Journal of Research in Forestry, Wildlife & Environment Vol. 13(1) March, 2021
E-mail: jrfwe2019@gmail.com; jfewr@yahoo.com
http://www.ajol.info/index.php/jrfwe
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ISBN: 2141 – 1778
Salami et al., 2021

DEVELOPMENT OF TREE HEIGHT-DIAMETER MODELS FOR ARAKANGA FOREST RESERVE, ABEOKUTA, OGUN STATE

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ABSTRACT

The study focused on the development of models for height- diameter relationship for Arakanga Forest Reserve.ARandom sampling technique was adopted for sample plot allocation while a total of 10 sample plots of 25 X 25m were laid in line transects for data collection. A total of 163 trees were encountered. The data collected was subjected to descriptive and inferential statistics. The mean DBH and the mean Height for the study area were 55.69cm and 13.25m respectively. The Height- diameter relationship was modelled using Curve Expert Professional software. Ratkowsky, Logistics and Richards models gave good result in describing the relationship between DBH and Height. All three models had the lowest AICC value of 123.08, 123.08 and 124.5 and Standard Error values 1.99, 1.99 and 2.0 rescpectively. Validation of the models was carried out using student T-test and Ratkowsky returned the best model with t-Statistics value of 0.02. Therefore, Ratkowsky model was adjudged as the best model for describing DBH and Height relationship in Arakanga Forest Reserve.

Keywords: Tree Height-Diameter, Arakanga, Forest Reserve and Abeokuta,

INTRODUCTION

The height-diameter relationship allows for efficient evaluation of site on the field and also the assessment of site from stereo aerial photographs by estimation from crown widths and tree heights measured on aerial photographs. The relationship between tree DBH and total height is a structural characteristic of a tree that describes key elements of stem form, and thus the volume of the harvestable stem, Osman *et al*., (2013). The height-diameter relationship describes the correlation between height and diameter of the tree in a stand on a given date and this can be represented by a linear or non-linear mathematical model.

One of the most important elements of forest structure is the relationship between tree height and diameter. Individual tree height and diameter are the most commonly measured variables for estimating tree volume, site index and other important variables in forest growth and yield.

Knowledge of the individual tree height (*h*) and DBH outside bark, is necessary for developing growth and yield models in forest stands. However, measuring diameter is more accurate, relatively easy and cheaper than measuring tree height (Colbert *et al*., 2002). As a result, in forest inventories, diameter is measured for all the sampled trees, but height is measured only for a subsample of trees because (1) tree height is time consuming to obtain (2) measurement errors are very common (3) there are usually visual obstructions due to the canopy closure in especially natural tropical rainforest ecosystem (Calama and Montero, 2004; Zhang *et al*., 2014) and (4) there is correlation between height and DBH.

Due to these problems, it is therefore a common practice to fit height-diameter models to predict height from measured DBH (Crecente-Campo *et al*., 2010). While DBHs are measured on all trees in a plot, measurement of height is limited to only few subsamples of trees. The height-DBH model is given in theequation below

$H = b0 + b1d$……………………1

Where H= total height (m), d = diameter at breast height (cm) b0 and b1 are parameters to be estimated.

Over the years, many different model forms and modeling approaches have been used to characterize the relationship between height and DBH. The most common models used in forestry are Chapman–Richards (Chapman, 1961; Richards, 1959), Weibull (Yang*et al*., 1978), Schnute (Schnute, 1981), exponential (Ratkowsky, 1990), logistic (Ratkowsky and Reedy, 1986), and Korf (Mehtatalo, 2004). In these models, tree height or diameter is usually expressed as a function of tree or stand age. Burkhart and Tennent (1977) and Tewari and Kumar (2002), found the Chapman–Richards function appropriate in describing height development over stand age for a variety of tree species.

A simplified version of the Chapman – Richards function is:

$Y = b0(1 - e^{-b1X})^{b2}$ ………………..2

Where:

Y is tree or stand size (e.g., height, diameter, volume), X is the independent variable (e.g., age), and b_0, b_1, and b_2 are the asymptote, rate, and shape parameters, respectively.

For a given tree species, the Height–DBH relationship varies with growing environment and stand conditions and it is not constant over time even within a single stand both in even and un-even aged stand (Pretzsch, 2009).

$H = \alpha + b0(1 - e^{-b1D})^{b2}$………3

Where:

H= total height, D= diameter at breast height, b_0, b_1, b_2 are regression parameters

As a consequence, Height–DBH models, which include DBH as the only explanatory variable, are fundamentally local and need to be defined for each single stand at every measurement occasion. The use of a local model may still provide the best unbiased estimates of tree height if based on a sufficient number of height measurements (Laar and Akca, 2007), but it is a costly and sometimes impractical approach. Also the Height–DBH relationship of a tree species, varies among different environments and stand conditions, e.g., stand density, basal area, and site index (Calama and Montero, 2004; Sharma and Zhang, 2004).

To account for this variation, generalized Height–DBH models were developed, in which stand-level variables (stand basal area, age, number of trees per ha, dominant or mean height) were introduced as additional explanatory variables (Temesgen and Gadow, 2004; Lei *et al*., 2009).

$H = \alpha + b0(BA)^{b1}(1 - e^{-b2(TPH)^{b3D}})$…………4

$H = \alpha + b0(BA)^{b1}(1 - e{-}b2TPHb3D)b4(SI)b5$…..5

Where:

H= total height (m), BA= stand basal area (m^2/ha), TPH= stand density (tree/ha),
D= diameter at breast height (cm), SI= site index (m) b0, b1, b2, b3 are regression parameters

The established height–diameter relationship is sensitive to stand conditions. This is important in mixed, uneven-aged stands in which several species, ages, structures and levels of competition coexist (Vargas-Larreta*et al*. 2009).

More recently, the hierarchical structure of Height–DBH data (i.e. trees grouped in plots and plots grouped in stands) results in a lack of independence between measurements because the observations in each sampling are correlated (Gregoire 1987). Mixed models have been successfully used to address the problem of correlation of the observations in the sample plots (Lappi, 1997; Calama and Montero, 2004; Adame*et al.,* 2008). This approach simultaneously estimates fixed parameters (parameters that are common to the entire population) and random parameters (parameters that are specific to each plot) within the same model and enables the variability between plots of the same population to be modeled.

Arcangeli*et al.* (2014) reported that the mixed-effect model is able to characterize the Height–DBH relationship more accurately than conventional generalized 'fixed-effect' methods. Some studies (Temesgen*et al*.,2008; Garber *et al*., 2009) have indicated that height estimation from non-linear mixed-effect modeling procedures show a better accuracy only when the random coefficients can be predicted (calibration approach) using a limited number of tree height measurements. When such calibration on a specific stand is not possible, the application of a mixed-effect model with random coefficients set to zero leads to high bias and low precision. Due to the complexity inherent in the calibration procedure, the use of a calibrated mixed-effect model would not be possible in many potential applications of Height–DBH models, such as those involving the implementation of these models within a growth simulator (Arcangeli*etal.,*(2014).

The models selected for use in this study for height estimation include Chapman-Richards,Gompertz Relation, Weibull, Logistic and MMF models. These models were chosen because they have been found to perform better overall than many other Height–DBH models.

The height-diameter models considered were sigmodal models from Curve Expert Professional

Gompertz Relation
Y=a*exp(-exp) (b-c*x)) …. Model 1
Richards
Y=a/(1+exp(b-c*x)) ^(1/d) …. Model 2
Logistic
Y=a/(1+b*e^(-cx)) .. Model 3
Logistic power
Y=a/(1+(x/b) **c) ….Model 4
MMF Y=(a*b+c*x^d)/(b+x^d).....Model5
Weibull Model
Y=a-b*exp(-c*x^d) …… Model 6
Ratkowsky Y=a/(1+exp(b-c*x)) ...Model7

Where:
Y= Height (m), x = DBH (cm), a, b, c, d are parameters to be estimate

MATERIALS AND METHODS

Description of the study area

The study was carried out in Abeokuta, Ogun State, Nigeria. Abeokuta lies within Latitude 7° and 7°5′ N and Longitude 3°3′ E and 3°37′. Arakanga Forest. Reserve (AFR) is one of the nine (9) forest reserves in Ogun State that falls under the purview of a peri-urban forest. AFR is about 2.3 km^2 long and made up of both the High forest and Savanna vegetation. Although the reserve is located in Odeda Local Government Area, it is closer to Akomoje, the headquarters of Abeokuta North Local Government Area and about 5 km from the centre of Abeokuta, the capital city of Ogun State (Awojuola, 2001; Onakomaiya, 1992). The environment is characterized by two distinct seasons. The longer wet season last for eight months (March~October) and shorter dry season last for four months (November~February). The relative humidity is high all year round, generally above 80% during the wet season and fluctuates between 60~80% during the dry season. The most humid months coincide with the rainy season spanning between March and October. Humidity and the long wet season ensure adequate supply of water and continuous presence of moisture in the air. This trend promotes perennial tree growth. The soils in the area are dominated by clayey loam developed on underlying granite. There are also laterite soils. Abeokuta has extensive free forest areas with two gazetted forest reserves of 61.19 km^2 land area. Major timber crops include Teak and Gmelina with other indigenous species from the free areas. The major occupation of the people in the study area is farming with agricultural crops such as cassava, maize, cocoyam, plantain, palm produce and vegetables. The area is also rich in fauna resources such as fish of various species, grasscutter, giant rat, grey rat, monitor lizard, weaver birds and others. Stone quarrying is also well developed. Major non-farm employments are provided by transportation and forestry activities such as timber exploitation, firewood, leaves collection and charcoal production.

Sampling and plot demarcation

Random sampling technique was adopted for sample plot allocation while a total of ten (10) sample plots of 25 X 25m were laid in line transects at 250m interval for data collection. Using this method ensured that the forest is relatively covered.

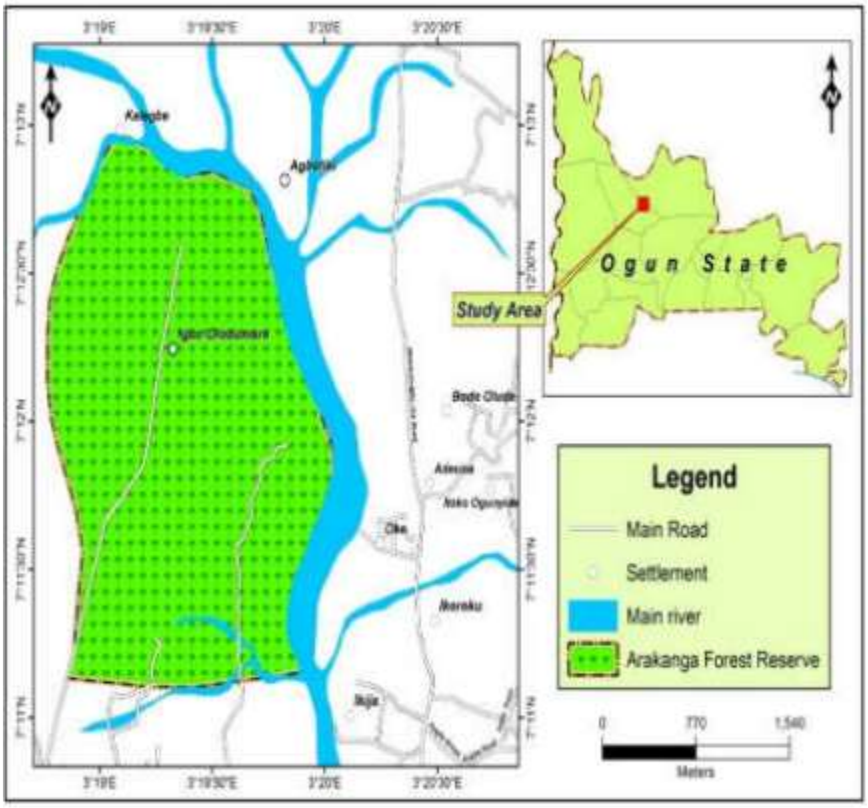


Figure 1: Map of Arakanga Forest Reserve
Adopted: Babatunde *et al.,* (2020)

Model Generation

The original data was divided into two. The first set (calibrating set), which comprise 70% of the tree data used for generating the models while the second set (validating set) which comprise 30% of the tree data used for validating the models.

Data Analysis

The data was analysed using Curve Expert Professional Software V. 2.6.5. DBH(cm) was used as the independent variable while Height (m) was used as the response or dependent variable. The models considered for analysing the data set were the sigmoidal models. This is because the data follows a sigmoidal pattern or an S-shape pattern which is typical of the genenal pattern of trees biological growth (Nugroho, 2014).

Assessment of the models

The models were assessed with the view of recommending those with good fit for further uses. The following statistical criteria were used Standard error of estimate (SE) and AIC criterion.

Akaike's Information criterion (AIC) is usually used for model selection and comparison especially where the models have the same response variables Heoting*et al*., (2006). The formula for AIC used as the criterion for model selection (Clave *et al*., 2005) is:

AIC=-2logL+2p
Where L is likelihood, p is the number of parameters in the model.
The model with the lowest AIC was selected as the best model as noted by Adesoye (2014).

Standard Error

Another criterion for model selection was the Standard Error used in the study.The formula for Standard Error used as the criterion for model selection is:

$$SE = \frac{\sqrt{MSE}}{r}$$

Where:
MSE is the Mean Square for Error in the data and r is the number of observations.

Validation of Models

Students T-Test

The values of the estimated parameters were inputted in the sigmodal model function considered to bet the best fit while x was substituted with Height. The result obtained (predicted height) was compared with the height from thevalidating set of data (30% of the entire data) using the Student's t-test. The model showing no significant difference between the observed Heightdata and the predicted Height was however considered to be suitable in describing the height-diameter of the trees in the reserve.

Residual plots

Residual probability plots were used for validation of the height-diameter models. For the reserve, residual plots for the best three models were selected. Models with Residual plots with probality greater than five percent were considered good fit.

RESULTS

Models for examining the relationship between DBH and Height were developed. On the whole, Logistic, Gompertz Relation, Logistic Power, Ratkowsky model, Richards, MMF and Weibull models were discovered and considered to be very adequate in describing the relationship between the diameter and height of trees in the study area. Akaike Information Criterion (AICC) value was used to rate the bestmodels since the models have the same response variable. A smaller AICC value means there is no significant difference in the stand structure in relation to the diameter and height in the ecosystem (Scaranello, 2011). The Standard error of estimate SE. was also used to examing the goodness of fit. The least Standard error of estimate represents the best curve fit. The probability of residual plots were also considered and residual with probability greater than five percent indicates a better predicted data that correspond to the observed data.

Table 1: AIC and Standard Error for best fitted models with parameters and their Standard Errors

Model	Parameters										
	A	SE	b	SE	C	SE	d	SE	AICC	SE	R^2
Ratkowsky	17.284	0.535	1.65	0.190	0.06	0.007			123.08	1.99	0.76
Logistic	17.285	0.536	5.212	0.99	0.06	0.007			123.08	1.99	0.76
Richards	16.92	0.538	4.09	3.00	0.08	0.004	2.61	2.25	124.2	2.00	0.69

Table 2. Validation Result of the Three best Height-Diameter Models for the Reserve.

Model	Mean Obs Height(m)	MeanPredic. Height(m)	t- Statistic	t-Critical	Rank
Ratkowsky	10.82	10.81	0.02	1.67	1st
Logistic	10.82	10.80	0.04	1.67	2nd
Richards	10.82	10.38	1.24	1.67	3rd

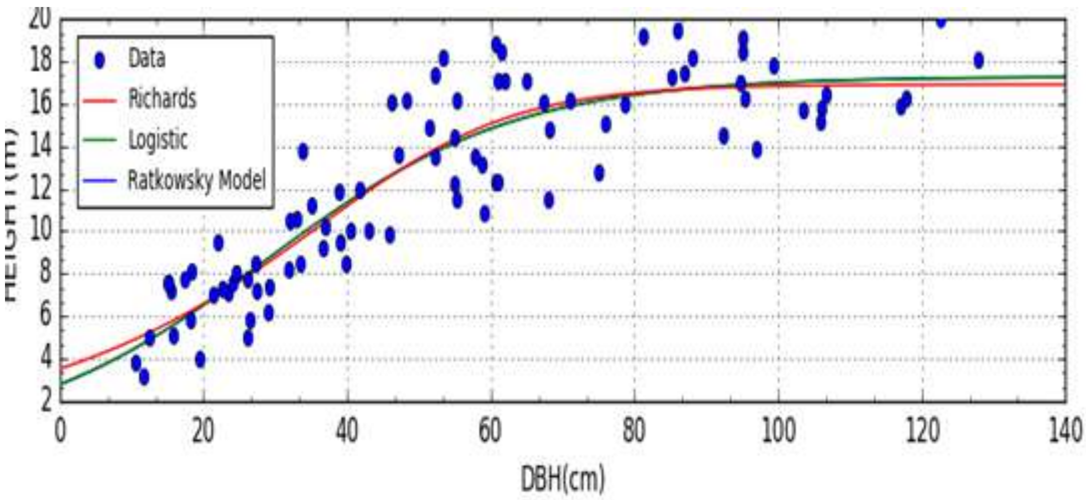
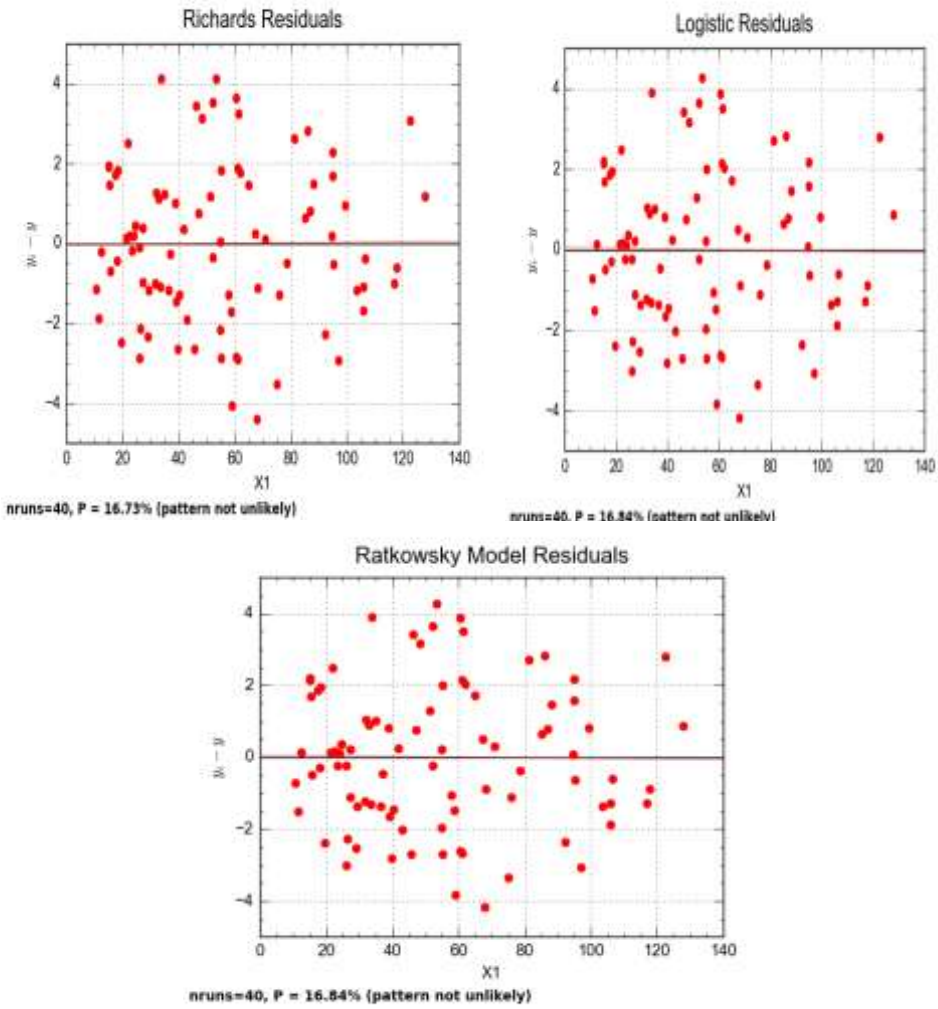


Figure 2. Best Fitted models selected for estimating Height in Arakanga Forest Reserve.



DISCUSSION

Height was plotted against Diameter at Breast Height.All the seven models tested were able to describe the relationship between Heightand DBH except Weibull model which at a stage colaspe catastrophically and could not describe the relationship. This result is in line with Nugroho, (2014) and Scaranello, (2012) who share similiar view as regards the consistency of Weibull model in describing the Diameter-Height relationship of trees. On the whole, the resultindicates that Ratkowsky, Logistic and Richards models were returned the three good models in describing the relationship between the variables as shown in Figure 2.The AIC value and Standard Error (SE) were used to rate the models, Ratkowsky and Logistic models with lowest AIC values of 123.08 and lowest Standard Error of 1.99 were taken as the best as shown in Table 1. The result of all the parameters a, b,c,d of the best fitted models were significant (P< 0.01) . The result of the T-test revealed that there is no significant difference between the Observed and Predicted height at (p<0.05) as shown in Table 2 for the first two models. However, Ratkowsky model gave the best fit among the three selected models. This is because it has the smallest t-Satistic value when compared with Logistic model and RichardsModel . This result is in line with Nugroho, (2014), whose result showed Ratkowsky model gave a good fit in describing Height-Diameter relationship. From the goodness of fit statistics in Table 1, it was observed that the R^2 values were low and were not used as assessment criteria since the models were non- linear. This is a confirmation that Height-diameter relationship may be influenced by other factors and the models will yield better convincing result if factors such as stand density, spacing, age and some climatic variations are added to the model. (Shamaki, *et al*. 2016). However, such information cannot be obtained in a single measurement, there is need for establishment of permanentsample plots that will be used for re-measurement over time.

CONCLUSION

On the whole, Ratkowsky model was adjudged as the best model in describing the relationship between Height and DBH in the study area.

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