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DEVELOPMENT OF REGRESSION MODELS FOR PREDICTING YIELD OF *Triplochiton scleroxylon* (K. Schum) STAND IN ONIGAMBARI FOREST RESERVE, OYO STATE, NIGERIA

Adeyemi, A.A. and Moshood, F.A.

Department of Forest Resources Management, Faculty of Agriculture, University of Ilorin, Ilorin, Nigeria
***Corresponding Author:** *adeyemi.aa@unilorin.edu.ng*, +2348032082627

ABSTRACT

We developed regression models for predicting yield of Triplochiton scleroxylon stands in Onigambari Forest Reserve in western Nigeria. Stratified random sampling technique was adopted for separating the stands into series based on their ages, viz.: 1979 plantation (40-year-old), 1988 plantation (31-year-old) and 1992 (27-year-old). Seventy five (75) 20m × 20m (0.04 ha) temporary sample plots were used (i.e. twenty five in each age series). Tree growth variables including diameter at breast height (Dbh); total height (THT); merchantable height (MHT); stem quality (SQ); crown length (CL) and crown diameter (CD) were measured on all trees within the sample plots to compute basal area (BA), slenderness coefficient (SC) and stem volume (SV). Trees were classified according to their slenderness coefficient (SC) as high (SC: >80), moderate (SC: 70-80) and low (SC: <70). Data were analyzed using descriptive statistics and regression analysis. Fitted models were assessed using F-test and coefficient of determination (R^2). Model validations were conducted using t-test and bias. The result showed that mean Dbh for 40, 31 and 27-year-old stands were 67.99 ± 15.40 cm, 50.97 ± 9.71 cm and 36.85 ± 5.19 cm, respectively, and the overall mean Dbh was 55.67 cm which was higher than 48 cm stipulated as the minimum merchantable size by logging policy of Nigeria. The diameter class >50 cm had the highest of 564 trees/ha followed by 40-50 cm diameter class with 317 trees/ha. The diameter class with the least number of trees was 10-20 cm with 4 trees/ha. The mean tree height for 40, 31 and 27-year-old were 36.97 ± 6.84 m, 34.84 ± 6.99 m and 25.38 ± 5.93 m, respectively. Height class 30-40 m recorded the highest number of 489 trees/ha followed by 20-30 m with 405 trees/ha while >50 m height class recorded the least number of 12 trees/ha. There were 953 trees/ha (78.44%) with low to moderate slenderness coefficient indicating that most of the trees in the study area were of good vigour, and could withstand windthrow or other wind-induced damages. The best yield prediction model was of the form: $V = -0.123 + 0.00673Dbh^3 - 3.419BA^3 + 0.020934MHT^3$ with R^2, SSE and bias values of 98.2%, 0.644 and 0.102, respectively. It is therefore recommended for future yield prediction in the study area.

Keywords: Stand, yield prediction, stem diameter, height classes, age series

INTRODUCTION

Nigeria is blessed with large forest land, where a wide variety of wood- (and non-wood) producing tree species are found. According to FAO (2010), forest resources provide employment for over 2 million people through the supply of fuel-wood and poles, and more than 80,000 people are working in the log processing industries, especially in the forest zones of the Nigeria south-west. Forests also provide hosts of non-wood products and services, which are unquantifiable as at now. Despite these immeasurable benefits, Nigeria has lost large percentage of her forest cover to factors including but not limited to, over-exploitation of resources and forest encroachment. In 1990, the forest estate in Nigeria was about 19% of the total land mass compared to this present time, about 7% of the total land mass in 2018 (World Bank, 2018).

The key to effective forest management is to understand the modus operandi of the forest ecosystem and how it can be translated to meet or address the demands of the society. Sustainable forest resources management needs reliable information on the current status of forest resources and forecast of the nature of those resources in future. This information can be gotten by developing forest growth or yield models, which would serve as tools in providing reliable information for decision-making. According to Adekunle (2007), models are veritable tools for effective management of any forest stand. They are tools for providing long-term decision-making in forest management, estimation of growing stock, timber valuation and allocation of forest areas for harvest to ensure continuous availability**.**

Regression model is mainly used to predict dependent variables by the values of one or more independent variables (Reimann *et al*., 2008). According to Avery and Burkhart (2002), yield equations are mathematical expressions, which relate tree volume to tree's measureable attributes such as diameter at breast height and/or height. They are used to estimate the average content of standing trees of various sizes and species. The need to increase the supply of timber, poles, and staking materials for socio-economic development through adequate mensuration of forest stands to determine and improve the quantity and quality of stands is imperative (Shuaibu and Alao, 2016). The relevance of direct measurements of standing trees to obtain basic information for the development of relationships between the various dimensions of a tree and its volume, which are used to estimate the volumes of other standing trees, cannot be over-emphasized (Shuaibu and Alao, 2016). Moreover, it may be very difficult and expensive to employ direct measurements to obtain information from standing trees, especially in forests with rough vegetation type, and considering the limitation of financial resources.

In sustainable forest management and forestry decision-making, there is a continuous need for high-quality information on forest resources (Aertsen *et al*., 2010). According to Higman *et al*. (2000), the basic requirement of a sound forest management strategy is the availability of reliable database that provides adequate information on the extent, state and potentials of the resources. Up-to-date information on forest resources and monitoring ongoing spatial processes in forested landscape are essential for sustainable management of forest resources (Mohammadi *et al*., 2010). Unfortunately, these information were, hitherto, unavailable for *Triplochiton scleroxylon* stand at Onigambari Forest Reserve. Consequently, there is no modelling system in place for subsequent monitoring of species growth and yield in the study area.

In Nigeria, much work has been done in this regard for plantation and exotic tree species like *Tectona grandis* (e.g., Adesoye and Oluwadare, 2008; Adeyemi and Adesoye, 2010; Popoola and Adesoye, 2012; Shamaki *et al*., 2016), *Gmelina arborea* (e.g., Adeyemi and Ukaegbu, 2017; Nurudeen *et al*., 2017) and Pinus species (e.g., Adesoye, 2014). However, none exists for *Triplochiton scleroxylon*. Without reliable yield models for the indigenous hardwood species, there is no basis for planning their sustainable use or management. Moreover, effective and efficient forest management is only possible when reliable information about the present and future conditions of the forest is available, reliable and accessible. Especially when managing a forest for production of commercially-valuable materials, estimation of present growth of variables which are not very easy to measure (such as timber volume) and to estimate the growth values in future are vital (Avery and Burkhart, 2002). Species-specific stand models that provide accurate estimates of stand growth and yield have become fundamental tools for evaluation of the various management alternatives in the forest. Furthermore, a proper and detailed inventory of tree growth characteristics is essential for the development of adequate models for planning and sound management decisions, just as it is crucial for stands of *Triplochiton scleroxylon* in Onigambari Forest Reserve.

MATERIALS AND METHODS

Study Area

The study was carried out in a *Triplochiton scleroxylon* plantation at Onigambari Forest Reserve in Oluyole Local Government Area of Oyo State (Fig. 1). The plantation is situated between latitudes 7°25'and 7°55'N, and longitudes 3°53' and

3°9'E. The plantation is of three age-series, and one of the very scarce collections of indigenous species in Nigeria. Onogambari Forest Reserve is one of the early forest reserves in the state, and is divided into five sub-stations, namely *Onigambari*, *Busogboro*, *Onipe*, *Olonde* and *Mamu* (Larinde and Olasupo, 2011). The reserve is within the tropical dry, semi-deciduous lowland forest (Onilude *et al*., 2015) and covers a total area of 17,984 ha (Ige, 2017). The plantation is divided into three age series of 1979 (5 ha), 1988 (3 ha) and 1992 (6 ha). The location is about 2 km east of Ibadan-Ijebu-Ode road, well obscured by some forest fallows in the neighbourhood of Onigambari area (Oduwaiye and Ajibode, 2005).

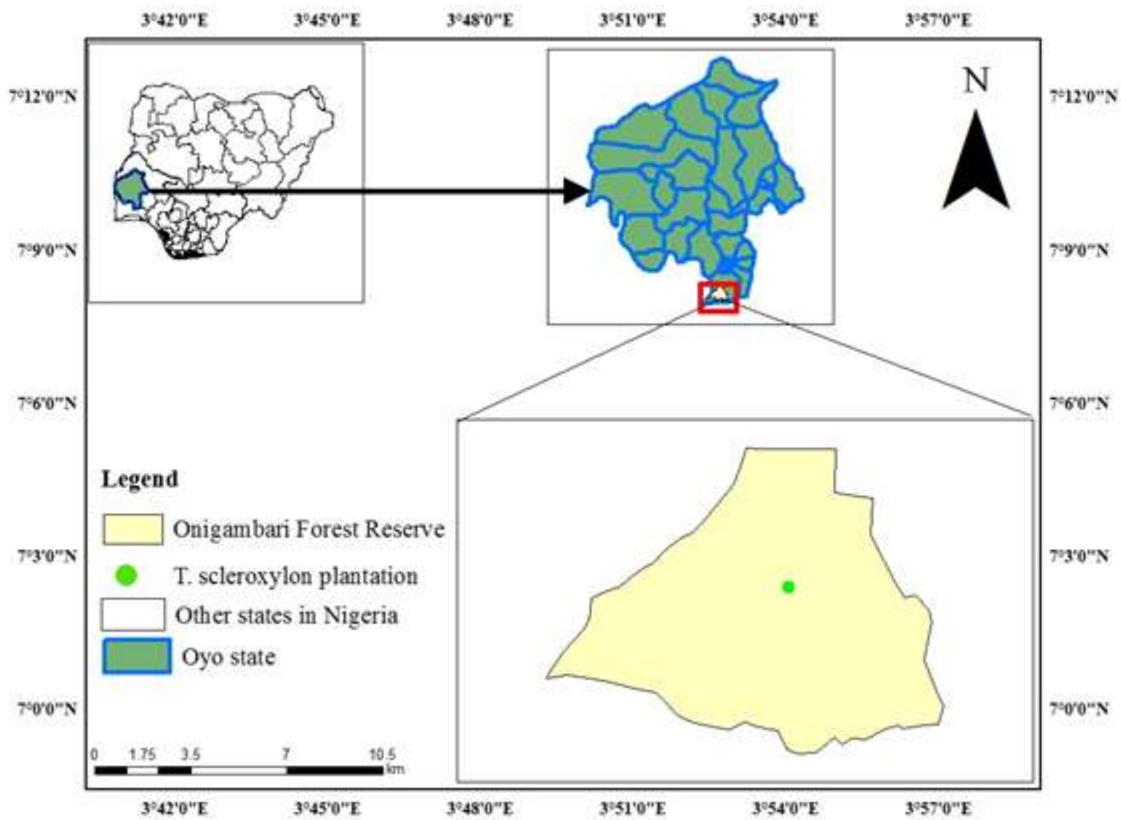

Fig. 1: Map of Onigambari Forest Reserve

There are two distinct wet seasons occurring in the reserve, May to July and September to November. The average annual rainfall is about 1257 mm while the relative humidity ranges from 84.5% in June to September, and 78.8% in December to January (Onilude *et al*., 2015). Rainfall is bimodal with peaks in July and September (Faleyimu and Agbeja, 2004). The reserve is divided into two: natural and plantation forests. The natural forest is made up of indigenous species such as *Terminalia spp*, *Irvingia gabonensis*, *Treculia africana*, among others while the plantation forest is made up of species such as *Triplochiton scleroxylon*, *Gmelina arborea* and *Tectona grandis* (Ige, 2017).

Sampling Procedure and Data Collection

A stratified random sampling technique was adopted for the study. The plantation was stratified into three series based on their ages: 40 year (5 ha), 31 years (3 ha) and 27 years (6 ha). A simple random sampling technique was then adopted in each of the age series for plot location and measurement. A total of twenty five (25) temporary sample plots of 20 m × 20 m were established randomly in each of the age series, and a total of 75 plots were sampled. Data collection involved a complete enumeration of all stems. Tree growth variable measurements were done using diameter tape and Spiegel Relaskop for diameter and height measurements, respectively. The growth variables measured include diameter at breast height (Dbh); diameter at the base (D_b); diameter at the top (D_t); diameter at middle (D_m); total height, merchantable height, crown length, crown diameter and an index of stem quality.

Data Analysis

Basal area

The basal area of each tree was computed using:

$BA = \frac{\pi D^2}{4}$……1

Where, BA = basal area (m^2) and D = diameter at breast height (m).

Slenderness Coefficient

Tree slenderness coefficient (SC) for all measured trees was computed using:

$SC = \frac{THT}{Dbh}$ … … 2

Where, THT = total height (m) and Dbh = diameter at breast height (m)

Individual trees were grouped into slenderness coefficient classes as: high (trees with SC: >80); moderate (trees with SC: 70-80) and low (trees with SC: < 70) slenderness coefficients (Adeyemi and Adesoye, 2016).

Volume Estimation

The volume for each tree in each sample plot was estimated using Newton's formula as follows:

$$V = \pi H\left[\frac{Db^2 + 4Dm^2 + Dt^2}{24}\right] \text{ …… } 3$$

Where, V = volume (m^3), H = height (m), D_b= diameter at the base, D_m = diameter at the middle and D_t = diameter at the top.

Descriptive Statistics

Descriptive statistics such as graphs were used to summarize measured and computed tree growth variables.

Modelling

The following volume prediction models were tried and retained among several others, for their suitability:

$V = b_0 + b_1BA + b_2BA^2 + b_3BA^3$ … 4

$V = b_0 + b_1LogBA + b_2(LogBA)^2 + b_3(LogBA)^3$…5

$V = b_0 + b_1Dbh + b_2Dbh^2 + b_3Dbh^3$ 6

$V = b_0 + b_1LogDbh + b_2(LogDbh)^2 + b_3(LogDbh)^3$ 7

$V = b_0 + b_1MHT + b_2MHT^2 + b_3MHT^3$……… 8

$V = b_0 + b_1LogMHT + b_2(LogMHT)^2 + b_3(LogMHT)^3$… 9

Where,
V = stem volume (m^3), BA = basal area (m^3), Dbh = diameter at breast height (m), MHT = merchantable height (m), Log = logarithm and b_0, b_1, b_2 and b_3 = regression parameters to be estimated for prediction.

Model Assessment

F-test

This was used to test the overall significance of the regression equations. The critical value of F (i.e., F-tabulated) at $\propto = 0.05$ level of significance was compared with the variance ratio (F-calculated). Where the variance ratio (F-calculated) was greater than the critical value (F-tabulated), such equation was therefore significant and was accepted for yield prediction in this study.

Coefficient of Determination (R^2)

This is the measure of the proportion of variation in the dependent variable that is explained by the behaviour of the independent variable. Model with high R^2 value (>50%) was accepted for prediction. The closer the value is to 100% or unity, the better for the models. This was computed using:

$$R^2 = 1 - \frac{SSE}{SST} \text{ …… } 10$$

Where, SSE is the error sum of squares and SST is the total sum of squares

Models Validation

Student t-test

This was used to test for any significant difference between the field-measured values and predicted values (model outputs) of the various models adopted.

Bias

The absolute difference was determined by dividing the difference between computed yields and model outputs as follows:

$$Bias = \sum \frac{V_2 - V_1}{V_2} \text{ … … } 11$$

Where, V_2 = observed volume or yield and V_1 = predicted values from models.

RESULTS

The descriptive statistics for tree growth parameters in the study area are presented in Table 1. The number of trees/ha encountered in the 40, 31 and 27-year-old stands were 419, 405 and 391, respectively. In 40-year old stand, Dbh ranged between 38.40 and 99.50 cm with a mean of 67.99 ± 15.40 cm. The THT ranged between 20.40 and 79.20 m with a mean of 36.97 ± 6.99 m. In the 31-year old stand, the mean MHT was 29.86 ± 7.01. The SQ ranged between 3.25 and 51.00 m with a mean of 30.19 ±7.11. The BA of 27-year old stand ranged between 0.06 and 0.19 m^2 with a mean of 0.11 ± 0.03 m^2. The mean volume in this stand was 3.02 ± 0.09 m^3. Details of the descriptive statistics are shown in Table 1.

Table 1: Descriptive statistics for tree growth variables

Growth Variables	Age (years)	N(ha)	Minimum	Maximum	Mean
	40	419	38.40	99.50	67.99±15.40
Dbh(cm)	31	405	12.00	68.50	50.97±9.71
	27	391	27.10	49.09	36.85±5.19
	40	419	20.40	79.20	36.97±6.84
THT(m)	31	405	9.00	55.00	34.84±6.99
	27	391	13.50	36.90	25.38±5.93
	40	419	16.22	75.02	32.66±6.84
MHT(m)	31	405	5.20	49.80	29.86±7.01
	27	391	9.30	32.70	21.18±5.93
	40	419	1.00	7.50	4.24±1.43
CL(m)	31	405	1.25	6.80	4.66±1.12
	27	391	1.25	7.70	4.59±1.40
	40	419	17.40	72.00	32.73±6.95
SQ(m)	31	405	3.25	51.00	30.19±7.11
	27	391	6.90	34.45	20.79±6.20
	40	419	0.50	9.09	3.42±1.31
CD(m)	31	405	1.15	8.55	4.19±1.12
	27	391	1.35	8.05	4.23±1.14
	40	419	0.12	0.78	0.38±0.16
BA(m^2)	31	405	0.01	0.54	0.21±0.08
	27	391	0.06	0.19	0.11±0.03
	40	419	36.43	114.97	56.07±12.62
SC	31	405	32.35	138.49	70.63±18.76
	27	391	36.34	107.74	70.27±19.15
	40	419	2.36	47.29	11.96±7.13
SV(m^3)	31	405	1.42	14.61	5.77±2.52
	27	391	1.32	4.44	3.02±0.94

NB*: Dbh = diameter at breast height; THT= tree total height; MHT= merchantable height; CL = crown length; SQ = stem quality; CD = crown diameter; BA= basal area; SC = slenderness coefficient; SV = stem volume; SD = standard deviation*

The tree diameter classifications for the *T. scleroxylon* stand in the different age series are shown in Fig. 2. In the 40-year-old stand, none of the trees was in the diameter classes 10-20 cm and 20-30 cm, 6 trees/ha fell in the 30-40 cm, which constituted 1.4% of the trees/ha. There were 62 trees/ha in the diameter class 40-50 cm, about 14.8% of the number per hectare. The diameter class with highest number of trees/ha was >50 cm with 83.8% of the trees encountered per hectare. In the 31-year-old stand, 4 trees/ha fell in the 10-20 cm diameter class. The diameter class with least number of trees/ha was 20-30 cm with zero number of trees/ha. Diameter classes 30-40 cm, 40-50 cm and >50 cm recorded 37 trees/ha (9.1%), 151 trees/ha (37.3%) and 213 trees/ha (52.6%), respectively. About 36 trees/ha fell in the diameter 20-30 cm, which constituted 9.2% of the trees per hectare in the 27-year-old stand. There were 251 trees/ha in the diameter class 30-40 cm, and about 104 trees/ha (26.6%) were in diameter class 40-50 cm. None of the trees were in the diameter classes 10-20 cm and >50 cm.

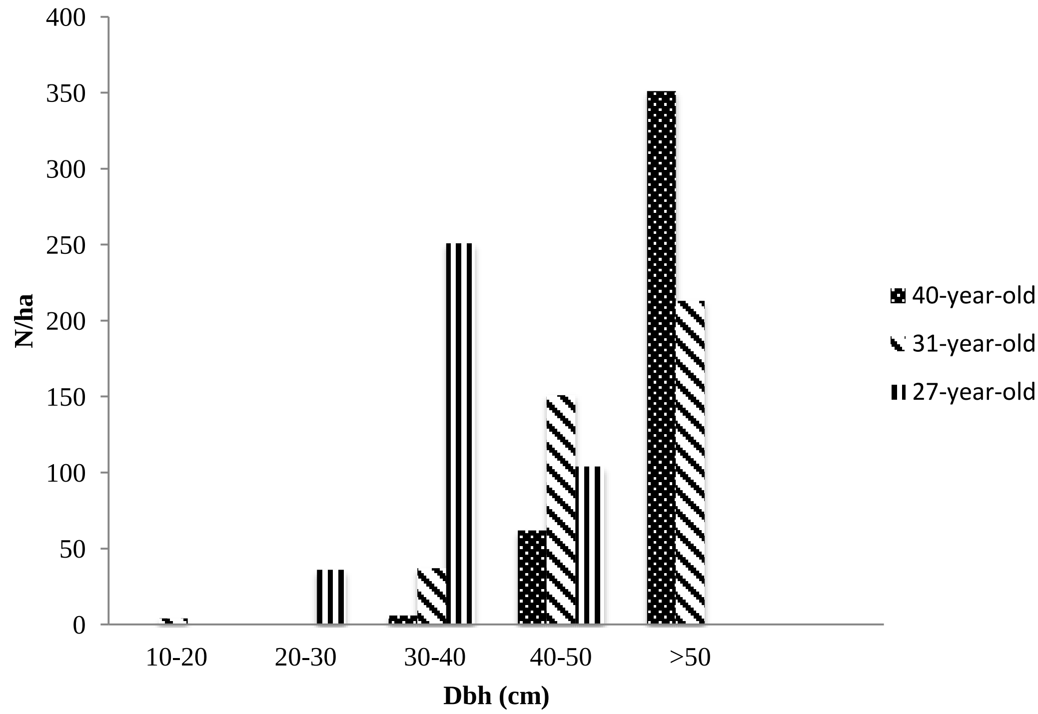

Fig. 2: Diameter classification for trees in the different age series in the study area

The tree height classifications in the different age series are shown in Fig. 3. In the 40-year-old stand, none of the trees fell in the height class 10-20 m. About 84 trees/ha fell in the 20-30 m, which constituted 20.1% of the trees/ha. There were 193 trees/ha, 132 trees/ha and 10 trees/ha in the height classes 30-40 m, 40-50 m and >50 m, respectively representing 46.1%, 31.5% and 2.4% of the trees/ha. In the 31-year-old stand, height class 30-40 m had 206 trees/ha, which constituted about 50.9% of the trees/ha. There were only 2 trees/ha in the height class >50 m, while height classes 10-20 m, 20-30 m and 40-50 m recorded 4 trees/ha (1%), 92 trees/ha (22.7%) and 101 trees/ha (24.9%), respectively. About 72 trees/ha fell in the height class 10-20 m, which constituted 18.4% of the trees/ha in the 27-year-old stand. There were 229 trees/ha (58.6%) in the height class 20-30 m and 90 trees/ha (23%) were in the height class 30-40 m. None of the trees were in the height classes 40-50 m and >50 m.

In 40-year-old stand, about 367 trees/ha had SC: <70 (low), constituting 87.6% of the trees encountered per hectare in the age series (Fig. 4). There were 26 trees/ha (6.21%) with SC: 70-80 (moderate), while 26 trees had SC >80 (high) constituting 6.2% of the trees encountered. In the 31-year-old stand, about 109 trees/ha, 107 tress/ha and 108 trees/ha have slenderness coefficient of <70, 70-80 and >80, which constituted 46.9%, 26.4% and 26.7% of the trees encountered per hectare, respectively. In the 27-year-old stand, 202 trees/ha (51.7%) had SC: <70, 61 trees/ha (15.6%)

had SC: 70-80, and there were about 128 trees/ha with SC: >80 constituting about 32.7% of the total trees encountered per hectare in the age series.

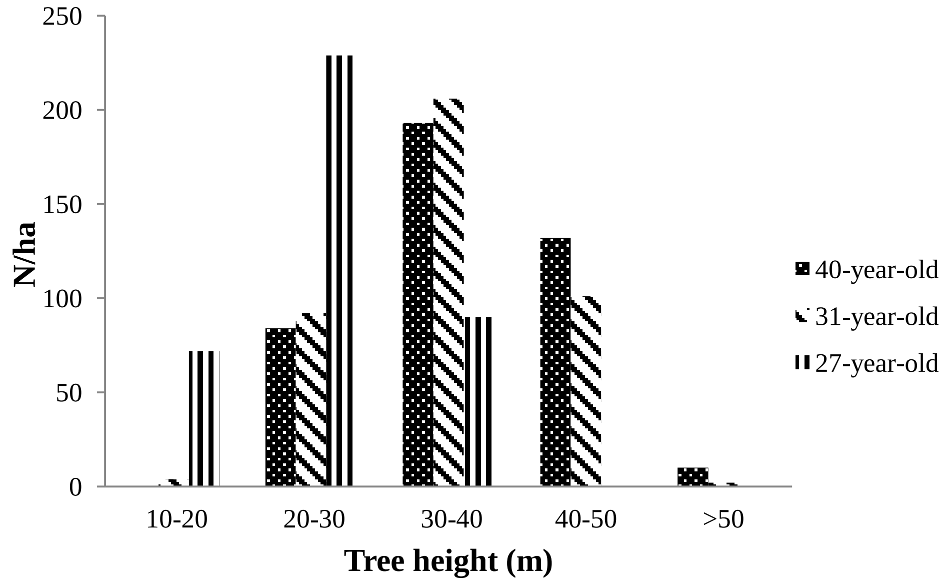

Fig. 3: Height classifications for trees in the different age series in the study area

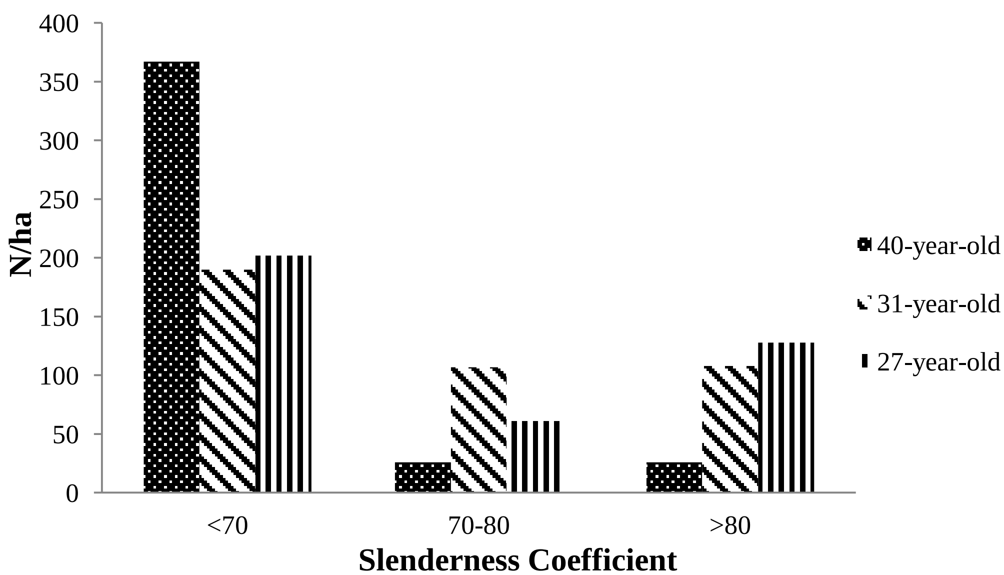

Fig. 4: Tree slenderness classification in the different age series in the study area

The correlation matrix for tree growth variables in the study area is shown in Table 2. Most of the growth variables had significant and positive correlations with each other with fewer variables having weak and negative correlations. There were significant and positive correlation between diameter at breast height (Dbh) and tree total height (THT), merchantable height (MHT), stem quality (SQ), basal area (BA) as well as stem volume (SV) with correlation coefficients (r) of 0.61, 0.61, 0.60, 0.99 and 0.93, respectively. Tree total height (THT) had significant and positive correlations with most of the measured tree growth variables except CL ($r = -0.04$; $P > 0.05$) and CD ($r = -0.15$). Merchantable height (MHT) positively correlated with all other tree growth variables apart from CL (-0.047) and CD (-0.15). Crown length (CL) had positive correlation with crown diameter (CD) and slenderness coefficient (SC) but had negative correlation with stem quality (SQ), basal area (BA) and stem volume (SV), where only stem quality (SQ) was significantly correlated. Stem quality (SQ) had significant and positive correlations with all other tree growth variables except CD (-0.145) and CL (-0.212). Crown diameter (CD) had weak, significant and negative correlations with BA and SV while Basal area (BA) had significant negative and positive correlation with SC (- 0.522) and SV (0.960).

Table 2: Correlation matrix for the tree growth variables in the study area

	Dbh	THT	MHT	CL	SQ	CD	BA	SC	SV
Dbh	1								
THT	0.61*	1							
MHT	0.61*	0.99*	1						
CL	-0.05	-0.04	-0.05	1					
SQ	0.60*	0.99*	0.99*	-0.21*	1				
CD	-0.18*	-0.15*	-0.15*	0.01	-0.15*	1			
BA	0.99*	0.60*	0.60*	-0.05	0.59*	-0.18*	1		
SC	-0.56*	0.30*	0.29*	0.01	0.29*	0.06*	-0.52*	1	
SV	0.93*	0.72*	0.73*	-0.05	0.71*	-0.18*	0.96*	-0.35*	1

** Significant (P <0.05); Dbh - diameter at breast height; THT - tree total height; MHT - merchantable height; CL - crown length; SQ - stem quality; CD - crown diameter; BA - basal area; SC - slenderness coefficient; SV - stem volume*

The yield model assessment results for *Triplochiton scleroxylon* in the study area are presented in Table 3. All the models have good fits, and are suitable for prediction going by their R^2-values and significance of regression. The best model was model 11 for its R^2-value and SEE value of 98.9% and 0.64, respectively.

Table 3: Model assessment results

S/N	Models	R^2	SEE	P-value
1	V= -0.6486 + 26.869BA + 3.56BA^2 + 19.11BA^3	94.2	1.46	0.000
2	V= 35.838 + 81.573(LogBA) + 64.725(LogBA)^2 + 16.815(LogBA)^3	93.4	1.55	0.000
3	V= -3.190 + 0.200Dbh - 0.003Dbh^2 + 0.000045Dbh^3	94.9	1.36	0.000
4	V= -218.703 + 121.848(LogDbh) + 39.349(LogDbh)^2 + 8.074(LogDbh)^3	90.7	1.85	0.000
5	V= -5.239 + 0.600MHT – 1.029MHT^2 + 0.211MHT^3	78.8	2.02	0.000
6	V= 83.437 – 148.867(LogMHT) – 32.114(LogMHT)^2 + 34.743(LogMHT)^3	58.4	5.17	0.000
7	V= -2.498 + 55.781BA + 0.287MHT – 0.111Dbh	90.2	0.99	0.000
8	V= -63.10 - 2.278(LogBA) + 6.123(LogMHT) + 25.226(LogDbh)	89.7	1.00	0.000
9	V= -64.421 – 0.441(*ln*BA) + 4.147(*ln*MHT) + 13.232(lnDbh)	74.7	3.43	0.002
10	V= -3.612 + 0.540Dbh^2 + 22.111BA^2 + 0.453MHT^2	97.8	0.85	0.000
11	V= -0.123 + 0.00673Dbh^3 – 3.419BA^3 + 0.020934MHT^3	98.2	0.64	0.000
12	V= -2.121 + 0.111Dbh + 24.111BA^2 + 0.11154MHT^3	96.4	0.89	0.000

The results of model validation are presented in Table 4. There were significant differences in mean in the mean observed (measured) and predicted values for models 1 to 7 and 9 (P<0.05). However, models 8, 10, 11 and 12 were insignificant with very small bias values, implying more suitability for prediction compared to others, especially models 1 to 7 and 9 (Table 5).

Table 4: Model validation results

S/No.	Models	t_{cal}	Bias	P-value
1	$V= -0.6486 + 26.869BA + 3.56BA^2 + 19.11BA^3$	6.670	0.259	0.002
2	$V= 35.838 + 81.573(LogBA) + 64.725(LogBA)^2 + 16.815(LogBA)^3$	6.466	0.290	0.001
3	$V= -3.190 + 0.200Dbh - 0.003Dbh^2 + 0.000045Dbh^3$	6.209	0.282	0.000
4	$V= -218.703 + 121.848(LogDbh) + 39.349(LogDbh)^2 + 8.074(LogDbh)^3$	6.911	0.312	0.028
5	$V= -5.239 + 0.600MHT – 1.029MHT^2 + 0.211MHT^3$	3.201	0.342	0.000
6	$V= 83.437 – 148.867(LogMHT) – 32.114(LogMHT)^2 + 34.743(LogMHT)^3$	5.623	0.382	0.000
7	$V= -2.498 + 55.781BA + 0.287MHT – 0.111Dbh$	7.237	0.280	0.020
8	$V= -63.10 - 2.278(LogBA) + 6.123(LogMHT) + 25.226(LogDbh)$	6.120	0.209	0.124
9	$V= -64.421 – 0.441(\mathit{ln}BA) + 4.147(\mathit{ln}MHT) + 13.232(\mathit{ln}Dbh)$	6.345	0.372	0.003
10	$V= -3.612 + 0.540Dbh^2 + 22.111BA^2 + 0.453MHT^2$	17.47	0.131	0.245
11	$V= -0.123 + 0.00673Dbh^3 – 3.419BA^3 + 0.020934MHT^3$	17.98	0.102	0.325
12	$V= -2.121 + 0.111Dbh + 24.111BA^2 + 0.11154MHT^3$	17.21	0.131	0.222

DISCUSSION

Most of the trees in the study area, particularly those in the 40-year-old stand were already above the stipulated minimum (48 cm) for timber exploitation in Nigeria, and it is very strange for such not to have been exploited by now. This is perhaps due to the fact that the plantations served dua-purpose of timber production and as a good habitat for *Anaphe venata*, an edible species of insect harvested and consumed by indigenous people in the area. At the inception of the plantation in 1979, during agricultural revolution and export drive, Federal Department of Forestry through Forestry Research Institute of Nigeria established the experimental plot for promotion of *Anaphe venata* export, which thrives very well under *Triplichyton scleroxylon* as the host. However, the objective of management has long been changed to that of timber. Nevertheless, those planted in 1992 are still below the stipulated minimum, implying that the age series (planted 1992) were still under-aged for timber considerations, if sustainable timber production remains the goal of the current management. On the other hand, very few of those planted in 1988 have reached maturity for timber or associated uses. The age differences significantly influenced the tree growths, as there were differences of up to 17 ± 3.5 cm between those planted in 1979 and 1988 (increment of about 1.7 ± 0.35 $cmyr^{-1}$) whereas between 1988 and 1992 stand, 2.8 ± 0.16 $cmyr^{-1}$ were added. Other consideration for this difference were believed to be those attributed to micro-sites, and perhaps due to irregular spacing. These had possibly affected the growth rate of trees for varied competitive factors. Stand with wider spacing tends to experience faster diametric growths compared to those with narrower spacing. This agrees with the findings of Eliakimu *et al.* (2015), who noted that there was a significant increase in diameter of a tree stand with increase in spacing among tree stems. This is because trees in such condition may have taking the advantages of wider growing space, and utilize same more effectively for root and crown developments since there would be reduced competitions. However, for timber considerations, increased spacing and growing space have tendency of negatively impacting the lumber recovery efficiencies. As observed by Iddi *et al.* (2010), increase in mean Dbh of trees in wider spacing may or may not be an advantage depending on market considerations since it enhances stem tapering and reduces lumber recovery during log conversion.

The very low slenderness coefficients of most tree stems in the area could be explained by the fact that tree diameters and height have direct correlations, an increase in one resulting in an increase in the other. This implies high stability, and low susceptibility to wind-induced damage or breakage. This is similar to the findings of Adeyemi and Ugo-Mbonu (2017), who reported low slenderness coefficient for most *Gmelina* stems. However, this may be atypical of *Triplochyton scleroxylon*. Nevertheless, microsite or better site quality may have played a role in this scenario, as the species was believed to have disproportionate net height-diameter growth with the height overweighing the girth (diameter). According to Adeyemi and Adesoye (2016), trees with high slenderness coefficient are more susceptible to breakage than those with low slenderness coefficients. The desirable height/Dbh ratios for adequate wind resistance vary according to species and country. In general, trees with a higher slenderness coefficient are much more susceptible to damage than trees with low slenderness coefficient (Ige, 2017). Stand with less density tends to have more trees with high slenderness coefficient. This may be due to the fact that those in this categories were younger in terms of age, and there were still hope for rapid height horizontal structural development, which might compensate for the vertical growth. The result indicates that tree slenderness coefficient values tend to decrease for larger trees and the largest slenderness coefficient values occur for the trees with small Dbh. This is in consonance with the works of Onyekwelu *et al*. (2003), Eguakun and Oyebade (2015) and Ige (2017).

The assessment result for the models using R^2, SEE and F-test revealed that all the models are significant and good for yield prediction. Low SEE value is noted to be a good indicator of fit for regression models (Adekunle, 2007; Adeyemi and Adesoye, 2010; Shuaibu and Alao, 2016). In this study, standard error of estimate (SEE) values of models ranged between 0.638 and 4.169. The validation results for the models, however, showed that most of the models were significant while models 8, 10, 11 and 12 were not significant and have small bias values, which depict better suitability for yield predictions. Although, models 10 and 12 are good, model 11 is preferred for future yield prediction in any of the three stands of *Triplochiton scleroxylon* in Onigambari Forest Reserve.

CONCLUSION

This study tested the efficacy of twelve (12) models for yield prediction in stands of *Triplochiton scleroxylon* in Onigambari Forest Reserve. The result has shown that only 1979 stand and a few stems in the 1988 stand are ripe, if any timber harvest is planned with sustainability in view. For 1988 and 1992 stands to be considered for partial harvesting, if need be, between 10 and 12 more years are required for growth and development in those stands to ensure sustainability. However, non-consumptive uses of *Anaphe venata* cocoons seems to be more lucrative, as this has kept the locals very busy. This can be strengthened to benefit those responsible for the management of the three plantations. Although the original intension of the Federal Government was to champion this course in West Africa (producing and exporting cocoons and the edible insect), this has been affected by government policy summersault, political instability and discontinuity, with the area now being managed for timber. The trees appear to be vigorous and structurally stable, and no signs of encroachment were yet seen. However, as pressure mounts, and there are increasing demands for timber, much needs to be done to prevent destruction in those plantations. Most of the developed models were not good for prediction going by their efficiencies and validation results. However, three of the models were good as they have low bias values, and the test of comparison between the observed and the predicted values were not significant. The best model developed was of the form: $V = -0.123 + 0.00673Dbh^3 - 3.419BA^3 + 0.020934MHT^3$ with R^2, SEE and bias values of 98.2%, 0.644 and 0.102, respectively. It is therefore recommended for prediction in the study area.

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