



Research article

Fitting non-linear models for tree volume estimation in strict nature reserve, South-West, Nigeria

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Abstract: This study tested the efficacy of nonlinear models for tree volume estimation in a complex tropical natural ecosystem. Data were collected from the four permanent sample plots located in Strict Nature Reserve in Akure forest reserve, each plot covering an area of 0.25 ha. All living trees within a diameter range (>10 cm) were measured within all the permanent sample plots. The data were pooled together and sorted according to family: Annonaceae, Meliceae, Sterculiaceae and Ulmaceae. Six non-linear models were fitted using curve expert for the volume models and ranked according to their best of fit using the Akaike's Information Criteria (AIC), standard error and significance at 5% level of probability. A total of 266 trees were sampled in the four plots but the study made use of 171 trees comprising of 17 species distributed among 4 families. Sterculiaceae had the highest number of species (6 species.) while the most abundant species was *Mansonia altissima*, followed by *Celtis zenkeri*. These species have 45 and 42 individual trees, respectively. The assessment criteria using AIC and standard error showed that the entire models are suitable for volume estimation in the study area. The non-linear models showed a reasonable variation depending on family. The result showed that Weibull, Gompertz Relation and Logistic Power models were the most consistent model that gave the best predicted volume when compared with the observed volume for each family in the study area but the Ratkowsky model ranked best of the six models generated when data from each family were combined. The student t-test showed that there were no significant differences between the observed and predicted volume. All the models are very good for tree volume estimation in the study area. Therefore, they are recommended for further use in this ecosystem and similar ones.

Keywords: Ecosystem - Model - Akaike's Information Criteria - Assessment - Species - Volume.

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INTRODUCTION

The substantial focus has been given to forestry for the development of estimation schemes to predict volume at the individual tree and stand-level due to the ecosystem's economic impact. Periodic inventories are often needed by forest industries and other organization as it helps to determine the quantity of wood utilization. Forest inventory were majorly conducted in plantation or in natural forest with the aim of estimating the timber volume of the plot obtainable in the entire stand (Adekunle 2007). Estimating tree volume is important for forest management due to its effectiveness in the assessment of growing stock, timber valuation, distribution of area allocated for harvest and decision-making process involving the use and management of the forest.

Natural forest ecosystems are characterized by dense canopy closure which makes it practically difficult and expensive to measure all the predictor variables for every tree in each plot. To overcome this problem, the use of volume equations with stem diameter and height as predictor variables has been developed (Adekunle 2007). Despite the increasing use of biomass and density, the volume is the most widely used traditional measure for tree quantity Koirala *et al.* (2017). Volume models that are able to quantify tree volume are indispensable for a tree to be subjected to felling for commercial uses (Mugasha *et al.* 2016). Several allometric tree volume models have been developed for different tree species and forest types in Europe (Zianis *et al.* 2005), North America (Ter-Mikaelian & Korzukhin 1997, Jenkins *et al.* 2004, Zhou & Hemstrom 2010) and Australia (Keith *et al.*

2000), but relatively few models have been developed for tropical forests in sub-Saharan Africa, as indicated in a review by Henry *et al.* (2011). Moreover, the reliability of forest volume estimates using the volume models that do exist for tropical forests is questionable because of high species diversity, tree sizes and varying geographic features that are not covered by these models (Hofstad 2005, Henry *et al.* 2011). This present study aims to develop a model for estimating volume of tropical hardwood species in a strict nature reserve located in the southwestern region of Nigeria.

MATERIALS AND METHODS

Study area

Akure Forest Reserve (Aponmu) is one of the Strict Nature Forest Reserves in Nigeria located in the tropical rainforest in Ondo East Local Government Area of Ondo State, and a segment of the forest popularly known as ‘Queen’s plot covers an area of about 32 hectares (Adeduntan & Olusola 2013) and lies between latitude 06.59718° N and longitude 004.49199° E. Akure forest reserve is within the lowland tropical rain forest type with the distinct wet and dry season. The climate is humid tropical with seasonal variation. The mean annual rainfall is about 4000 mm with double maxima in the months of July and September and a short relatively dry period in August (Adeduntan 2009). December through to February constitutes the major dry season while January and February are the driest months with each having less than 30 mm rainfall (Ola-Adams & Hall 1987). Temperature ranges from about 20.6°C to 33.5°C. The monthly mean temperature is about 27°C, which is a favorable condition to the growth of tropical rainforest (Adeduntan 2007). The natural vegetation in the high forest composed of many varieties of hardwood timber such as *Milicia excelsa* (Welw.) C.C. Berg, *Mansonia altissima* (A Chev.) A Chev., *Cola gigantea* A Chev., *Terminalia superba* Engl. & Diels, *Terminalia Ivorensis* A Chev., *Afzelia africana* Sm. ex Pers. (Adekunle *et al.* 2013).

Data collection

Data is collected from four permanent sample plot located in the strict nature reserve in Akure forest reserve. It is under the management of Forestry Research Institute of Nigeria (FRIN), Ibadan, Nigeria. Each plot has a total size of 0.25 ha in which total mensuration of tree diameter and height were carried out. All living trees within the range of specified stem diameter (>10 cm) were measured within all the permanent sample plots. The data were pooled together and sorted according to family: Annonaceae, Meliceae, Sterculiaceae and Ulmaceae. The following tree growth variables were obtained on the field: diameter at breast height was used with the aid of girth tape, diameter at the base, diameter at the middle, diameter at the top and total height were used with the aid of Spiegel relaskop.

Data analysis

Basal area estimation: The basal Area (BA) of individual trees was estimated using the formula according to Husch *et al.* (2003) in equation 1:

$$BA = \frac{\pi D^2}{4}$$

Where, BA= Basal area (m²), D= Diameter at breast height (cm), π = Pie (3.142).

Volume estimation: The volume of all trees in the sample plots was computed using the Newton’s formula:

$$V = \frac{\pi H}{24} (Db^2 + 4Dm^2 + Dt^2)$$

Where, V = Volume (m³), H = Total height (m), Db = Diameter at the base (cm), Dm = Diameter at the middle (cm), Dt = Diameter at the top (cm) and π = 3.142

Correlation coefficient calculation

Spearman correlation was carried out to examine the type of relationship between the tree growth variables.

Fitting of the volume models

To fit our models, individual tree growth variable belonging to respective family in the sample plot were used. The tree growth variables in each family were as well pooled together to generate model that could be used for volume estimation in tropical ecosystem of southwest Nigeria and in other places with similar vegetation and environmental factor (Adekunle 2007)

Six non-linear models were fitted using curve expert for the volume models and ranked according to their best of fit using the Akaike’s Information Criteria (AIC), standard error and significance at 5% level of probability.

| | |
|-------------------|-------------------------------|
| Logistic Power | $V = a/(1+(x/b)**c)$ |
| Gompertz Relation | $V = a*\exp(-\exp(b-c*x))$ |
| MMF | $V = (a*b + c*x^d)/(b + x^d)$ |
| Weibull | $V = a - b*\exp(-c*x^d)$ |
| Logistic | $V = a/(1 + b*e^{-(cx)})$ |
| Ratkowsky model | $V = a / (1+\exp(b-c*x))$ |

Where, a, b, c and d are the estimated tree growth parameters, V is the volume in (m³), x is the DBH (cm) while exp. is the exponential.

Assessment of the models

Akaike's Information Criteria (AIC) are commonly used for model selection and comparison Hoeting *et al.* (2006). The candidate model with the lowest AIC is selected as the best model as reported by Scaranello *et al.* (2012) and Adesoye (2014). Other criteria include the use of standard error of the estimate and residual plots that shows how the error of the estimate is evenly distributed.

Validation of the models

The model validation was done by comparing the models output values with observed values on the field, this makes curve expert professional suitable for modeling volume as the software has model validation criterion in-built. The validation process examines the usefulness or validity of the model, (Marshall & Northway 1993). The residual plot was also used for model validation as it shows whether there is an upward or downward trend to the data as well as showing whether the residuals bias upward or downward. The best-fitted models for each family and pooled data were selected for predicting volume from tree diameter. The predictive capacity of the models was tested by checking the significant difference between the observed and predicted value using student t-test as well as bias percentage and root mean square error.

RESULTS

Table 1. Species encountered in the study area and their relative abundance in sample plot.

| Species | Abundance |
|--|------------|
| <i>Anonidium mannii</i> (Oliv.) Engl. & Diels - Persee | 20 |
| <i>Cleistopholis patens</i> (Benth.) Engl. & Diels | 1 |
| <i>Monodora myristica</i> (Gaertn.) Dunal | 1 |
| <i>Entandrophragma angolensis</i> (Welw.) C.DC. | 4 |
| <i>Entandrophragma utile</i> (Dawe & Sprague) Sprague | 8 |
| <i>Trichilia heudelotii</i> Planch. ex Oliv | 1 |
| <i>Trichilia monadefia</i> (Thonn.) J J De Wilde | 2 |
| <i>Cola gigantea</i> A Chev. | 14 |
| <i>Cola hispida</i> Brenan & Keay | 4 |
| <i>Mansonia altissima</i> A.Chev. | 45 |
| <i>Sterculia oblongata</i> R.Br. | 1 |
| <i>Sterculia rhinopetala</i> K Schum | 9 |
| <i>Triplochiton scleroxylon</i> K. Schum | 16 |
| <i>Celtis mildbraedii</i> Engl. | 3 |
| <i>Celtis zenkeri</i> Engl. | 42 |
| Total | 171 |

In total, 266 trees were sampled in the four plots but the study made use of the 171 trees in the four families that were selected for this study. The selected species and their relative abundance are presented in table 1. Table 2 shows the various family and number of species in the respective family, the result shows that Sterculiaceae had the highest number of species (6 species). The most abundant species was *Mansonia altissima* this was followed by *Celtis zenkeri* Engl. These species have 45 and 42 individual trees, respectively. Summary of the growth variables as well as the species and family names are listed in table 3. The Sterculiaceae family has the minimum and maximum diameter at breast height of 12.4 cm and 105 cm respectively. The minimum height was 15.00 m found in the Ulmaceae family while the maximum height of 81.7 m was found in the Sterculiaceae family. The standard error for diameter at breast height ranged from 1.27 to 7.28 while the

standard error for total height ranged from 0.86 to 4.11. Table 4 showed the correlation matrix between the tree growth variables. The result revealed a strong relationship between the growth parameters for each family and the pooled data.

Table 2. Tree species distribution into families in the study area.

| Family | No of species |
|---------------|---------------|
| Annonaceae | 3 |
| Meliaceae | 5 |
| Sterculiaceae | 6 |
| Ulmaceae | 2 |
| Total | 17 |

Table 3. Descriptive statistics of tree growth variables for families and the pooled data.

| Families | DBH (cm) | | | | Height (m) | | | |
|---------------|----------|------|-------|--------|------------|------|-------|-------|
| | Mean | SD | Min | Max | Mean | SD | Min | Max |
| Annonaceae | 36.32 | 2.76 | 13.50 | 83.50 | 28.3 | 1.87 | 15.5 | 57.00 |
| Meliaceae | 39.33 | 7.28 | 16.00 | 97.00 | 34.48 | 4.11 | 19.40 | 79.00 |
| Sterculiaceae | 28.48 | 1.64 | 12.40 | 105.00 | 39.59 | 1.52 | 19.00 | 81.70 |
| Ulmaceae | 25.66 | 1.34 | 12.50 | 55.00 | 33.95 | 1.45 | 15.00 | 58.00 |
| Pooled | 32.03 | 1.27 | 11.00 | 142.00 | 36.38 | 0.86 | 11.00 | 81.70 |

Table 4. Correlation Matrix of tree growth variables for families and the pooled data.

| Family | Variables | DBH (cm) | BA (m ²) | H (m) | V (m ³) |
|---------------|----------------------|----------|----------------------|-------|---------------------|
| Annonaceae | DBH (cm) | 1.00 | | | |
| | BA (m ²) | 0.97 | 1.00 | | |
| | H (m) | 0.68 | 0.74 | 1.00 | |
| | V (m ³) | 0.90 | 0.98 | 0.82 | 1.00 |
| Meliaceae | DBH (cm) | 1.00 | | | |
| | BA (m ²) | 0.99 | 1.00 | | |
| | H (m) | 0.83 | 0.80 | 1.00 | |
| | V (m ³) | 0.95 | 0.95 | 0.90 | 1.00 |
| Sterculiaceae | DBH (cm) | 1.00 | | | |
| | BA (m ²) | 0.95 | 1.00 | | |
| | H (m) | 0.64 | 0.52 | 1.00 | |
| | V (m ³) | 0.88 | 0.91 | 0.66 | 1.00 |
| Ulmaceae | DBH (cm) | 1.00 | | | |
| | BA (m ²) | 0.98 | 1.00 | | |
| | H (m) | 0.72 | 0.70 | 1.00 | |
| | V (m ³) | 0.87 | 0.91 | 0.78 | 1.00 |
| Pooled | DBH (cm) | 1.00 | | | |
| | BA (m ²) | 0.95 | 1.00 | | |
| | H (m) | 0.67 | 0.59 | 1.00 | |
| | V (m ³) | 0.92 | 0.93 | 0.72 | 1.00 |

Note: DBH= Diameter at breast height; BA= Basal Area; H= Height; V= Volume.

Result of the non-linear models

In the Annonaceae Family, the result indicates that the Logistic, Ratkowsky model and Weibull model gave a good fit. As a result, they are very adequate for tree volume estimation as shown in table 5 with their AIC values as; -39.45, -39.46 and -36.98 while the standard error was; 0.39, 0.39 and 0.40 respectively. The logistics model gave the best line fit because of the low AIC and standard error values. The t-test result carried out for the observed and predicted volume indicates that the t-statistics of 0.04 is less than the t-critical level of 1.72, meaning there is no significant difference ($p > 0.05$) between the observed and predicted volume as shown in table 6.

The result of the volume models for Meliaceae indicates that Gompertz Relation, Logistic Power, and Ratkowsky model gave the lowest AIC value and standard error of 2.28, 2.28, 2.28 and 1.02, 1.02, 1.02 respectively which make it the best model that could estimate volume in the study area. The validation of the result shows that t-statistic of 1.63 is less than t-critical of 1.74, meaning there is not a significant difference between the observed volume and predicted volume.

Logistic Power, Gompertz Relation and Weibull model were adjudged to be well fitted models for Sterculiaceae family in volume estimation as shown in table 5 with their AIC values as 37.19, 38.86 and 39.09

and their standard error as 1.23, 1.23 and 1.24 respectively as shown in table 5. Meanwhile, Logistic Power gives the best model because of its low AIC value and standard error; this was however confirmed by the result of the residuals with a probability of 96.30% with the independent variable spreading across the horizontal line. The t-test result carried out for the observed and predicted volume indicates that the t-statistics of 0.28 is less than the t-critical level of 1.66, meaning there is no significant difference ($p > 0.05$) between the observed and predicted volume as shown in table 6.

Table 5. The Non-Linear Volume Models and their Assessment Criteria for each Family and the Pooled Data.

| Family | Models | Parameters Estimate | | | | AIC | Std. Error |
|---------------|-------------------|---------------------|-----------------------|-----------------------|------|--------|------------|
| | | a | b | c | d | | |
| Annonaceae | Logistic | 24.00 | 207.00 | 0.07 | | -39.45 | 0.39 |
| | Ratkowsky | 24.00 | 5.33 | 0.07 | | -39.45 | 0.39 |
| | Weibull | 23.40 | 22.90 | 2.91×10^{-8} | 3.92 | -36.98 | 0.40 |
| | Gompertz | 360.00 | 2.14 | 0.01 | | -38.92 | 0.40 |
| | Logistic Power | 6300.00 | 688.00 | -2.86 | | -36.94 | 0.42 |
| | MMF | -4.38 | 14.10 | 84.60 | 1.30 | 16.56 | 1.36 |
| Meliceae | Gompertz Relation | 14.90 | 98.50 | 1.51 | | 2.28 | 1.02 |
| | Logistic Power | 14.90 | 65.60 | -0.85 | | 2.28 | 1.02 |
| | Ratkowsky | 14.90 | 85.30 | 1.29 | | 2.28 | 1.02 |
| | Logistic | 14.90 | 1.13×10^{13} | 0.45 | | 2.37 | 1.02 |
| | Weibull | 17.10 | 17.10 | 4.42×10^{-6} | 2.85 | 22.83 | 1.78 |
| | MMF | -2.08 | 1130.00 | 66.80 | 1.28 | 26.72 | 1.99 |
| Sterculiaceae | Logistic Power | 35.30 | 102.00 | -2.54 | | 35.19 | 1.23 |
| | Gompertz Relation | 27.10 | 1.86 | 0.03 | | 36.86 | 1.23 |
| | Weibull | 22.60 | 22.50 | 9.63×10^{-6} | 2.59 | 39.09 | 1.24 |
| | Ratkowsky | 19.50 | 4.42 | 0.06 | | 39.47 | 1.25 |
| | MMF | -2.41 | 1030.00 | 66.50 | | 66.97 | 1.45 |
| | Logistic | -3.56×10^8 | -5.34×10^8 | 0.03 | | 77.01 | 1.55 |
| Ulmaceae | Gompertz Relation | 85.30 | 2.03 | 0.02 | | -64.52 | 0.48 |
| | Logistic Power | 9080.00 | 882.00 | -2.63 | | -64.52 | 0.48 |
| | Weibull | 0.06 | 0.06 | 2.49×10^{-7} | 2.77 | -62.39 | 0.49 |
| | Logistic | 14.30 | 150.00 | 0.09 | | -63.18 | 0.49 |
| | Ratkowsky | 14.2 | 5.01 | 0.09 | | -63.18 | 0.49 |
| | MMF | -1.39 | 1040 | 33.5 | 1.34 | -43.45 | 0.6 |
| Pooled Data | Ratkowsky | 17.4 | 4.73 | 0.07 | | 29.56 | 1.08 |
| | Weibull | 17.3 | 17 | 8.71×10^{-7} | 3.24 | 32.68 | 1.09 |
| | Gompertz | 24.3 | 1.97 | 0.03 | | 34.08 | 1.10 |
| | Logistic Power | 26.9 | 85.1 | -2.91 | | 35.61 | 1.11 |
| | MMF | -2.59 | 1020 | 70.8 | 1.23 | 117.47 | 1.40 |
| | Logistic | -3.12×10^8 | -5.45×10^8 | 0.03 | | 125.00 | 1.44 |

Table 6. Validation Result of the Non-Linear Models with Bias, Bias percentage, RMSE, and Student T-test.

| Family | Model | Bias | RMSE | Bias % | Observed Volume | Predicted Volume | T-stat | P-value | Remark |
|---------------|-------------------|-------|------|--------|-----------------|------------------|--------|---------|--------|
| Annonaceae | Logistic | -0.00 | 0.37 | -0.15 | 1.94 | 1.95 | 0.04 | 0.48 | ns |
| | Ratkowsky | -0.00 | 0.37 | -0.01 | | | | | |
| | Weibull | 0.00 | 0.36 | 0.19 | | | | | |
| | Gompertz Relation | 0.06 | 1.30 | 6.00 | 3.24 | 3.00 | 1.63 | 0.06 | ns |
| Meliaceae | Logistic Power | 0.08 | 1.25 | 8.00 | | | | | |
| | Ratkowsky | -0.03 | 1.27 | -3.00 | | | | | |
| Sterculiaceae | Logistic Power | 0.02 | 1.21 | 2.00 | 1.84 | 1.81 | 0.28 | 0.38 | ns |
| | Gompertz Relation | -0.27 | 1.41 | -27.00 | | | | | |
| | Weibull | 0.00 | 1.21 | 0.40 | | | | | |
| Ulmaceae | Gompertz Relation | -0.08 | 0.76 | -8.00 | 1.07 | 1.16 | 1.22 | 0.11 | ns |
| | Logistic Power | 0.01 | 0.47 | 1.00 | | | | | |
| | Weibull | -0.51 | 1.01 | -51.00 | | | | | |
| Pooled data | Ratkowsky | 0.05 | 1.09 | 5.00 | 1.79 | 1.71 | 0.99 | 0.17 | ns |
| | Weibull | 0.02 | 1.08 | 2.00 | | | | | |
| | Gompertz Relation | -0.03 | 1.09 | -3.00 | | | | | |

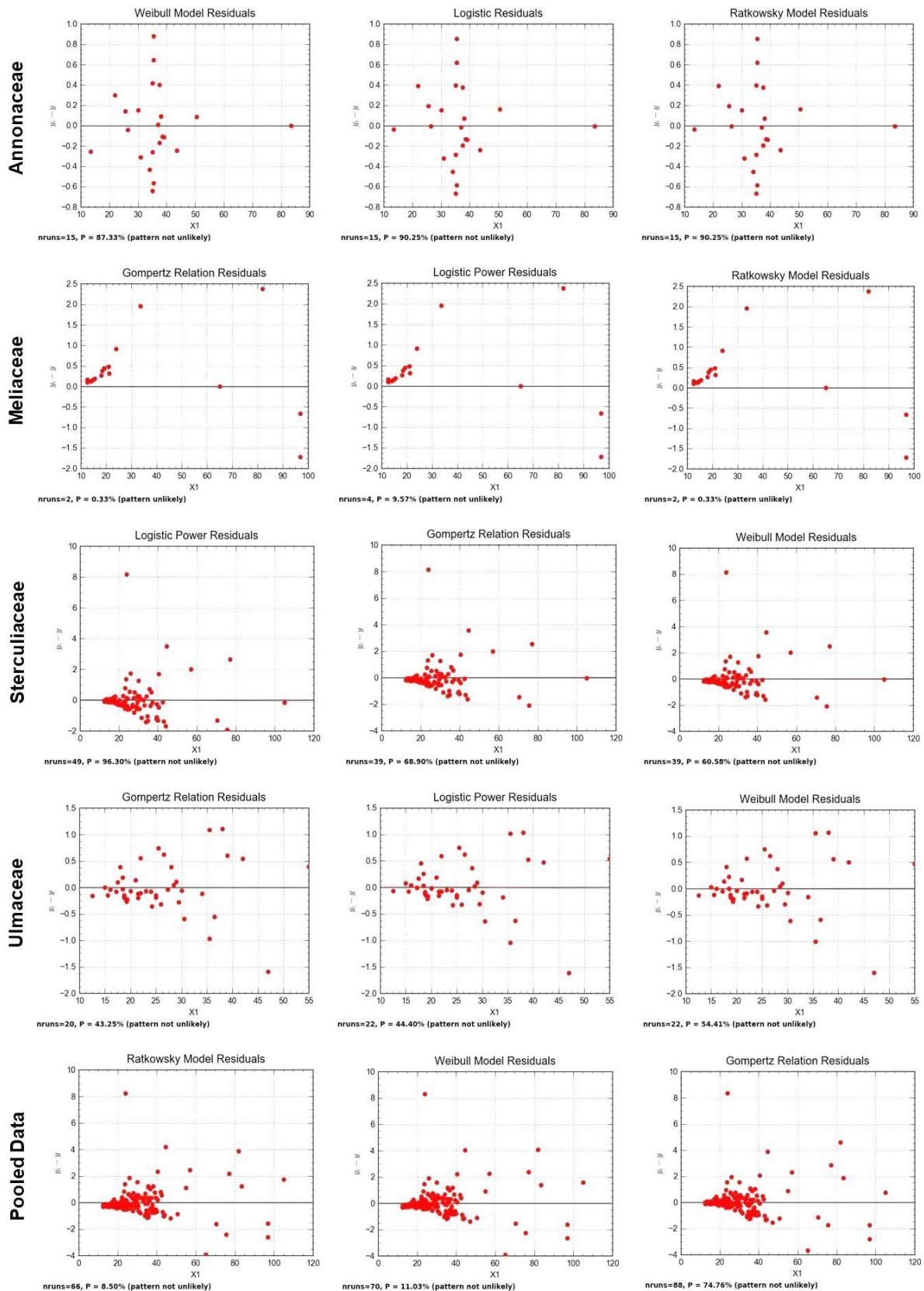


Figure 1. Residual results per each model for the families and the pooled data at DBH (cm) and Volume (m^3).

For the Ulmaceae family, Gompertz Relation, Logistic Power, and Weibull model gave a good fit in calculating the volume using the diameter as the predicting variable. The AIC value and standard error of Gompertz Relation was -64.52 and 0.48 respectively, see table 5. The result of the validation indicates that there is no significant difference at ($p>0.05$) in the observed volume and predicted volume as seen in table 6.

Ratkowsky Model, Weibull Model, Gompertz Relation, Logistic Power, MMF, and Logistic were adjudged the best fit for the prediction of volume. However, the Ratkowsky model was return the best model due to its www.tropicalplantresearch.com

lowest AIC value and standard error; 29.56 and 1.08 respectively, table 5. The t-test result carried out for the observed and predicted volume indicates that the t-statistics of 0.28 is less than the t-critical level of 1.66, meaning there is no significant difference ($p>0.05$) between the observed and predicted volume as shown in table 6. In addition, the residual plot showed a good fit as the data were evenly distributed which confirmed the goodness of fit of the model, figure 1. Generally, the percentage biases when the output of each model was compared with the observed volume are less than 30% for all the models. The Annonaceae, percentage biases ranges from 0.15 to 0.19%. Meliaceae ranges from -3 to 8%, For Sterculiaceae, percentage biases are from -27 to 2%, For Ulmaceae, percentage biases ranges from -51 to 1%. For the pooled data, percentages biases range from -3 to 5%.

DISCUSSION

Tree species diversity obtained in this study area is typical of the tropical rainforest ecosystem (Adekunle 2007). Seventeen Nigerian tropical tree species distributed among 4 families and 171 individuals were encountered in the study area. The ecosystem is rich in species and diversity. Species in this ecosystem are very useful as timber, enrichment of soil fertility, creation of microclimate and supply of many non-timber forest products. The tree growth variable measured in the study area showed that the mean DBH value of Annonaceae, Meliaceae, Sterculiaceae, Ulmaceae and the pooled data were 36.32 cm, 39.33 cm, 28.48 cm, 25.66 cm, 32.03 cm respectively as shown in table 3. This shows that most of the trees encountered in this study area are below the minimum merchantable size of 48cm stipulated by the logging policy of southwestern Nigeria (Adekunle 2006). It was observed from the correlation matrix that a positive linear relationship exists between the variables tested at individual family and the pooled data. This result is in accordance with the findings of Adekunle (2007) who observed a positive linear relationship between the tree growth variable. There was a strong relationship between DBH and volume for respective family and the pooled data with a correlation value of 0.90, 0.95, 0.88, 0.87, and 0.92 for Annonaceae, Meliaceae, Sterculiaceae, Ulmaceae, and the pooled data. This agreed with the findings of Akindele & Lemay (2006) who reported that volume is linearly related to DBH or basal area in a curvilinear manner.

The effectiveness of non-linear model for estimating volume in the tropical forest ecosystem was also considered in this study. Logistic, Gompertz Relation, Ratkowsky, MMF, Logistic Power, and Weibull model were considered and suitable for describing the volume-diameter relationship in the study area. The assessment criteria (AIC and standard error) showed that the entire models are suitable for volume estimation in the study area. The non-linear models showed a reasonable variation depending on family. The result showed that Weibull, Gompertz Relation and Logistic Power model are the most consistent model and the models gave the best-predicted volume when compared with the observed volume for each family in the study area but Ratkowsky model ranked the best of the six models generated when data from each family were combined. The residual plots for the models generally showed an even spread of residuals above and below the zero line with no systematic trend. At the bottom left corner of each residual plot, the observed number of runs is listed, as well as the likelihood which shows that the observed number of runs of the models fitted the data correctly (*i.e.* the residuals are randomly distributed around the curve). The result of the student t-test showed that there was no significant difference ($p>0.05$) in the models' outputs. All the non-linear models developed in this study were discovered to be very adequate for yield estimation in the study area and they are recommended for further use.

CONCLUSION

The study tested the efficacy of nonlinear models for tree volume estimation in the tropical natural ecosystem. The tree growth data were obtained from four permanent sample plots located in the strict nature reserve. One hundred and seventy-one trees comprising 17 species distributed among 4 families were involved in the model generation and validation. All the models developed in this study were discovered to be very adequate for yield estimation and are recommended for tree volume estimation in the tropical natural forest ecosystem of southwest Nigeria and in any similar ones.

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