



Forest structure analysis and yield models for tree species in Okeluse Forest Reserve,
Ose LGA, Ondo state, Nigeria

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ABSTRACT

To attain a sustainable forest management decision, accurate information is needed on structure and growth of major forest components. This information can be derived by using functional forest models. Therefore, the study involved formulating site-specific models for yield prediction in Okeluse Forest Reserve, Ondo State, Nigeria. Systematic sampling technique was adopted with 20 1-km-long transects laid at 500 m intervals. Four plots (50 × 50 m) were laid alternately at 250 m intervals, along each of the transects. A total of 80 sample plots were used for the study. All trees with diameters (Dbh) ≥ 10 cm were measured for diameter, height, stem quality and crown length. All measured trees were identified to species-level. Data were analysed, using descriptive statistics and regression analysis. The yield-prediction models were evaluated, using root mean square error (RMSE), R^2 , Akaike information criterion (AIC) and F-test. Models were validated, using paired-sample t-test and absolute bias. Seventeen tree species, belonging to 12 families, were encountered. *Lophira alata* occurred most with RD of 15.9%. Four (4) of the species encountered (i.e., *Azelia africana*, *Entandrophragma cylindricum*, *Lophira alata* and *Pterygota macrocarpa*) were vulnerable. Seven (7) of the tree species (i.e., *Albizia lebbek*, *Anogeissus leiocarpus*, *Antiaris toxicaria*, *Blighia sapida*, *Ceiba pentandra*, *Mansonia altissima* and *Triplochytton scleroxylon*) were least concern. The mean species importance value index was 75.74 ± 25.59 . Average basal area and stem volume were $31.47 \pm 8.91 \text{ m}^2$ and $125.89 \pm 35.64 \text{ m}^3/\text{ha}$, respectively. Most of the trees had low slenderness coefficient, indicating excellent stability and low susceptibility damage. The best yield-prediction model was of the form: $V = -55.234 + 0.9863(\ln Dbh) - 2.114BA^2 + 0.3492MHT$ with R^2 , RMSE, AIC and absolute bias of 88.5%, 1.02, 57.62 and 0.210, respectively. The model also showed no significant difference in the mean observed and predicted yield values. It is therefore recommended for future predictions in the study area.

Keywords: Tree species composition; stand density; yield prediction models

INTRODUCTION

Understanding forest structure is essential for sustainable forest management practices, such as timber harvesting, reforestation and biodiversity conservation (Adeyemi *et*

al., 2015. Tree is defined as the totality of vegetation taller than 5 m in height. However, Hansen *et al.* (2013) defined tree cover as the biophysical presence of tree and may assume the form of natural forests or plantations existing over a range of canopy densities. Forest management is currently perceived as an activity aiming at both sustaining wood production and providing firewood, food, other goods and services to burgeoning populations. Forests should be managed sustainably because they are the centres for cultural, spiritual, and recreational activities (Mammo *et al.*, 2016).

Yield modelling in forestry involves using mathematical models to predict the future growth, volume and biomass of forest stands under various management scenarios, providing crucial information for decision-making in forest management and planning (Fortin and Langevin, 2011). These models help foresters anticipate timber production, assess the impact of silvicultural treatments like thinning, and contribute to broader analyses like carbon stock estimation and economic evaluations. Yield prediction is an essential activity in forest management, especially for the production of commercially important outputs such as fuelwood and sawn timber. Often times, it is necessary to predict the future growth scenarios, even before the establishment of plantations or at the very early stages. The results of such estimations will be used for planning purposes and necessary calculations such as expenses and profits. Mathematical models play a vital role in predicting those values for effective planning.

In sustainable forest management and forestry decision-making, there is a continuous need for high quality information on forest resources (Aertsens *et al.*, 2010), which, sometimes, are unavailable. 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). Hitherto, this information is unavailable for tree species at Okeluse Forest Reserve.

In Nigeria, considerable work has been done by many researchers on different species at different forest in the development of volume equations using models, based on the height-diameter relationship. For instance, *Pinus caribaea* in South-West Nigeria (Adesoye, 2014), tree species in Oban Forest (Adeyemi and Adesoye, 2016), *Gmelina arborea* stand in Edondon *Gmelina* Plantation, Cross River State (Adeyemi and Ukaegbu, 2016), *Tectona grandis* stands in Omo Forest Reserve (Chukwu and Osho, 2017), Teak stands in Nimbria Forest Reserve (Shamaki *et al.*, 2011) among several others. However, little work has been done at Okeluse Forest Reserve in that regard.

In addition, yield models are invaluable for providing useful information for effective planning and management of forest resources (Adeyemi and Ukaegbu, 2016). For timber production, as well as other purposes, an estimate of growing stock is often expressed in terms of timber volume. However, this is not yet in place for the study area. Sustainable forest and Forest resources management require reliable estimates of growing stock. This is because such information guides forest managers in timber evaluation as well as in the allocation of forest areas for harvest (Adeyemi and Adesoye, 2010; Adesoye, 2014). For timber production as well as other purposes, an estimate of growing stock is often expressed in terms of timber volume, which can be estimated from easily measurable tree dimensions such as stem diameter and tree height.

The potential of yield models in planning future harvests and to ensure sustainable harvests in Okeluse Forest Reserve has not been explored. The main objective of the study is

to develop yield prediction models for trees species in Okeluse Forest Reserve. The development of effective and accurate models to predict forest growth and products during the forest rotation is essential for forest managers and planners. Decision-makers need information on the present yield of the forest for the purpose of monitoring growth (Ade-oni *et al.*, 2016). Hence, accurate inventory information has to be obtained about the tree characteristics in Okeluse Forest Reserve for yield modelling. Models need to be continually updated to reflect current management practices.

MATERIALS AND METHODS

The Study Area

The study was carried out at Okeluse Forest Reserve in Ose Local Government Area (LGA) of Ondo State, Nigeria. The forest reserve is about 14,400 ha, and it is located between latitudes 6°43'0" and 6°50'0"N, and between longitudes 5°33'30" and 5°47'30"E. Okeluse is about 5 km south-west of Ifon. It is bordered in the north by Ute and in the south by Ogbesse in Edo State. Okeluse is one of the 12 forest reserves in Ondo State.

The climate of the forest reserve is tropical with average annual rainfall of about 1500 mm, while the relative humidity is 94%. The wind speed of the reserve is 00 m/s with a mean temperature of about 23°C. The study area is located within the rain forest zone of south-west Nigeria.

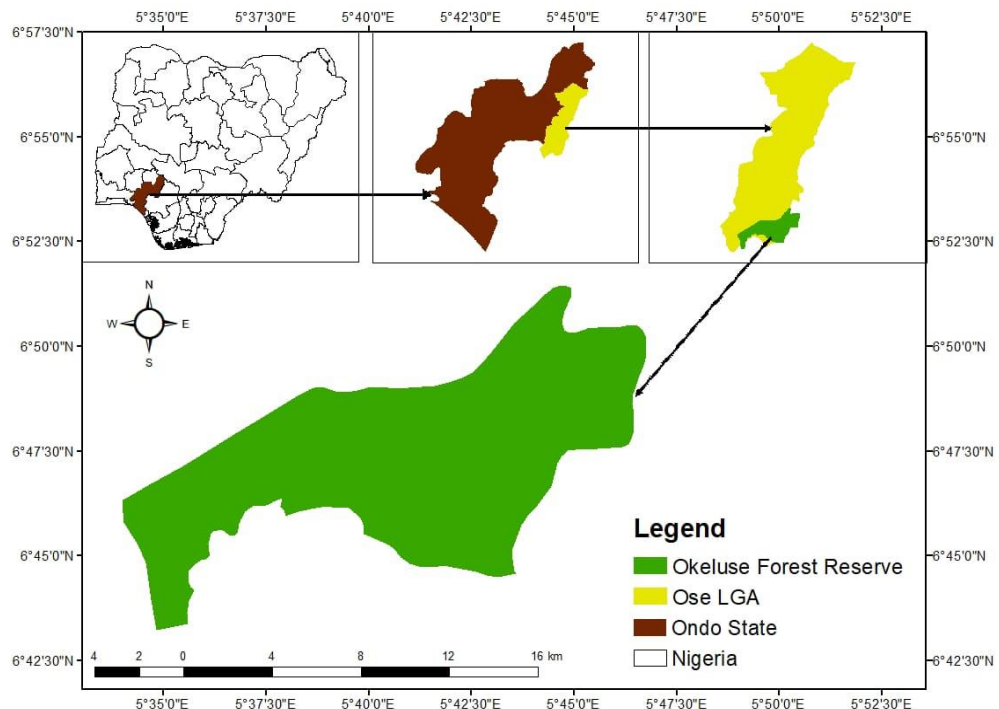


Figure 1: Map of the study area

Sampling Procedure and Data Collection

Systematic sampling technique was adopted for sample plot location. Twenty (20) transects of 1 km long, evenly distributed over the forest reserve were laid at 500 m interval. Four (4) plots of 50 × 50 m (0.25ha) were then laid alternately at 250 m intervals, along each transects. A total of 80 sample plots (20 ha) were used for the study. In the sample plots study area, all living trees with Dbh ≥10 cm were identified by species-to-species levels and measured. Tree growth parameters, including diameters at the base, breast height (Dbh), middle and merchantable top; tree heights; stem quality (SQ); crown length and crown diameter, were measured using diameter tape and Spiegel Relaskop. All other important species with Dbh value below 10 cm were recorded. All the identified species were classified based on their IUCN status using IUCN Red List of Threatened Species (IUCN, 2024).

Data Analysis

Relative density

Species relative density (RD) for each of the tree species was determined using:

$$RD(\%) = \left(\frac{n_i}{N} \right) \times 100 \dots \dots \dots (1)$$

Where:

n_i = number of individual species;

N = total number of species in the sampled area.

Relative frequency

The relative frequency of individual species was computed as follows:

$$RF = \frac{n_i}{N_i} \times 100 \dots \dots \dots (2)$$

Where:

Rf = Relative frequency of species;

n_i = number of individuals of each species;

N_i = total number of all tree species observed in the plots studied or sampled plots.

Relative dominance

The relative dominance of the species was computed as follows;

$$RD_o = \frac{BA_s}{BA_T} \times 100 \dots \dots \dots (3)$$

Where:

RD_o = Relative dominance of species;

BA_s = Total basal area of a species (involving addition of all trees basal areas per species, as computed in equation 5 below);

BA_T = Total basal area of all species (summation of all individual tree basal areas for species in the sampled plots).

Importance value index (IVI)

The importance value index (IVI) was computed as follows:

$$IVI = \sum RF + RD_o + RD \dots \dots \dots (4)$$

Where:

Rf = Relative frequency of species (%);

RD_o = Relative dominance of species (%);

RD = Relative density of species (%).

Basal area

Tree basal area of each tree was computed, using:

$$BA = \frac{\pi D^2}{4} \dots \dots \dots (5)$$

Where:

D = diameter at breast height (m).

Slenderness coefficient

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

$$SC = \frac{THT}{DBH} \dots \dots \dots (6)$$

Where: THT = total height (m); Dbh = diameter at breast height (m).

Individual trees were grouped into slenderness coefficient classes as: high (with SC: >80); moderate (with SC: 70-80) and low (with SC: <70) (Adeyemi and Adesoye, 2016; Ige, 2017; Shamaki and Oyelade, 2022).

Tree volume computation

The volume of each tree was calculated in every plot using Newton's formula (Husch *et al.*, 2003):

$$V = \left(\frac{h}{6}\right) (a_b + 4 a_m + a_t) \dots \dots \dots (7)$$

Where:

V = tree volume (m³); a_b, a_m, a_t = tree cross-sectional area at the base, middle and top of merchantable height, respectively (m); h = total height (m).

Plot volume was obtained by adding the volumes of all the trees in the plot. Tree volume per hectare was obtained by averaging the plots' volumes and multiplied by 4 (each plot is 0.25ha).

Descriptive statistics and correlation analysis

Descriptive statistics such as mean and graphs were used to summarize tree growth parameters and stand variables. Karl Pearson's Correlation analysis was also conducted to examine linear relationships among measured and tree growth variables and stand parameters.

Model calibration

The following yield functions were tried amongst others:

$$V = a + b_1SQ^2 + b_2SC^2 + b_3Dbh \dots \dots \dots (8)$$

$$V = a + b_1Db^3 + b_2MHT^3 + b_3\log Db \dots \dots \dots (9)$$

$$V = a + b_1Db + b_2Dbh + b_3\log SC \dots \dots \dots (10)$$

$$V = a + b_1\log SQ^2 + b_2SC + b_3BA \dots \dots \dots (12)$$

$$V = a + b_1\log Db + b_2MHT^3 + b_3Db \dots \dots \dots (13)$$

$$V = a + b_1\ln Dbh + BA^2 + MHT \dots \dots \dots (14)$$

$$V = a + b_1Db + b_2BA + THT^2 \dots \dots \dots (15)$$

$$V = a + b_1DB + b_2THT^3 + B_3BA^3 \dots \dots \dots (16)$$

$$V = a + b_1\ln(MHT) + MHT^2 + MHT^3 \dots \dots \dots (17)$$

$$V = a + b_1Db + b_2BA^2 + b_3THT^2 \dots \dots \dots (18)$$

Where:

V = stem volume; SQ = stem quality; MHT = tree merchantable height; BA = basal area (m³), Dbh = diameter at breast height (m), SC = slenderness coefficient; DB = diameter at the base; MHT = Merchantable height (m), and a, b₁, b₂ and b₃ = estimate of regression parameters.

Models Assessment

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

Coefficient of Determination (R²): This is the measure of the proportion of variation in the dependent variables that is explained by the behaviour of the independent variables. For the model to be accepted, the R² value must be high (>50%):

$$R^2 = 1 - \frac{SSE}{SST} \dots \dots \dots (19)$$

Where: SSE = sum of squares error and SST = sum of squares total.

Root mean square error (RMSE): The absolute root mean square error (RMSE) was computed using:

$$RMSE = \sqrt{\sum_{i=1}^n (V_i - \lambda_i)^2 / n} \dots \dots \dots (20)$$

Where: n = number of sample stands; V_i = computed tree volume variables; λ_i = volume estimated from the models.

Akaike Information Criterion (AIC): Also, Akaike Information Criterion (AIC) was used as a model selection criterion. The lower the AIC value, the better the model:

$$AIC = 2k - 2\log(L) \dots \dots \dots (21)$$

Where: k = number of estimated parameters in the model; L = the maximized value of the likelihood function for the model.

Models Validation

Model validation was achieved by dividing the collected data into two sets. The first dataset was used for calibrating the models (model formulation or calibration set), while the second dataset (model-validation set) was used for validating the models. The following statistics were then computed for validating the formulated models.

Paired sample t-test: This was used to test for any significant difference between the actual values or field values and the predicted values (model output) of the various models adopted.

Bias: The absolute percentage difference will be determined by dividing the difference between estimated values and models output by the same observed volume and multiplied by 100.

$$\text{Bias} = \sum \frac{v_2 - v_1}{v_2} \dots \dots \dots (22)$$

Where: v_2 = actual (observed) volume; v_1 = predicted volume from the model.

RESULTS

Tree Species Composition in the Study Area

A total of Seventeen (17) tree species belonging to 12 families of trees were encountered within the sampled plots. *Lophira alata* occurred the most with relative density (RD) of 15.9% (Table 1).

Table 1: Tree species compositions in the study area

S/N	Species	Family	n/ha	RD (%)	IUCN
1	<i>Azelia africana</i>	<i>Fabaceae</i>	11	2.5	VU
2	<i>Albizia lebbbeck</i>	<i>Fabaceae</i>	22	5.1	LC
3	<i>Anogeissus leiocarpa</i>	<i>Combretaceae</i>	5	1.2	LC
4	<i>Antiaris africana</i>	<i>Moraceae</i>	24	5.5	NE
5	<i>Antiaris toxicaria</i>	<i>Moraceae</i>	23	5.3	LC
6	<i>Blighia sapida</i>	<i>Sapindaceae</i>	16	3.7	LC
7	<i>Ceiba pentandra</i>	<i>Bombaceae</i>	25	5.8	LC
8	<i>Daniella ogea</i>	<i>Caesalpiniaceae</i>	35	8.1	NE
9	<i>Entandrophragma cylindricum</i>	<i>Meliaceae</i>	27	6.2	VU
10	<i>Lophira alata</i>	<i>Ochnaceae</i>	69	15.9	VU
11	<i>Mansonia altissima</i>	<i>Malvaceae</i>	15	3.5	LC
12	<i>Milicia excelsa</i>	<i>Moraceae</i>	26	6	NE
13	<i>Nauclea diderrichii</i>	<i>Rubiaceae</i>	35	8.1	NE
14	<i>Pterygota macrocarpa</i>	<i>Sterculiaceae</i>	25	5.8	VU
15	<i>Tectona grandis</i>	<i>Lamiaceae</i>	27	6.2	NE
16	<i>Terminalia superba</i>	<i>Combretaceae</i>	33	7.6	NE
17	<i>Triplochiton scleroxylon</i>	<i>Malvaceae</i>	16	3.7	LC
Total			434	100	

N.B.: IUCN - International Union for Conservation of Nature; VU - vulnerable; LC - least concern, NE - not evaluated

The least-occurring species were *Anogeissus leiocarpa* with Relative density of 1.2%, *Afzelia africana* with relative density of 2.5%, *Mansonia altissima* with RD of 3.5% and *Triplochiton scleroxylon* with relative density of 3.7%. The *Moraceae* was observed to be the most encountered family in the area. Four (4) of the tree species encountered in the area were Vulnerable (Vu), based on the IUCN classification, representing 23.5% of the encountered tree species, while Seven (7) of the tree species encountered were least concerned (LC) based on the IUCN classification, representing 41.2% of the encountered tree species. Six (6) species have not been evaluated (NE) against the IUCN-standard, representing 35.3% of the identified species as presented in Table 1.

Table 2 presents the species composition and importance value index (IVI) within the area. *Lophira alata* was predominant, with relative density (15.9%), frequency (100%), dominance (24.4%) and importance value index of 140.3%. The mean species importance value index was 75.7 ± 25.6 .

Table 2: Relative frequency, density, dominance and importance value index of trees in the study area

S/N	Species	Family	RF (%)	RD (%)	RD _o	IVI
1	<i>Afzelia africana</i>	<i>Fabaceae</i>	2.9	2.5	1.45	35.2
2	<i>Albizia lebbbeck</i>	<i>Fabaceae</i>	5.7	5.1	4.58	72.2
3	<i>Anogeissus leiocarpa</i>	<i>Combretaceae</i>	2.9	1.2	1.01	33.4
4	<i>Antiaris africana</i>	<i>Moraceae</i>	7.0	5.5	4.00	84.5
5	<i>Antiaris toxicaria</i>	<i>Moraceae</i>	6.3	5.3	5.58	79.6
6	<i>Blighia sapida</i>	<i>Sapindaceae</i>	4.7	3.7	1.95	55.6
7	<i>Ceiba pentandra</i>	<i>Bombaceae</i>	5.1	5.8	2.72	64.7
8	<i>Daniellia ogea</i>	<i>Caesalpiniaceae</i>	7.4	8.1	7.11	96.4
9	<i>E. cylindricum</i>	<i>Meliaceae</i>	7.4	6.2	8.30	95.8
10	<i>Lophira alata</i>	<i>Ochnaceae</i>	8.7	15.9	24.38	140.3
11	<i>Mansonia altissima</i>	<i>Malvaceae</i>	4.1	3.5	4.13	51.3
12	<i>Milicia excelsa</i>	<i>Moraceae</i>	6.4	6.0	6.35	81.1
13	<i>Nauclea diderrichii</i>	<i>Rubiaceae</i>	7.0	8.1	8.78	91.9
14	<i>Pterygota macrocarpa</i>	<i>Sterculiaceae</i>	7.0	5.8	5.06	85.8
15	<i>Tectona grandis</i>	<i>Lamiaceae</i>	5.1	6.2	3.17	65.6
16	<i>Terminalia superba</i>	<i>Combretaceae</i>	7.0	7.6	7.21	89.8
17	<i>T. scleroxylon</i>	<i>Malvaceae</i>	5.3	3.7	4.21	64.2
Mean			5.9	5.9	5.88	75.7
SD			1.6	3.2	5.29	25.6

Summary Statistics and Correlation Results

The descriptive statistics for tree growth parameters in the study area are presented in Table 3. Tree Db ranged between 20.37 and 214.83 cm with a mean of 74.70 ± 28.79 cm. Tree Dbh ranged between 9.23 and 159.13 cm with a mean of 62.77 ± 26.04 cm. Tree total heights (THT) were between 7.70 and 29.41 m with a mean of 19.77 ± 4.15 m. Tree merchantable heights (MHT) ranged between 4.90 and 25.40 m with a mean of 15.14 ± 4.12 m. Tree stem quality (SQ) ranged between 3.21 and 88.00 m with a mean of 11.22 ± 5.26 m. Tree basal area ranged between 18.09 and 50.46 m²/ha with a mean of 31.47 ± 8.91 m²/ha. Tree volume ranged between 72.3 and 201.83 m³/ha with a mean of 125.89 ± 35.64 m³/ha.

Table 3: Descriptive statistics for tree growth variable in the study area

Growth variables	Mean $\pm$ SD	Minimum	Maximum
Db (cm)	74.70 $\pm$ 28.79	20.37	214.83
Dbh (cm)	62.77 $\pm$ 26.04	9.23	159.13
THT(m)	19.77 $\pm$ 4.15	7.70	29.41
MHT(m)	15.14 $\pm$ 4.12	4.90	25.40
SQ(m)	11.22 $\pm$ 5.26	3.21	88.00
CD(m)	11.40 $\pm$ 48.65	2.98	1021.00
BA/ha(m ²)	31.47 $\pm$ 8.91	18.09	50.46
V/ha(m ³)	125.89 $\pm$ 35.64	72.34	201.83
SC	37.06 $\pm$ 17.98	11.00	156.56
N/ha	86.8 $\pm$ 12.66	68	20

NB.: Db = diameter at the base; Dbh = diameter at breast height; THT= tree total height; MHT= merchantable height; SQ = stem quality; BA= basal area; SC = slenderness coefficient; V = stem volume

The correlation matrix for tree growth variables in the study area is presented in Table 4. The result showed that most of the growth variables had significant and positive correlations with one another, with fewer variables having weak and inverse correlations.

Table 4: Correlations among tree growth variables in the study area

	Db	Dbh	THT	MHT	SQ	CL	CD	BA	V
Db (cm)	*1.00								
Dbh (cm)	*0.92	*1.00							
THT (m)	*0.46	*0.49	*1.00						
MHT (m)	*0.52	*0.54	*0.88	*1.00					
SQ (m)	*0.28	*0.30	*0.58	*0.64	*1.00				
CL (m)	*0.09	*0.10	*0.25	*0.06	*-0.65	*1.00			
CD (m)	*0.10	*0.08	0.03	*0.08	0.02	0.00	*1.00		
BA (m ²)	*0.91	*0.97	*0.46	*0.50	*0.29	*0.09	*0.07	*1.00	
V(m ³)	*0.76	*0.73	*0.47	*0.48	*0.29	*0.10	*0.06	*0.76	*1.00
SC	*-0.66	*-0.75	-0.01	*-0.15	0.03	-0.04	-0.05	*-0.63	*-0.40

NB.: Db = diameter at the base; Dbh = diameter at breast height; THT= tree total height; MHT= merchantable height; SQ = stem quality; BA= basal area; SC = slenderness coefficient; V = stem volume

Diameter at the base had negative correlation with Slenderness coefficient ($r = -0.66$). Diameter at breast height, tree total height (THT), merchantable height (MHT), crown length (CL), crown diameter (CD), basal area (BA) and volume (V) had positive correlations with the entire measured tree growth variable except slenderness coefficient (SC). Stem quality (SQ) had significant and positive correlations with all other tree growth variables apart from CL ($r = -0.65$) and the correlation values with CD and SC were not significant ($r = 0.02$) and ($r = -0.05$), respectively.

Diameter, Height and TSC Class Distribution

Figure 2 presents tree diameter classes in study area. About 5 trees/ha belong to the diameter 10-20 cm, having the least number of trees/ha. There were 43 trees/ha in the diameter class 20-30 cm. About 44 trees/ha were in diameter class 30-40 cm with 50 trees/ha

in the diameter class 40-50 cm. The diameter class >50 cm has the highest number of trees 292 trees/ha.

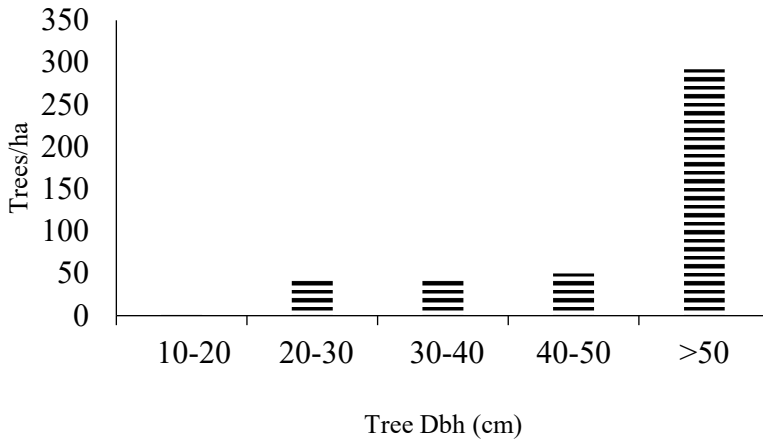


Figure 3: Diameter class of trees in the study area

The tree height classifications in the study area are shown in Figure 3. There were 3 trees/ha in the height class of <10 m, which constituted 0.7%. There were 43 trees/ha (9.9%) in the height class of 10-15 m. About 161 trees/ha were in height class of 15-20 m, constituting 37.1%. The height class of 20-25 m had 170 trees/ha, representing 39.2% of the trees encountered. The class of >25 had 57 trees/ha, which is 13.1%.

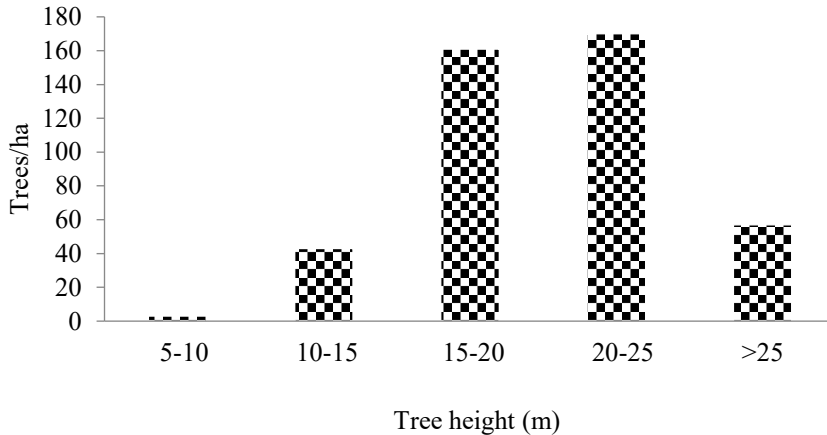


Figure 4: Tree height classifications in the study area

Tree slenderness coefficient classifications for the stand are shown in Figure 4. The majority (92.4%) of trees/ha belong to SC <70 indicating low susceptibility to windthrow by the greater percentage of trees found in the study area. There were 19 trees/ha in the class 70-80, about 4.4% of trees/ha. There were 14 trees/ha in the SC >80 (3.2%).

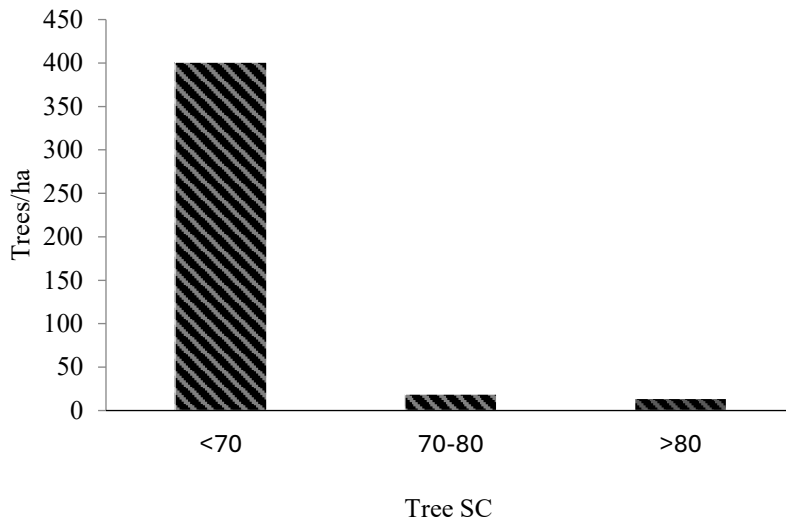


Figure 5: Tree slenderness coefficient classification in the study area

Fitted Yield Models

The fitted yield models for trees species in the study area are presented in Table 5. All the models are good for prediction going by their R^2 -values and significance of regression ($P < 0.05$). The RMSE values were very small (Table 5). All the models had R^2 -value $> 50\%$. The best was model 6 ($R^2 = 88.5\%$, RMSE = 1.02, AIC = 65.90).

Table 5: Formulated models for Okeluse Forest Reserve

S/N	Models	R^2	RMSE	AIC	F	P-value
1.	$V = -0.566 + 54.453SQ^2 + 9.234SC^2 + 13.450 Dbh$	54.2	5.21	132.61	897.63	0.00
2	$V = 45.453 + 232.456Dbh^3 + 34.344THT^3 + 4.2345LogDb$	58.2	5.82	158.02	986.12	0.00
3	$V = 34.233 + 45.325Db + 443.233Dbh + 0.0034 LogSC$	62.4	4.69	92.73	888.12	0.00
4	$V = -3.343 + 13.345LogSQ^2 + 23.342SC + 5.345BA$	60.1	4.23	76.85	783.39	0.00
5	$V = 3.234 + 65.234LogDb + 34.123THT^3 + 0.4302Db$	64.2	5.01	93.32	1001.41	0.00
6	$V = -55.234 + 0.9863(lnDbh) - 2.114BA^2 + 0.3492THT$	88.5	1.02	65.90	2104.53	0.00
7	$V = 34.556 + 55.781BA + 0.3342Db - 34.233 THT^2$	60.2	5.16	107.51	999.23	0.00
8	$V = 65.222 - 2.278Db + 13.343THT^3 + 34.234BA^3$	59.7	5.92	211.45	995.12	0.00
9	$V = -45.51 + 0.04543(lnMHT) - 3.342MHT^2 + 0.1231MHT^3$	85.2	1.24	71.37	2348.19	0.00
10	$V = 854.22 + 0.3432Db + 34.222BA^2 + 13.212THT^2$	57.8	5.62	154.05	967.12	0.00

RMSE= Residual mean square error; AIC = Akaike information criterion

The results of model validation are presented in Table 6. The results showed that there were significant differences between the observed (measured) and the predicted mean merchantable volumes under most models ($p < 0.05$) excluding models 6, 7, 8, 9 and 10, which showed that there was no significant difference between observed and the predicted values ($p > 0.05$). The most suitable model was model 6, with the least bias.

Table 6: Model validation results

S/N	Models	t	p-value	bias
1	$V = -0.566 + 54.453SQ^2 + 9.234SC^2 + 13.450 Dbh$	9.123	0.002	0.464
2	$V = 45.453 + 232.456Db^3 + 34.344THT^3 + 4.2345LogDb$	8.345	0.001	0.400
3	$V = 34.233 + 45.325Db + 443.233Dbh + 0.0034 LogSC$	9.342	0.000	0.531
4	$V = -3.343 + 13.345LogSQ^2 + 23.342SC + 5.345BA$	8.321	0.028	0.432
5	$V = 3.234 + 65.234LogDb + 34.123THT^3 + 0.4302Db$	7.432	0.000	0.551
6	$V = -55.234 + 0.9863(lnDbh) - 2.114BA^2 + 0.3492THT$	13.890	0.148	0.210
7	$V = 34.556 + 55.781BA + 0.3342Db - 34.233 THT^2$	9.430	0.230	0.465
8	$V = 65.222 - 2.278Db + 13.343THT^3 + 34.234BA^3$	9.342	0.124	0.509
9	$V = -45.51 + 0.04543(lnMHT) - 3.342MHT^2 + 0.1231MHT^3$	13.940	0.281	0.301
10	$V = 854.22 + 0.3432Db + 34.222BA^2 + 13.212THT^2$	8.343	0.245	0.131

DISCUSSION

Seventeen (17) tree species belonging to 12 families identified in this study were lower than the figures reported for other tropical rain forests. The low species occurrence and flora diversity in the area are a result of consistent exploitation of timber and non-timber species, especially by unauthorized persons, who encroached in search of industrial round wood. This has negatively impacted biodiversity in the reserve. The current rate of wood and non-wood harvestings run contrary to the principle of sustainable forest management, because most of the felled trees were neither replaced within, nor artificial regenerations occurring anywhere else outside the disturbed areas. Okeluse Forest Reserve has been faced with a lot of anti-biodiversity interventions. In recent times, part of the reserve had been concessioned by the state government for commercial agriculture, which would further impoverish the degraded forest in no distant time, as over-exploitation complicates good forest management options. For instance, Aigbe and Godwin (2015) recorded 72 tree species in 30 families in Oban Forest Reserve while Haastrup *et al.* (2015) recorded 43 tree species in 20 families for Onigambari Forest Reserve due to reduced exploitation rate in those areas. The very limited number of tree species was a consequence of continued overexploitation. The reserve is devoid of young trees as a result of negative impacts illegal logging, which damaged the understory vegetation. However, the area was higher in terms of species diversity compared to 10 tree species belonging to 8 families reported for Ohaji/Egbema watershed in Imo state (Ibe *et al.*, 2014). Very few IUCN Red-listed tree species were encountered since most of the species were choice species for timber and have not been spared by the illegal loggers. Many of the species were being exploited before they reach maturity, which could enhance higher productivity in the forest, if they had been allowed to flourish and act as mother trees.

Nevertheless, the mean Dbh of 62.77 ± 26.04 cm in the area was higher than 48 cm stipulated as the minimum merchantable size by logging policy of Nigeria for a tropical rain forest, as cited by Adeyemi and Ukaegbu (2017). The concentration of trees in the Dbh class >50 cm is a sign of extreme case of forest depletion, as trees in the lower diameter classes

were also cleared in the course of forest clearance for illegal farming. Only few ones were retained to provide shade. On the other hand, regenerations have been badly hampered and most of the mother trees reduced. This corroborates the findings of Adekunle (2014), who noted that there are species with high Dbh of 68 cm in protected areas, but due to dissimilar factors. This is however contrary to the findings of Jimoh *et al.* (2012), who observed that Oban Division of Cross River National Park was characterized by dominance of tree species in lower diameter classes. Also, the diameter and height distributions, which show the horizontal structure and vertical pattern of the forest, respectively, are an indication that these forests have the ability for continuous growth (Aladesanmi *et al.*, 2020). Nevertheless, this is only possible if overexploitation and forest degradation are discontinued.

Most of the trees had low slenderness coefficient, which is very good for excellent stability and low susceptibility to wind-induced damage or breakage. According to Rudnicki *et al.* (2004) and Kontogianni *et al.* (2011), only trees with values above a threshold of 80 are prone to wind-induced breakage while forest trees with slenderness coefficient below 80 indicate excellent stability. Similarly, Adeyemi and Adesoye (2016) noted that trees with high slenderness coefficients are more susceptible to breakage than those with low slenderness coefficients.

The mean basal area $31.47 \pm 8.91 \text{ m}^2$ recorded in the study area was higher than the suggested minimum (15 m^2) for a well-stocked natural forest in Nigeria as noted by Alder and Abayomi (1994). Similarly, it was higher than the value of 11.39 m^2 reported by Akinsanmi and Akintunde (2016). The higher basal area may be due to the fact that the samples were concentrated within the area with reasonable densities, and it is expected that density and stocking would affect the basal area per unit area. However, if extrapolations are to be made, in terms of trees per hectare, which should range between 300 and 700 trees per hectare, the reserve is very deficient with an average of 68 trees per hectare.

The best yield prediction model is of the form: $V = -55.234 + 0.9863(\ln Dbh) - 2.114BA^2 + 0.3492THT$ ($R^2 = 88.5\%$; RMSE = 1.02; AIC = 65.90), having a very low bias. According to Adekunle (2007), Adeyemi and Adesoye (2010), models with high R^2 and low RMSE demonstrate extensive suitability. Percentage bias less than 30% is an indication of good fit models (Adekunle, 2007). The less the percentage bias, the better the suitability of the model for volume prediction. Models 6, 9 and 10 have less percentage bias and are good for predicting timber yield in the study area, but model 6 remained the best for that purpose.

CONCLUSION

Majority of the tree species identified in the study area belong to *Moraceae* family. However, most tree species in the study area are of least concern and some have not been evaluated as four vulnerable tree species, according to IUCN-standard. Although the reserve has witnessed a profound rate of overexploitation in recent years with greater negative impacts on the small-diameter trees, leaving the area with staggering number of trees in diameter $>50 \text{ cm}$, thus making the diameter a good predictor of yield along with basal area and tree height. This study has shown that the numbers of tree species in the study area are limited due to high rate of deforestation, but most of the tree stem were in stable conditions which implies good vigour and could withstand wind-induced damage.

Although two of the developed models (i.e., models 6 and 9) have very good predictive abilities for yield estimation in the forest reserve, the most suitable model is of the form $V = -55.234 + 0.9863\ln Dbh - 2.114BA^2 + 0.3492THT$ ($R^2 = 88.5\%$; RMSE = 1.02; AIC

= 65.90; bias = 0.210). Moreover, there were no significant differences in mean observed and the predicted yield. It is therefore recommended for yield prediction in Okeluse Forest Reserve, since none of such has existed hitherto. Furthermore, inventory should be conducted periodically in order to have a good estimate of yield. For a reliable yield assessment project, model 6 is recommended for application.

In addition, the degraded areas should be reforested and restored with healthy indigenous trees to prevent environmental consequences that might arise as a result of forest degradation in the area. Lastly, there should be periodic monitoring of the forest reserve to reduce the rate of illegal exploitation in the reserve.

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