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Volume Equations for Sustainable Forest Management of Ngel-Nyaki Forest Area in Taraba State, Nigeria

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ABSTRACT: Tree volume measurements are used for different purposes, such as commercial, scientific, and policies-making. The species generic volume model aimed at estimating tree volumes for sustainable management of the area; which is lacking for Ngel-Nyaki Forest Reserve in Taraba State, Nigeria. The reserve is a protected area with high rate of exploitation and fire outbreak, losing its original landmass. Data were collected using systematic sampling design; one thousand four hundred and forty nine (1,449) lives trees with the diameter at breast height (*Dbh*) ≥ 10 cm were measured for Dbh (1.3 m) and total tree height. A tree mean diameter of 1.53 m, mean total height of 49.69, mean BA of 1.08 m^2 and mean volume of 34.96 m^3 were recorded in the area. Most of the individual trees (n=1,227) were in the lower diameter distribution and lower height distribution (n=1,022). The forest structure is an inverse J-shape; hence, an inverse 'J-shape' diameter distribution indicated healthy regeneration potentials. When natural regeneration occurs in an uneven forest over a long period of time, the number of trees decreases from small to high diameters. The parameters estimated indicate that the intercepts of the equations for all the models (except 3 and 5) were negative. The combined variable model of Spur which has diameter square (D^2) and total tree height (THt) as independent variables was adjudged as the most plausible and fitted model for the area. The residual scattered plot indicates good fits and confirmed the effectiveness of weighted least squares in normalizing variance.

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Keywords: Diameter at breast height, Management, Model, Total-height, Uneven-forest, Volume.

INTRODUCTION

The size of individual trees is measured using a variety of characteristics, including tree volume. Tree volume measurements are used for many purposes, including: commercial, scientific, and policies-making. Depending on the level of information required and the complexity of the measurement process; measurements can be only the stem volume or the stem volume and the volume of the branches.

An estimate of the volume of wood contained in a forest is critical when managing it for commercial timber output. This estimate is also necessary for assessing forest biomass, carbon storage, and fuel sources, among other things. The estimate is based on the volume of individual trees, either directly or indirectly. As a result, estimating stem volume is a crucial part of forest measurement. Volume and the measurements used to determine it (diameter, height, form, stand basal area, top height, etc.) are still the most essential tree and stand attributes, notwithstanding changes in selling, processing, and marketing techniques.

Direct or indirect methods can be used to estimate tree volume, depending on preference and ease of use. Water displacement, standard sectional, taper step, graphical, and taper Line methods are all part of the direct method. Volume tables, tariffs, volume equations, and variance reduction procedures are examples of indirect methods. Volume equations are mathematical expressions which relate tree volume to tree's measurable attributes such as diameter at breast height and/or height (Akindele, 2005). These variables are used to determine how much wood is in standing trees of varied sizes and kinds; i.e. they calculate the average volume of a single tree of a certain size (Nurudeen *et al.,* 2014).

The long-term management of forest resources necessitates a substantial amount of supporting information. Estimating current growth of variables that are difficult to quantify (such as timber volume) and estimating future growth values are critical, especially when managing a forest for the production of commercially important products. The long-term viability of the available wood resources and their advantages necessitates proper planning, which requires understanding of the forest's developing stock (Akindele *et al*., 2001).

In this context, estimating tree volume is critical for effective decision-making and forest resource management. Because timber volume is one of the basic forest management component; fracture volume estimations are useful in the forest inventory (Chaidez 2009). Knowing the volume of wood resources and their growth rates is critical for forest management and planning (Altriell *et al.*, 2010). The volumetric equations are useful in general and are required for the development and implementation of a forest management plan. They must be adjusted for different species, regions, and physiognomic types (Tonini and Borges 2015) to ensure sustainable forest management. Thus, to the best of our knowledge, there has been no any recent study on volume equations for the study area

METHODOLOGY

Location of the study area

Ngel Nyaki uneven forest is situated around western escarpment of Mambilla Plateau in Taraba state, Nigeria. It comprises approximately 46 km^2 of impressive sub-montane to mid-altitude forest, lying between 1400-1500 m above sea level (Chapman and Chapman 2001); due to deforestation and forest degradation in the area, presently the reserve has a vegetation cover of only about 10 km^2 with the current map shape as observed using Google Earth Pro software (Version 7.3.2, 2019) and digitized on Quantum Geographical Information System (QGIS) (version 3.22.1) (Figure 1). Taraba State lies between Latitudes 7°00' 00" N and 9° 58' 51" N and Longitudes 9° 52' 28" E and 12° 39' 51" E; occupying a total land mass of approximately 54, 473 km^2 (Meer *et al.,* 2018). The State is bordered on the northwest with Gombe State, Plateau and Nassarawa states at the west and with Adamawa state at the northeast border; it also shares its southwest boundary with Benue State. An international boundary on the east separates Taraba state from the Republic of Cameroon. The State is made up of three (3) major ecological zones (Southern guinea savanna located in the south western part of the State, Northern guinea savanna in the northeast and Montane Forest in the southeast) (Meer *et al.,* 2018).

Taraba State is characterized by distinct seasons (wet and dry). The wet season lasts on the average, from April to October. Mean annual rainfall varies from 1,058 mm in the north to over 1,300 mm in the south. The dry season lasts from November to March; relative humidity dropping to about 15%. Mean annual temperature is 280 °C with maximum temperatures varying between 350 °C and 300 °C. The minimum temperatures range between 150 °C and 230 °C. The temperatures are low throughout the year and the rainy season lasts from February to November with a mean annual rainfall of over 1,850 mm; the Mambilla plateau has climatic characteristics typical of a temperate climate.

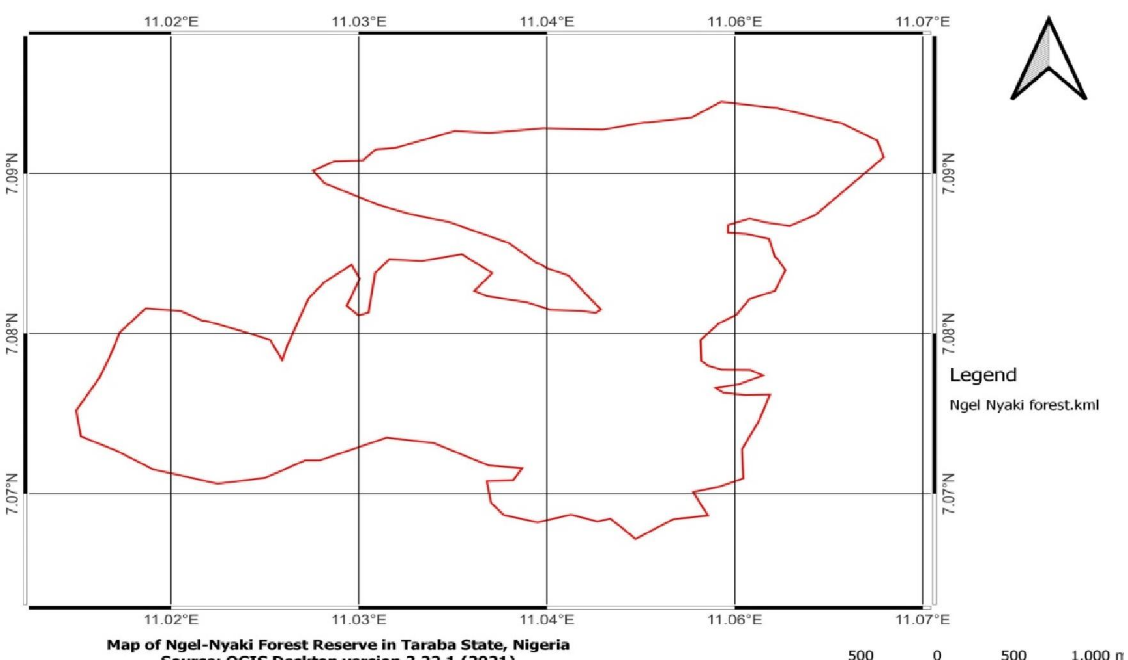

Figure 1: Map of NgelNyaki Forest Reserve in Taraba State, Nigeria

Data collection

The data for this study were collected from Ngel-Nyaki protected forest area; using systematic sampling design. Prior to the field survey, QGIS (version 3.22.1) was used to plot coordinates on map of the protected forest area; Microsoft Excel 2010 software was used to generate random numbers (between the lowest and the highest coordinates plotted on QGIS). Ten coordinates on the map (of the forests) were randomly picked, marked and transfer to Garmin e-trex 10 GPS for tracking on the field (Chenge and Osho, 2018). This was done in order to access the sampling plots locations as simple and as quick as possible (FAO, 2020). At the field, each coordinate in the study area was traced and temporary sample plots (TSP) size 50×50 m were systematic laid exactly on the point of the coordinates, for trees assessment. Ten TSPs were laid in the protected forest area.

The number of individual lives woody tree species occurring within each sample plot were counted and recorded. Trees with the diameter at breast height (Dbh) ≥ 10 cm were measured for Dbh and total tree height (*H*). Diameter at breast height (Dbh) was measured at 1.3 m above the ground to the nearest 0.001 m (0.1cm); and total tree height was measured to the nearest 0.1 m. Diameter tape and Haga altimeter were used to measure DBH and tree total height, respectively (Dau *et al.,* 2016; Dau and Chenge, 2016).

Statistical Analyses

The structure of the natural forests area was analyzed using descriptive statistic (mean, standard deviation, minimum, maximum, standard error and Charts (bar)) (Chenge *et al.,* 2019; Amonum *et al.,* 2019). Stem diameter and tree total height distributions were plotted using Pivot table on Microsoft Excel spreadsheet (2010 version) and assessed to ascertain the management effect on tree stand structure of the study area under the protection of Taraba State Government, Nigeria for policy implementation on sustainable forest management of the reserve.

Basal area of all individual trees in the protected area was estimated using equation [1]. By adding the basal areas of all individual trees in the plot, the total plot BA was computed. The mean plot basal area was calculated by adding all the plots' basal areas and divided the result by the number of sample plots. The mean plot basal area was multiplied by the actual number of sample plots in one hectare to get the basal area per hectare:

$$BA = \frac{\pi D^2}{4} \qquad Equation \qquad [1]$$

Where: BA= basal area (m2); D= diameter at breast height (cm); π =3.142.

$$Vc = \frac{\pi D^2}{4} h \qquad Equation \qquad [2]$$

Where: Vc= Cylidrical volume (m^3); D= diameter at breast height (cm); π =3.142, h=tree total height.

Volume equations from different authors were fitted into 75% of the data collected from the study area, the most plausible and fitted model with ease of application was chosen based on certain criteria (such as coefficient of determination (R^2), Adjusted R^2, Root Means Square Error, F-value and residual plot as described by Adekunle *et al.* (2004); Aigbe *et al.* (2012); Dau *et al.* (2016). All the criteria were summed and ranked; the model with the lowest rank value was chosen (Table 3). The volume model chosen based on the criteria, was validated using 25% data which was set aside from the data collected from the field; these 25% was not used during model testing (calibration) (Marshall and Northway, 1993). Paired sample T-test was used to test for significant difference between the cylindrical volume and the predicted volumes (model output) of the fitted model generated according to Goulding (1979) and Nurudeen *et al.,* 2014).

Volume Models

$$V = b_0 + b_1 * \ln Dbh \qquad Husch \qquad [3]$$

$$V = b_o + b_1 * Dbh^2 \qquad Kospesky \,\&\, Gehrhardt \qquad [4]$$

$$V = b_o + b_1 \ln(Dbh^2 * Tht) \qquad Spur \qquad [5$$

$$V = b_0 + b_1 * Dbh^2 + b_2 ln(Dbh^2 * THt) + b_3 THt \qquad Stoate \qquad [6]$$

$$V = b_0 + b_1 * Dbh^2 + b_2 * THt \qquad Spur \qquad [7]$$

$$V = b_0 + b_1 \ln Dbh + b_2 + \ln THt \qquad Schumacher \,\&\, Hall \qquad [8]$$

$$V = b_0 + b_1 * Dbh + b_2 * THt \qquad Schumacher \,\&\, Hall \qquad [9]$$

$$V = b_0 + b_1 Dbh * THt \qquad Berkhout/Husch \qquad [10]$$

Where: V= tree volume (m^3), lnV=natural log of Vol, Dbh (cm) =Diameter at breast height (1.3m), THt=Total Height (m).

RESULTS

Growth Characteristics and Structure of Ngel-Nyaki Forest Reserve in Taraba State, Nigeria

The summary statistics of the growth characteristics of Ngel-Nyaki protected area was determined and the result is presented in Table 1. The total trees measured in Ngel-Nyaki uneven forest area were 1,449 from temporary sample plots, with a tree mean diameter of 1.53 m, mean total height of 49.69 m, mean BA of 1.08 m^2 and mean volume of 34.96 m^3. The minimum and maximum stem diameter (m) in the study area was obtained as 1.53 m and 1.18 m, respectively; 49.69 m and 30.66 m were recorded as the minimum and maximum for tree total height, respectively. The minimum and maximum total volume and basal area were all estimated and result shown on Table 1.

Table 1: Summary Statistics of Growth Characteristics of Ngel-Nyaki Forest Reserve in Taraba State, Nigeria

Variables	Mean	Std. Dev.	S.E	Min.	Max.
Dbh (m) per ha	1.53	0.82	0.73	1.53	1.18
Total height (m) per ha	49.69	11.63	0.48	49.69	30.66
BA (m^2) /ha	1.08	1.41	1.14	1.08	1.24
Volume (m^3) /ha	34.96	56.22	1.27	34.96	45.59

Where: Dbh=Diameter at breast height (1.3m), B.A=Basal area

Tree diameter and total height distributions were determined (Figure 2 and 3). Most of the individual trees in the area were in the lower diameter distribution and lower height distribution. One thousand two hundred and twenty two sampled trees (*n* = 1,227) in the area had a Dbh distribution less than 70.00 cm, this was followed by Dbh distribution between 69-134 cm which had 161 individual trees; the density of trees in the larger Dbh classes was comparatively low with only 27 sample trees in the diameter distribution between 200 cm and above. The diameter (Dbh) distributions indicate an inverse ‘J-shape’ pattern which is typical of natural forests in the tropics (Figure 2).

Tree total height distribution of trees in the study area (Figure 3) show that, most of the trees (*n* =1,022) had a tree total height less than 13.00 m, this was followed by height distribution class of 12-22 m which had 225 trees in the class, 87 trees were identified with a total height between 22-32 m; 61 and 52 trees were in the height distribution class of 32-42 m and 42-52 m, respectively (Figure 3).

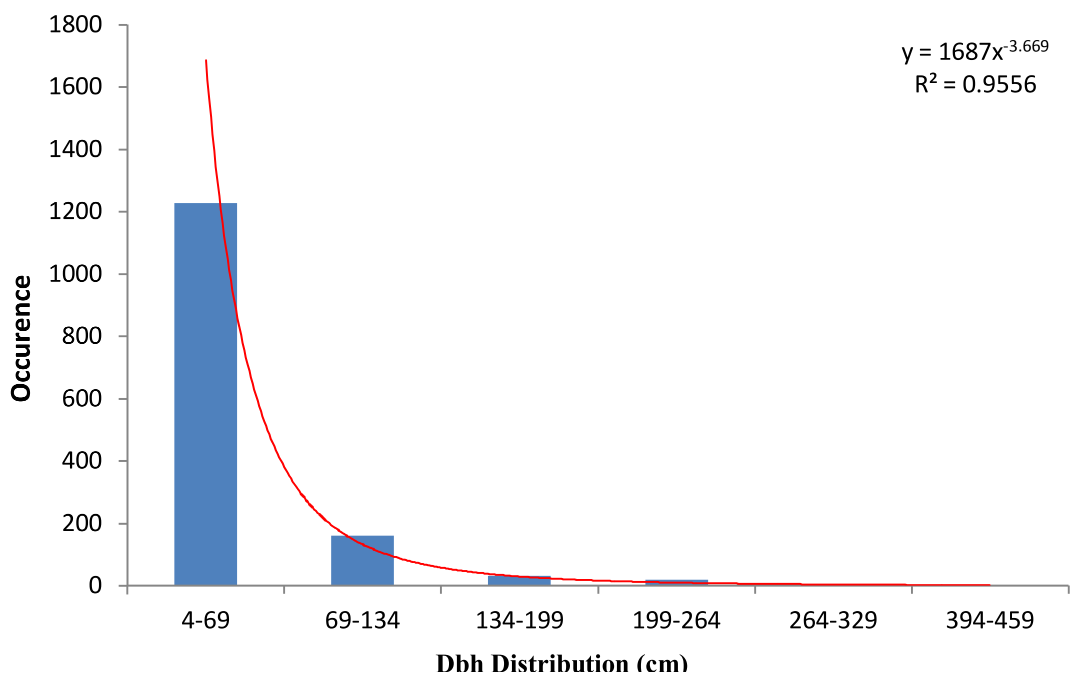

Figure 2: Diameter Distribution of Trees in the Study Area

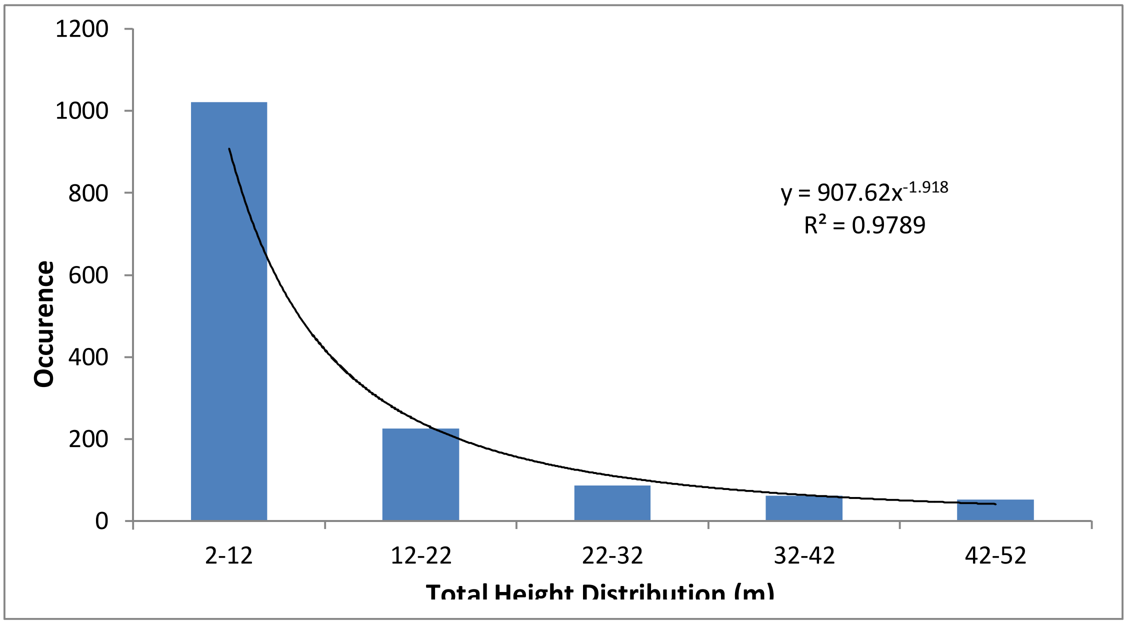

Figure 3: Total Height Distribution (m) of Trees in the Study Area

Species Generic Volume Models for Ngel-Nyaki Forest Reserve in Taraba State, Nigeria

Table 2 shown the parameters estimated from the species generic volume models for the study area; the criteria for the model selection were ranked (Table 3) and the model with lowest value of ranking was chosen. Volume model number six [6] was ranked first among the fitted models, followed by model seven [7]; the two models were adjudged the best for predicting the volume of trees in study area because they performed better based on the criteria used in assessing the equations. However, predicted volume from model six was tested using paired sample T-test, and the result indicate significant different with the observed volume. Thus, model seven [7] was adopted for estimation of volume in the study area since the model is next to model six; its ability to predict volume that is not significant different from the observed volume, and due to easiness of application when compared with model six.

Figure 4 shows the residual values against observed volume, using model 7. The residual volume was randomly scattered throughout the positive and negative axes, without upward or downward bias. This indicates that the model utilized in this study is well-fitting with plausibility when validated using Paired Two Sample for Means T-test (p=0.86). The residual scattered plots assessed the homogeneity of variance and conform the model(s) to regression analysis assumption.

Figure 5 shows a linear relationship between the observed and predicted volume in the study area. Model 7 $(V = -1.76 + 34.62Dbh^2 - 0.11THt)$ was chosen and used to predict volume which was in linear with the observed volume in the study area.

Table 2: Parameters Estimates from the Volume Models for Ngel-Nyaki Forest Reserve in Taraba State, Nigeria

Model no.	b_o	B_1	B_2	B_3	R^2	R Adj.	RMSE
3	30.762	15.859	-	-	0.246	0.246	26.546
4	-2.839	33.801	-	-	0.966	0.966	5.6525
5	11.575	6.143	-	-	0.257	0.256	26.361
6	-9377	35.075	-2.438	0.371	0.979	0.979	4.4689
7	-1.760	34.615	-0.107	-	0.967	0.966	5.5965
8	-3.181	4.642	10.707	-	0.259	0.258	26.330
9	-12.387	71.385	-0.520	-	0.708	0.707	16.5377
10	-5.493	1.624	-	-	0.871	0.871	10.9660

*=significant

Table 3: Ranks of Criteria used for Model Selection

Model no.	R^2 (%)	R Adj.	RMSE	Total	Ranks
3	8	8	8	24	**8**
4	3	2	3	8	**3**
5	7	7	7	21	**7**
6	1	1	1	3	**1**
7	2	2	2	6	**2**
8	6	6	6	18	**6**
9	5	5	5	15	**5**
10	4	4	4	12	**4**

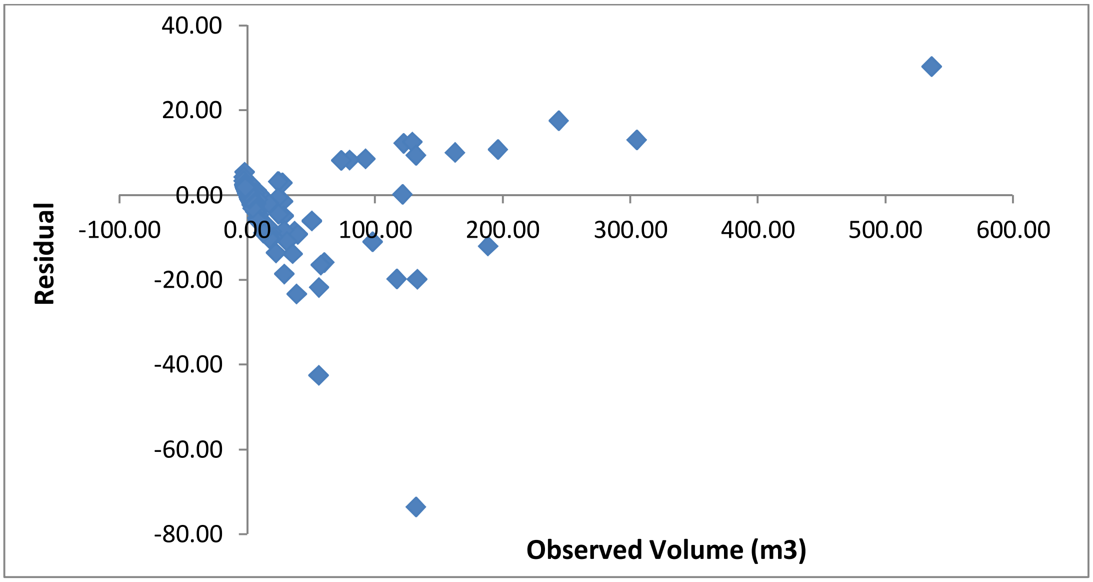

Figure 4: Residual Scatter Plot on Tree Volume for Ngel-Nyaki Forest Reserve

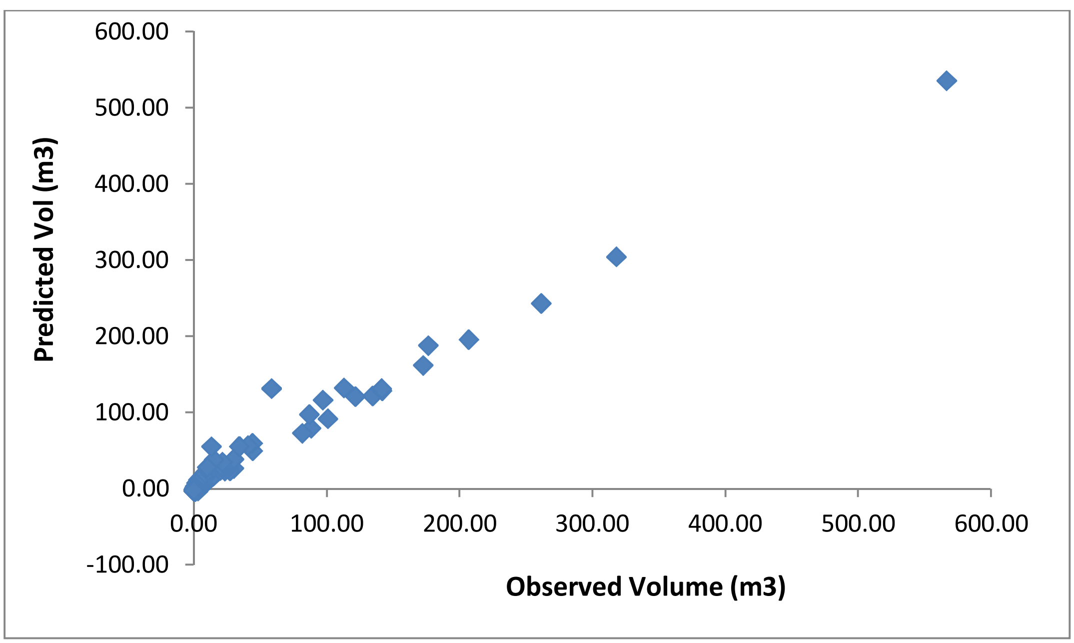

Figure 5: Linear Relationship between Observed and Predicted Tree Volume for Ngel-Nyaki Forest

Reserve

DISCUSSION

Growth Characteristics and Structure of Ngel-Nyaki Forest Reserve in Taraba State, Nigeria

The summary statistics of the growth characteristics of Ngel-Nyaki forest area indicates that, individual tree stands have relatively small trunks with taller trees occupying the area. This is a sign of disturbance of matured trees such as exploitation or indiscriminately felling of trees for various purposes in the area (Bunde *et al.,* 2018). The study area have an optimum (34.96 m^3/ha) quantity of wood volume; this could be used to determine biomass of the study area, the amount of carbon storage, fuel wood and other bio-resources.

Given the importance of the forest to the neighboring communities and the state, the low basal area per ha (1.08 m^2) recorded in the area could be linked to excessive tree felling and indiscriminate bush burning in the forest. The value obtained for basal area (B.A) is very low when compared with the finding of Nurudeen *et al.* (2014), who reported a finding on "Regression Models for Tree Volume Prediction in Stands of *Tectona grandis* (Linn) at Federal College of Forestry, Jericho, Ibadan, Oyo State Nigeria"; they reported a B.A of 610.24 m^2/ha. Adeyemi (2016) reported a basal area between 10.6 to 27.42 m^2 at different locations in Oban Forest, Nigeria. Aigbe and Ekpa (2015) reported basal area of 102.8 m^2 in tropical rainforest of Afi river forest reserve in Cross river State, Nigeria.

The diameter pattern of any forest ecosystem is a vital criterion by which one may assess its stability, growth, volume output, assortment structure and maturity (Egonmwan and Ogana 2020). The ability to determine when a stand may be economically harvested for a certain product is based on understanding diameter distributions of forest ecosystems (Ekpa *et al.* 2014). For sustainable forest management, diameter distribution is very important, due to its capacity to forecast and assists forest managers in making informed decisions (such as silvicultural treatment prescription and distribution determination (Carretero and lvarez 2013).

The forest structure of the study area is an inverse J-shape (reverse J-shape); hence, the reverse 'J-shape' diameter distribution indicated healthy regeneration potentials. The lower diameter distribution could grow and develop into mature trees and replace the old ones in the future if proper conservation efforts are practice in the study area. When natural regeneration occurs in natural forest over a long period of time (with minimal or no disturbance), the number of trees decreases from small to high diameters (Djomo, 2011; Chenge *et al.,* 2019). Thus, this called for effective management for sustainable conservation of the study area for the purpose of biodiversity preservation and climate change mitigation in Taraba state and Nigeria as a whole.

Species Generic Volume Models for Ngel-Nyaki Forest Reserve in Taraba State, Nigeria

The species generic volume model aimed at estimating tree volumes for tree species which is lacking in Ngel-Nyaki Forest Reserve in Taraba State, Nigeria. Species generic model tend to compress variation from different tree species in a study area; since most tree species in the tropical guinea savanna have the same tree structure with an umbrella canopy structure, as opposed to tropical rain forest.

Parameters estimated from the species generic models indicate that the intercepts of the equations for all the models (except 3 and 5) were negative. This result is in line with the report of Aigbe and Ekpa (2015), who reported that, negative intercepts are expected for merchantable tree size. In this study, the combined variable model of Spur which has diameter square (Dbh^2) and total tree height (THt) as independent variables was adjudged as the plausible and most fitted model for the area.

The combined variable model fitted the data better with ease of application than other forms of volume functions based on the criteria for model selection. This result is not in line with the report of Aigbe and Ekpa (2015), who reported that, generalized logarithmic volume function performed better than other forms of volume functions in tropical rainforest of Afi river forest reserve in Cross river state, Nigeria.

Variable-top merchantable volume equations for plantation-grown Scots pine (*Pinus sylvestris*) and Sitka spruce were also established by John *et al.* (2011). The best findings for overall volume came from a logarithmic expression of wood tree volume.

Yousefpour *et al.* (2012) also estimated a logarithmic stem volume equation based on tree height and diameter at breast height (Dbh), which was measured for *PinuspinasterAit*. The data was collected in north Iran's Inkiashahr region. The two-variable model's volume estimation had the lowest relative standard error of 10%. They discovered that the converted logarithmic model was the most effective.

In South Korea, Daesung *et al.* (2017) developed and validated stem volume equations for *Pinusdensiflora, Pinuskoraiensis, and Larixkaempferi*. The validation of the equation showed that the combined-variable function seems to be the best model. In addition, the model based solely on DBH was found to be applicable in the field. When compared to prior investigations, these models were more accurate. The residual scattered plots implied good fits and confirmed the effectiveness of weighted least squares in normalizing variance.

CONCLUSION

The reserve is a protected area with high rate of exploitation and fire outbreak, losing its original landmass. The uneven forest area had a tree mean diameter of 1.53 m, mean total height of 49.69 m, mean B.A of 1.08 m^2 and mean volume of 34.96 m^3. Most of the individual trees (n=1,227) were in the lower diameter distribution and lower height distribution (n=1,022). The forest structure is an inverse J-shape; hence, an inverse 'J-shape' diameter distribution is an indication of healthy regeneration potentials. The parameters estimated indicate that the intercepts of the equations for all the models (except 3 and 5) were negative. The combined variable model of Spur which has diameter square (D^2) and total tree height (THt) as independent variables was adjudged as the plausible and most fitted model for the area. The residual scattered plot indicates good fits and confirmed the effectiveness of weighted least squares in normalizing variance. Thus, it is recommended that, sustainable forest management policies should be re-strengthen for the conservation of the forest area due to its role on climate change mitigation which cannot be over emphasize. Also, there is the need to update and map out the study area, since land encroachment has hampered with the original gazette forest area.

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