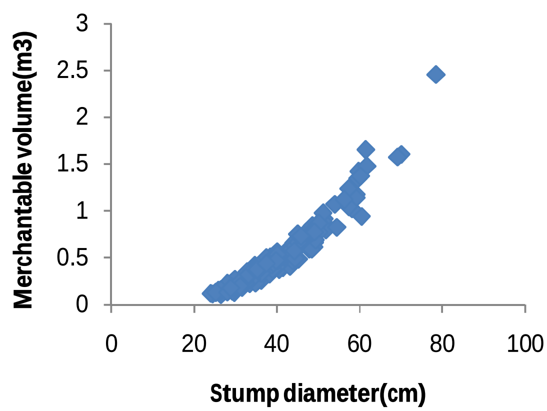

Figure 1d: Relationship between Total tree volume and Stump diameter

The parameters of tree growth models developed in this study are presented on Tables 3 – 6. The tree model is based on the relationship between total volume, merchantable volume and other tree growth variable predictors.Several volume equations were fitted to the predictor variables(Tables 3 – 6) and the best volume equations were selected. The equations adjudged the best were based on highest adjusted coefficient of determination, lowest standard error and highest F ratio. Equations code 6 and 12 were adjudged the best for total volume based on Dbhand stump diameter respectively (Tables 3 and 4) while equations code 6 and 6 were adjudged the best for merchantable volume based on Dbh and stump diameter respectively (Tables 5 and 6). This suggests that data transformation is effective in stabilizing errorvariance, and the use of the D^2H as a weightingfactor in this study appeared to be appropriate for reducingheteroscedasticity. Theresidual plots for the model generallyindicate an even spread of residuals above and below the zeroline, with no systematic trend (Figures 2a–d).The Figures indicated a homogenous distribution of residuals, which implies independence of experimental errorand suggests thatthe assumption of linear regression do not appear to have been violated by the equations. The results of the t-test carried out to validate each of the equation at 95% probability level, shows that there was no significant difference ($p > 0.05$) between predicted and observed values for all the models (Table 7).The coefficientof determination (R^2) for the models, ranged between 0.981 and 0.999. This suggests that a substantial proportion of the variation in treevolumeis explained by Dbh, stump diameter, merchantable height and totaltree height.

Table 3: Total Tree VolumeModels for*Tectona grandis* in Ogwashi – Ukwu Forest Reserves Based on Diameter at Breast Height

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta(lnDbh) + \varepsilon_i$	-3.343	1.103	-	-	0.195	0.718	43.28
2.	$V = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-3.342	0.650	-	-	0.195	0.713	43.28
3.	$V = \alpha + \beta Dbh^2 + \varepsilon_i$	0.590	0.000	-	-	0.221	0.702	39.25
4.	$lnV = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-7.328	1.050	-	-	0.964	0.111	4665
5.	$V^{-1} = \alpha + \beta(lnDbh^2) + \varepsilon_i$	8.952	-1.115	-	-	0.854	0.248	1055
6.	$V = \alpha + \beta Dbh^2 H_T + \varepsilon_i$	0.020	7.36 x 10^{-5}	-	-	0.981	0.111	8999
7.	$V = \alpha + \beta(lnDbh^2 H_T) + \varepsilon_i$	-10.17	1.197	-	-	0.814	0.346	772
8.	$lnV = \alpha + \beta(lnDbh^2 H_T) + \varepsilon_i$	-9.001	0.948	-	-	0.972	0.097	6170
9.	$lnV = \alpha + \beta_1 Dbh + \beta_2 Dbh^2 + \varepsilon_i$	-2.928	0.111	0.000	-	0.963	0.111	2314
10.	$lnV = \alpha + \beta_1 Dbh^2 H_T + \beta_2 \ln Dbh^2 H_T + \varepsilon_i$	-8.256	5.337 x 10^{-5}	0.872	-	0.974	0.095	3253
11.	$V = \alpha + \beta_1 D_{bh}{}^2 + \beta_2 D_{bh}{}^2 H_T + \beta_3 lnD_{bh} H_T + \varepsilon_i$	-0.305	0.004	0.000	0.067	0.307	0.605	27
12.	$lnV = \alpha + \beta_1 D_{bh}{}^2 + \beta_2 D_{bh}{}^2 H_T + \beta_3 lnD_{bh} H_T + \varepsilon_i$	-8.273	0.000	1.294 x 10^{-5}	0.864	0.974	0.094	2174

Table 4: Total Tree VolumeModels for *Tectona grandis* in Ogwashi – Ukwu Forest Reserves Based on Stump Diameter

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta \ln(Dst) + \varepsilon_i$	-4.192	0.738	-	-	0.179	0.720	39
2.	$V = \alpha + \beta ln(Dst^2) + \varepsilon_i$	-4.192	0.738	-	-	0.179	0.720	39
3.	$V = \alpha + \beta Dst^2 + \varepsilon_i$	0.539	0.000	-	-	0.189	0.716	42
4.	$lnV = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	-9.197	1.259	-	-	0.996	0.037	42716
5.	$V^{-1} = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	10.80	-1.318	-	-	0.861	0.224	1093
6.	$V = \alpha + \beta Dst^2 H_T + \varepsilon_i$	-0.163	6.41×10^{-5}	-	-	0.996	0.046	54138
7.	$V = \alpha + \beta ln(Dst^2 H_T) + \varepsilon_i$	-12.68	1.413	-	-	0.850	0.310	1001
8.	$lnV = \alpha + \beta ln(Dst^2 H_T) + \varepsilon_i$	-10.90	1.110	-	-	0.997	0.030	6575
9.	$lnV = \alpha + \beta_1 Dst + \beta_2 Dst^2 + \varepsilon_i$	-3.738	0.126	0.000	-	0.995	0.043	16172
10.	$lnV = \alpha + \beta_1 Dst^2 H_T + \beta_2 \ln Dst^2 H_T + \varepsilon_i$	-10.73	8.515×10^{-7}	1.091	-	0.997	0.030	33194
11.	$V = \alpha + D_{st}{}^2 + \beta_2 D_{st}{}^2 H_T + \beta_3 lnD_{st} H_T + \varepsilon_i$	-1.984	0.003	0.000	0.233	0.273	0.677	22
12.	$lnV = \alpha + \beta_1 D_{st}{}^2 + \beta_2 D_{st}{}^2 H_T + \beta_3 lnD_{st} H_T + \varepsilon_i$	-11.10	0.000	1.700×10^{-5}	1.082	0.999	0.018	59410

Table 5: Merchantable Volume Models for *Tectona grandis* in Ogwashi – Ukwu Forest Reserves Based on Diameter at Breast

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta(lnDbh) + \varepsilon_i$	-1.322	0.521	-	-	0.161	0.320	32
2.	$V = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-1.322	0.261	-	-	0.161	0.320	35
3.	$V = \alpha + \beta Dbh^2 + \varepsilon_i$	0.259	0.000	-	-	0.176	0.317	38
4.	$lnV = \alpha + \beta(lnDbh^2) + \varepsilon_i$	-8.515	1.091	-	-	0.906	0.191	1693
5.	$V^{-1} = \alpha + \beta(lnDbh^2) + \varepsilon_i$	23.49	-2.941	-	-	0.777	0.857	614
6.	$V = \alpha + \beta Dbh^2 H_m + \varepsilon_i$	0.0066	7.4 x 10^{-5}	-	-	0.982	0.047	9596
7.	$V = \alpha + \beta(lnDbh^2 H_m) + \varepsilon_i$	-3.705	0.489	-	-	0.805	0.155	729
8.	$lnV = \alpha + \beta(lnDbh^2 H_m) + \varepsilon_i$	25.61	-2.637	-	-	0894	0.645	1216
9.	$lnV = \alpha + \beta_1 Dbh + \beta_2 Dbh^2 + \varepsilon_i$	-3.994	0.118	0.000	-	0.905	0.192	838
10.	$lnV = \alpha + \beta_1 Dbh^2 H_m + \beta_2 \ln Dbh^2 H_m + \varepsilon_i$	-8.591	1.055 x 10^{-5}	0.887	-	0.976	0.096	3611
11.	$V = \alpha + \beta_1 {D_{bh}}^2 + \beta_2 {D_{bh}}^2 H_m + \beta_3 lnD_{bh} H_m + \varepsilon_i$	-0.078	-4.459 x 10^{-6}	2.730 x 10^{-5}	0.047	0.178	0.317	14
12.	$lnV = \alpha + \beta_1 {D_{bh}}^2 + \beta_2 {D_{bh}}^2 H_T + \beta_3 lnD_{bh} H_T + \varepsilon_i$	38.62	0.000	0.000	-4.359	0.949	0.408	1102

Table 6: Merchantable Volume Models for *Tectona grandis* in Ogwashi – Ukwu Forest Reserves Based on Stump Diameter

Code	Model Form	α_0	β_1	β_2	β_3	R^2_{adj}	SEE	F ratio
1.	$V = \alpha + \beta \ln(Dst) + \varepsilon_i$	-1.681	0.597	-	-	0.151	0.322	32
2.	$V = \alpha + \beta ln(Dst^2) + \varepsilon_i$	-1.681	0.269	-	-	0.151	0.322	39
3.	$V = \alpha + \beta Dst^2 + \varepsilon_i$	0.238	0.000	-	-	.151	0.322	32
4.	$lnV = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	-10.51	1.312	-	-	0.947	0.144	3128
5.	$V^{-1} = \alpha + \beta \ln(Dst^2) + \varepsilon_i$	28.49	-3.494	-	-	0.788	0.834	657
6.	$V = \alpha + \beta Dst^2 H_m + \varepsilon_i$	-0.063	6.36 x 10^{-5}	-	-	0.996	0.021	44823
7.	$V = \alpha + \beta ln(Dst^2 H_m) + \varepsilon_i$	-4.54	0.564	-	-	0.834	0.143	884
8.	$lnV = \alpha + \beta ln(Dst^2 H_m) + \varepsilon_i$	-29.69	1.110	-	-	0.878	0.634	1263
9.	$lnV = \alpha + \beta_1 Dst + \beta_2 Dst^2 + \varepsilon_i$	-4.897	0.135	0.000	-	0.946	0.145	1540
10.	$lnV = \alpha + \beta_1 Dst^2 H_m + \beta_2 \ln Dst^2 H_m + \varepsilon_i$	-10.48	2.905 x 10^{-6}	1.072	-	0.997	0.033	30642
11.	$V = \alpha + D_{st}{}^2 + \beta_2 D_{st}{}^2 H_m + \beta_3 lnD_{st} H_m + \varepsilon_i$	-0.508	1.397 x 10^{-5}	1.429 x 10^{-5}	0.096	0.153	0.322	12
12.	$lnV = \alpha + \beta_1 D_{st}{}^2 + \beta_2 D_{st}{}^2 H_m + \beta_3 lnD_{st} H_m + \varepsilon_i$	49.26	0.000	0.000	-5.452	0.969	0.321	1913

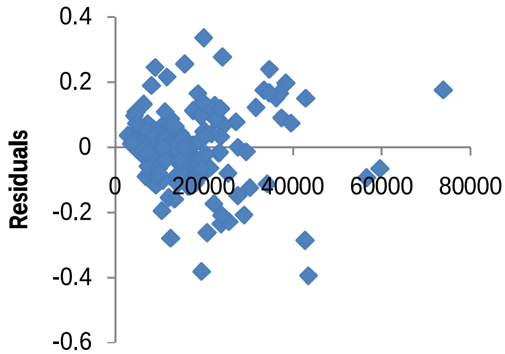

Figure 2a: Residual plot using Total tree volume function based on Dbh^2THT

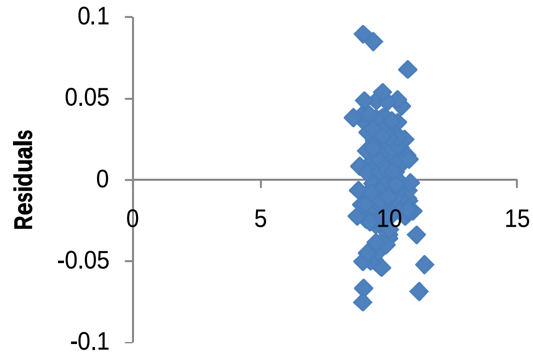

Figure 2b: Residual plot using LnTotal tree volume function based on Dst^2, Dst^2THT & $\ln Dst^2THT$

s

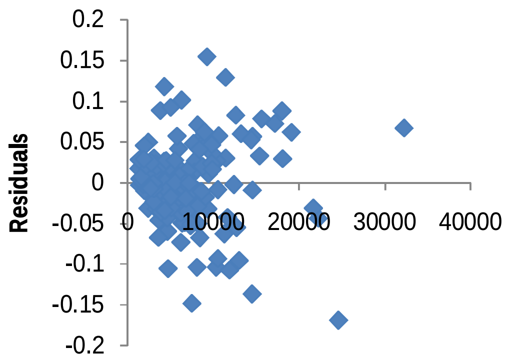

Figure 2c: Residual plot using Merchantable volume function based on Dbh^2MTH

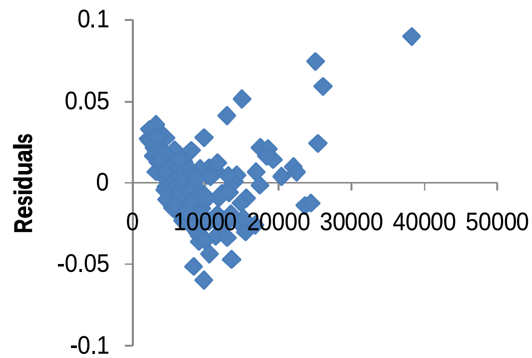

Figure 2d: Residual plot using Merchantable volume function based on Dst^2MHT

Table 7: Results of model validation fortree growth models in Ogwshi – Ukwu Forest Reserve

Model Form	t_{cal}	$t_{critical}$	$R_{o/p}$	M_o	M_p	Remark
= + h^2 +	0.0024	1.974	0.99	1.220	1.220	Ns
= + 1 2 + 2 2 + 3 +	1.259	1.974	0.93	1.220	1.294	Ns
= + h^2 +	0.0801	1.974	0.99	0.5053	0.5055	Ns
= + 2 +	0.2522	1.974	0.99	0.5053	0.5049	Ns

t_{cal}- t calculated, $t_{critical}$- critical t, $R_{o/p}$- correlation between observed and predicted values, M_o- mean of observed values, M_p- mean of predicted values, ns – not significant at $p \geq 0.05$

Conclusion

This study revealed that Diameter at breast height and stump diameter had strong linear relationship indicating that one could serve as substitute for the other in tree volume estimation. This study also proved that the relationship between stump diameter/ tree volume anddbh/tree volume is not perfectly linear indicating that linear regression equations may not be appropriate in fitting individual tree volume equations for the forest reserve under investigation, which made data transformation necessary and needed. The volume model developed is recommended for use by the management of the reserves inregulating cut, a basis for establishing compartment as a management unit in the forest reserve,determination of the optimal allocation of timber resources to satisfy a given management objective when there are competing uses and also for allocation of forest land for harvest.

Reference

Abayomi, J. A. (1984): Volume tables for Naucleadiderrichii in Omo forest reserve, Nigeria. Nigerian Journal of Forestry 13(1&2):46-52.

Adekunle V.A.J and Olagoke A.O (2008): Diversity and biovolume of tree species in natural forest ecosystem in the bitumenproducing area of Ondo State, Nigeria: A baseline study, Biodiversity and Conservation 17: 2735-2755.

Akinsanmi, F. A. (1999): Updating Environmental Information in Nigeria. Invited Lead paper presented at the 26th Annual Conference of the Forestry Association of Nigeria held in Maiduguri, Borno. November 7-12, 1999. 15pp.

Akindele, S.O. (1989): Teak yields in the dry lowland rain forest area of Nigeria. Journal of Topical Forest Science,.2(1):32-36.

Akindele, S.O. (1992): An appropriate volume-age function for teak stand in Gambari Forest Reserve, Nigeria. Journal of Agriculture, Science and Technology, 2(2): 158-161.

Akindele, S. O., (2003): Volume prediction from stump diameters of Gmelina arborea (Roxb) trees in Akure forest reserve. Nigeria. Niger. J. Forestry 33(2), 116-123.

Aigbe H. I., ModuguW. W. and Oyebade B. A (2012): Modelling volume from stump diameter of Terminalia ivorensis (A. Chev) in Sokponba Forest Reserve, Edo State, Nigeria. ARPN journal of Agricultural and Biological Science. 7(3):146-151.

Aigbe H. I.,Akindele S. O. and Onyekwelu J. C (2013): Volume equations for Oban Tropical Forest Reserve, Cross River State, Nigeria. Nigeria Journal of Forestry (NJF) 43(1):53-67.

Aigbe H. I.andOyebade, B.A. (2014): Comparison of stump diameter and diameter at breast height for tree volume estimation of Terminalia ivoresis in Sokponba Forest Reserve, Nigeria. Journal for Applied Research 6(1): 1-14.

Avery, T. E. and BurkhartH. E. (2002): Forest Measurements. Fifth Edition. McGraw-Hill,New York, USA.456pp.

Alder D. and Abayomi J.O. (1994): Assessment of data requirements for sustained yield calculations, unpublished report preparedfor the Nigeria Tropical Action Programme, FORMECU, FederalDepartment of Forestry, Ibadan, Nigeria, p. 28.

Bush, M.B. (2003):Ecology of a changing planet, Prentice Hall, New Jersey, 477pp.

Bylin, C. V. (1982): Volume prediction from stump diameter and stump height of selected species in Louisiana. USDA Forest Service, Southern Forest Experiment. Station, New Orleans Louisiana. Research paper-182. August 1982.11p.

FAO, (2011):State of the World's Forests, 2011, FAO Rome, 164 pp.

FORMECU (2000). Forest resources study of Nigeria, the revised forest management plan of Delta State. Prepared by Geometrics International in association with Beak Consultants Limited, 122pp.

FRA, (2010): Global Forest Resources Assessment 2010, Main report. FAO Forestry Paper,163, FAO Rome, 340 pp.

Hart, G. (1973): Timber of South East Asia. Timber Research and Development Association. Hugheden Valley, High Wycombe, Bucks.

Husch, B., Miller, C.I. and Beers, T.W., (1982): Forest Mensuration, 3rd ed. Wiley, N.Y. 402 pp.

Meteorological Service Station (2003): Weather CharacteristicsofDelta State ofNigeria. Unpublished. 2:.2 – 21.

Onyekwelu, J. C., MosandI, R. and Stimm, B (2008): Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in South-Western Nigeria. Journal of Tropical Forest Science, 20(3): 193-204.

Osho, J.S.A. (1983). Volume Prediction from Stump Diameter for Teak (tectonagrandis L. F) in Onigambari Forest Reserve. Nig, J. For. 13(1-2),53-56.

Parresol, B. R. (1998): Prediction and error of baldcypress stem volume from stump diameter. Southern Journal of Applied Forestry 22(2):69-73.

Perekeme, I. J. (2000): Sail geology of the Niger Delta swamp areas of Delta State of Nigeria. Geology Journal 5(41):pp.38-51

Robertson B. (2002). Growing teak in the top end of the NT. Ag note 812 No. 26

Turner, I. M., (2001): The Ecology of Trees in Tropical Rain Forest. Cambridge University Press, Cambridge, p. 298.