Development of Allometric Equations for estimating Frond Biomass of Nipa Palm (Nypafruticans Wurmb) in the Mangrove Forest of Cross River State, Nigeria

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Abstract

Nipa palm (Nypafruticans Wurmb) is one of the most dominant species of the mangrove forest in Cross River State and is contributing significantly to the mangrove carbon stock in the area. Destructive sampling was used for the study, where a sample of 30 fronds was purposively selected as candidates for model development and validation. Each candidate was measured for dbh before it was cut down from the base. The dbh ranged from 5to 14.1cm. After felling, the frond was measured for length, cut into sections, weighed and aliquots collected from the base, middle and top portions as specimens and weighed fresh in the field. The aliquots were oven-dried to constant dry weights in the laboratory and used to convert the candidates' wet weights to dry weights. About 75% (21 observations) of the data were used for model calibration and the remaining part (9 observations) for model validation. The calibration dataset was fitted with eight different equation formats. The fitted equations were evaluated for goodness-of-fit using both graphical and quantitative analysis procedures. The validation results of paired sample t-test, and test for bias showed that threeof the equations were valid for predicting the biomass of individual fronds of Nipa palm in the area. However, a logarithmic transformed equation was selected, having the least AIC -9.107), FI (0.970) and RMSE (0.1775) values and the highest R^2 (90%) and F-Val (177.91) values.It was corrected for bias with a correction factor of 1.015878and transformed back to its original form ($B = 0.094681 \times D^{1.834}$)*.The equation is recommended for estimating the biomass of individual fronds of Nipa palm in the mangrove forest in Cross River State, Nigeria.*

Introduction

Climate change is currently the major global environmental problem threatening the survival and development of mankind. It is caused by anthropogenic activities that are releasing large amounts of greenhouse gases (GHGs) into the atmosphere. Carbondioxide (CO_2) is the major GHG produced by humans, which is having the single greatest effect on climate change, being responsible for over 60% of the enhanced greenhouse effect (Amakiri, 2010). Forest ecosystems store carbon. They play vital roles in regulating global carbon balance, and mitigating global climate change (Tomppoetal., 2010). Concerns about the impact of CO_2 emissions from forest destruction on the global climate has led to increased emphasis on estimating the world's forests current carbon stocks and their changes for forest carbon stocks quantification and monitoring in the fight against global warming. Quantification and monitoring of forest carbon stocks are important for international trade in carbon credits. The amount of carbon sequestered by a plant can be estimated from its biomass, since approximately 50% of plant biomass is carbon (Losietal., 2003; Montagu etal., 2005). Therefore, to determine the carbon pools of the forest, it is necessary to first determine the biomass of each component of the forest (e.g. large trees, small trees, palms, and downed wood) (Kauffman and Donato, 2012).

In carbon inventory, more consideration is always given to the most significant pools. A species' contribution to carbon stockin a particular forest depends so much on the stock density and sizes of its individuals in the forest area. According to Suzuki and Tagawa (1983), total aboveground biomass is greatly affected by stocking (density), basal area, and height. Nipa palm (NypafruticansWurmb.) is now one of the most dominant species of the mangrove forest in Cross River State, Nigeria. It is an exotic species introduced into the Calabar region in 1906 and has become invasive, replacing the indigenous species and colonizing large areas of the forest (James etal., 2007; Okugboet al. 2012). Unlike the native mangroves species which are intensively exploited by the local people for both domestic and commercial uses, Nipa palm is not exploited because, being an alien species, the people lack knowledge of the various uses it can be put to. Thus, Nipa palm is growing very luxuriantly in the area, sequestering and holding in stock large amount of carbon, which is contributing significantly to the mangrove carbon stock in the area.

Cross River State needs to quantify and monitor the carbon stocks of all forest ecosystems in the State for active participation in carbon mitigation programmes, such as Reducing Emissions from Deforestation and Forest Degradation, and Enhancing Forest Carbon Stocks in Developing Countries (REDD+), and other financial incentives tied to conservation of standing forests (Kauffman and Donato, 2012). This requires accurate estimation of biomass.Biomass determination using direct method, by cutting and weighing all the plants in sample areas (Fu and Wu, 2011)is the most accurate method of quantifying aboveground biomass Shrestha

(2014). However, due to the destructive, tedious, laborious, time consuming and very costly nature of direct measurement, the aboveground biomass is commonly estimated by the use of allometric biomass equations, which relate one or more easily measurable variables, mostly stem diameter at breast height (and sometimes height), to total aboveground biomass (Kauffman and Donato, 2012; Shrestha, 2014).Allometric equations have been developed for a variety of mangrove species occurring across a broad geographical range (Kairo etal., 2009; Komiyama etal., 2005; Poungparnetal., 2002; Soares and Schaeffer-Novelli, 2005).Unfortunately, there is none developed for Nipa palm fronds in Cross River State mangrove forest.Therefore, the focus of this study was to develop anallometric equation for accurate estimation of the biomass of Nipa palm fronds for carbon stock accounting and monitoring in the area.

Materials and Methods

Study Area

The study was carried out in the mangrove forest of Cross River State, which is part of the large eastern block of mangrove forests in Nigeria. The area is located between latitudes 441′30″ and 503′20″N, and longitudes 806′10″ and 835′05″E. It extends from the Cross River estuary, eastwards, to the Nigerian boundary with Cameroon, reaching 7-8km in width and stretching inland into the estuary for about 26km (FAO, 2005). The mangroves in this area cut across Odukpani, Calabar South, Akpabuyo and Bakassi Local Government Areas of Cross River State. The map of the mangrove forest in Cross River State is shown in Figure 1

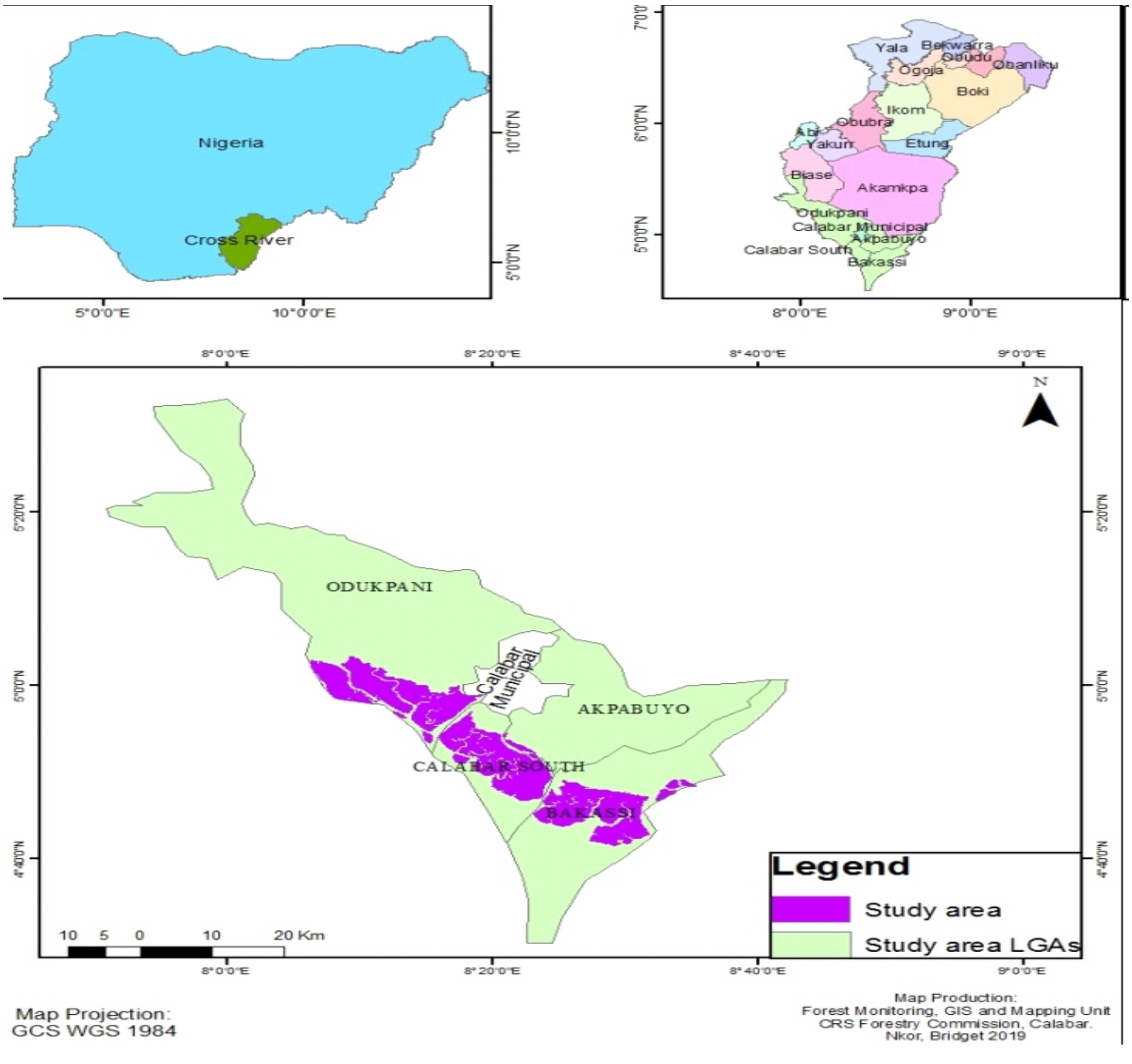


Figure 1: Map showing the location of mangrove in Cross River State with maps of Nigeria and Cross River State inset

Sampling Techniques

A destructive sampling of30 fronds was purposively conducted in selecting candidates for model development. The candidates were selected from different clusters of Nipa palms and on the basis of absence of broken topor dieback. To ensure a representative distribution, candidate fronds were selected to cover the range of sizes of the palm fronds in the area. This is in line with the assertions by Avery and Burkhart (2002); Clutter et al. (1983) Demearschalk and Kozak, (1975); Marshall and Demearschalk, (1986)that candidates for model developmentshould be selected purposively to cover the whole range of the size classes of interest.

Data Collection

Each selected candidate was measured for dbh(at 1.3m above ground level) using the diameter tape before it was cut down from the base.After felling, each frond was measured for length with the metric measuring tape and then cut into sections, weighed and aliquots collected from the base, middle and top portions as specimens. The aliquots were weighed fresh in the field as soon as they were collected and later transported to the laboratory for biomass determination.

Biomass Determination

In the laboratory, the aliquots were oven-dried at a temperature of 105°C to constant dry weights. The candidates' wet weights were converted to dry weights (biomasses) by multiplying each candidate's wet weight by a conversion factor developed between its (the candidate's)aliquot's oven-dry weight and wet weight as shown in equation (1):

$$DW_C = \frac{DW_A}{WW_A} \times WW_C \quad \text{...} (1)$$

Where; DW_C = each candidate's dry weight (kg),
DW_A = oven-dry weight of the respective aliquot of each candidate (g),
WW_A = wet weight of the respective aliquot of each candidate (g) and
WW_C = each candidates' wet weights (kg).

Model Development

The doublet observations (Dbh and biomass) obtained from the 30 individual palm fronds of Nypafruticans were then used to develop the biomass equation for the species. The dataset was divided into two parts; one part (21 observations) was used for model calibration and the other part (9 observations) for model validation. Eightmodels were selected as candidates for the biomass equation (Table 1). The functions were fitted to the calibration data set (Clutter et al., 1983). . The data were summarised in tables in Microsoft Excel before they were used to test the functions. Ordinary least squares regression procedure in R-Studio (Crawley, 2005)was used in fitting the different models and deriving the final equation.

Table 1: Candidate models for the biomass equations

Model Form	Model Code
$B = b_0 + b_1 D^{0.5} + \varepsilon_i$	2
$B = b_0 + b_1 D + \varepsilon_i$	3
$B = b_0 + b_1 D^2 + \varepsilon_i$	4
$B = b_0 + b_1 D + b_2 D^2 + \varepsilon_i$	5
$\ln B = b_0 + b_1 D^{0.5} + \varepsilon_i$	6
$\ln B = b_0 + b_1 D + \varepsilon_i$	7
$B = b_0 + b_1 \ln D + \varepsilon_i$	8
$\ln B = b_0 + b_1 \ln D + \varepsilon_i$	9

Where; B = stem biomass, D= diameter at breast height, b_0 and b_1 are estimated parameters, while ε_i = error term.

All the fitted models wereevaluated in two stages.First,verification was carried out using both graphica l and quantitative analysis of the residuals to assess each model's accuracy, precision and conformity to the general assumptions of linear regression.Some of the criteria used were Adjusted Coefficient of Determination (R^2), F-statistic (F) and Root Mean Square Error (RMSE)that were generated fromthe regression analysis used in fitting the models. Furnival Index (FI) and Akaike Information Criterion (AIC)were also calculated with equations (10) and (11).

$AIC = 2K - 2\ln L$ .... (10)

Where: AIC is Akaike information criterion,

K is the number of parameters

L is the maximum likelihood value

The model with the lowest AIC value is the preferred one (Mohammed *et al*., 2015).

$= \quad ' \quad ^{-1}$ .... (11)

Where: FI is the Furnival Index,

RMSE is Root Mean Square Error of the regression equation and

$[f'(B)]^{-1}$ is the geometric mean of the derivative of the dependent variable with respect to biomass. The derivative of an untransformed dependent variable is 1.0, while the derivative of the dependent variables that were transformed with natural logarithm ($\log_e$) was given by:

$' \quad ^{-1} = \quad \frac{1}{} \; \ln$ .... (12)

Where: ΣlnB is the sum of the dependent variable transformed with $\log_e$,

n is the sample size and

$[f'(B)]^{-1}$ is as defined in equation (11).

After the verification, the best three performing models were selected for validation using9 observations (biomass and dbh) independentof those used in fitting the models. The models were validated with paired sample t-test at 5% level of significance and test of bias using equations (13) and (14), respectively.

$= \frac{}{}$ .... (13)

Where; is t -test statistic, is mean of the difference between pairs and is the standard erro r of the difference between pairs. The hypotheses tested were:

Null hypothesis (H_O): There is no significant difference between the observed and predicted values.

Alternative hypothesis (H_A): There is significant difference between the observed and predicted values.

For a valid model this comparison should show no significant difference (Akindele, 1990).

$= \frac{-}{} \times 100$... (14)

Where , is bias, and are, respectively, measured and predicted values of the models' dependent va riable (biomass) and is number of paired observations (measured and predicted values).

The best performing equation was a natural logarithmic equation. It was selected and a correction factor (CF) calculated for it using equation (15) (Sprugel, 1983).

$= \frac{2}{2}$ .... (15)

Where SEE is the standard error of estimate of the regression(0.1775)

Results and Discussion

Summary Statistics

The summary statistics of the doublet observations (biomass and Dbh) obtained from the 21 individual palm fronds of Nypa fruticans that made up the calibration dataset are presented in Table 2.The dbh ranged from 5.0 cm to 14.1 cm, with a mean of 9.6 cm and standard deviation of 2.6 cm, while biomass ranged from 1.81 kg to 14.54 kg, with a mean of 6.26 kg and standard deviation of 3.23 kg.

Table 2 : Summary statistics of the Dataset for Calibrating Biomass Equations for Nipa Palm Fronds in Cross River Mangrove Ecosystem

Statistic	Dbh (cm)	Biomass (kg)
Mean	9.6	6.2629
Standard Error	0.57	0.704816
Standard Deviation	2.60	3.229874
Sample Variance	6.78	10.43209
Kurtosis	-0.659	0.876478
Skewness	0.069	0.862537
Minimum	5.0	1.814159
Maximum	14.1	14.53697
Count	21	21

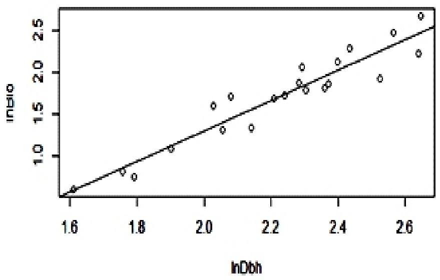
Fitted Equations

The results of the equations fitted for estimation of biomass of Nipa palm fronds revealed model 9 as the best, having the least AIC -9.107), FI (0.970) and RMSE (0.1775) and the highest R^2 (90%) and F-Val (177.91). The estimated parameters and results of fit statistics for all the models are presented in Table3.Resultsof various graphical analyses (scatter plots, line graphs and histograms) showing how model 9 fit the dataset are presented in Figure 2.

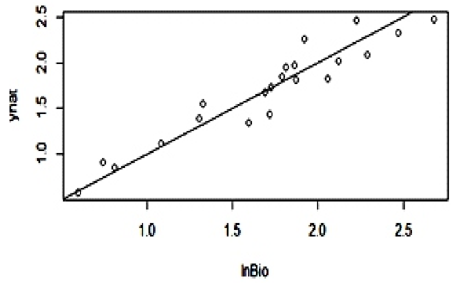
Table 4 : Assessment Criteria of Biomass Equations for Nipa Palm Fronds in Cross River Mangrove Ecosystem, Nigeria

Model Code	Equation	Assessment Criteria AIC	FI	R^2 (%)	F-Val	RMSE	Rank
9	$\ln B=-2.373+1.834\ln D$	-9.107	0.970	90	177.91	0.1775	1st
6	$\ln B = -2.060+1.226D^{0.5}$	-6.776	1.026	89	157.23	0.1877	2nd
7	$\ln B=-0.2118+0.1997D$	-2.988	1.123	86	128.14	0.2054	3rd
4	$B=0.5803+0.0580D^2$	76.524	1.364	82	93.184	1.364	4th
3	$B=-4.512+1.126D$	77.331	1.39	81	88.951	1.39	5th
5	$B=-1.01868+0.34810D+0.04033D^2$	78.322	1.394	81	44.65	1.394	6th
2	$B=-14.466+6.764D^{0.5}$	79.238	1.455	80	79.581	1.455	7th
8	$B=-15.693+9.888\ln D$	81.891	1.55	77	67.884	1.55	8th

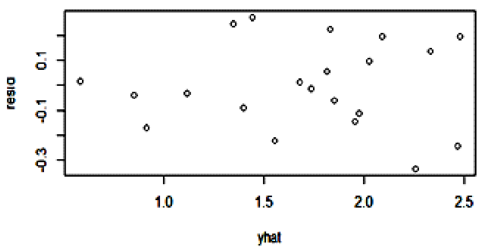
Where; B = stem biomass, D= diameter at breast height, AIC = Akaike Information Criterion , FI = Furnival Index, RMSE = Root Mean Square Error, F-Val = F -Value, R^2= Adjusted Coefficient of Determination



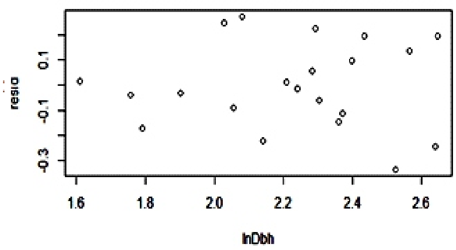
(a) Scaterplot and trendline for the equation



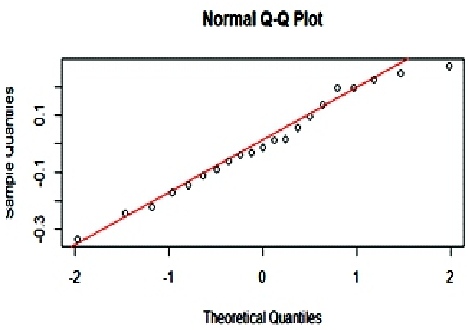
(b) Scaterplot and trendline of predicted versus observed values



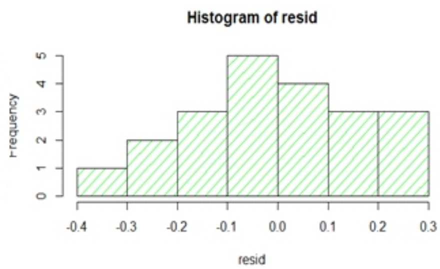
Plot of residual versus predicted values



(d) Plot of residual versus observed values



(e) Normality plot



(f) Frequency distribution of the residuals

Figure 2: Results of various graphical analyses of the residuals

Model Validation

The results for paired sample t-test and test forpercentagebias are presented in Table 4. The calculated t-values (t-stat) ranged from 0.71038 to 0.73444 and werelower than the t-critical value of 2.306.The results revealed that there was no significant ($p>0.05$) difference between the biomass computed directly and the biomass values obtained using the developed equations. The results ofthe test forpercentagebias showed that the values ranged from 5.9% to 6.8%, with equation (9) having the least bias (5.9 %).The correction factor calculated for the selected equation is 1.015878and the back transformed and corrected form of the equation is presented as equations (16).

$$B = 0.094681 \times D^{1.834} \quad \text{.......} \quad (16)$$

Table 4 : Validation Results for Suitable Biomass Equations for Nipa Palm Fronds in Cross River Mangrove Ecosystem

Model Code	t-stat	t-critical	P-value	Mean Bias (%)	Remark
9	0.73444	2.306	0.4836	5.9	Selected
6	0.71792	2.306	0.4932	6.3	Adequate
7	0.71038	2.306	0.4977	6.8	Adequate

Forest biomass is commonly estimated by the use of allometric biomass equations. The theoretical basis of allometry assumes that one or more parts of an organism are directly proportional in growth or size to the other parts of it (Komiyama etal. 2008).Several studies have used allometry as a powerful tool for estimating the aboveground biomass of mangroves with crown area, number of prop roots and total tree height as aboveground biomass predictors (Coronado-Molina etal., 2004), and dbhand total tree height as aboveground biomass predictors (Smith and Whelan, 2006).

In this study, dbh was used as the only predictor variable to develop the allometric equation for estimating the biomass of individual fronds of Nipa palm. Dbh was adopted as the sole predictor variable because it is easy to measure accurately in the field and is a more acceptable variable ((Komiyama etal. 2008; Segura and Kanninen, 2005) unlike height or length, which is difficult to measure accurately in the field, especially in mangrove ecosystems(Kauffman and Donato, 2012; Lupembe, 2014), where the working environment poses additional challenges.The leaning position of most of the fronds makes it even more difficult to measure their heights accurately. Matsui et al. (2014), who developed frond biomass equation with fronds' dbh and length in Southern Thailand, were compelled to predict length from dbhby the difficulty involved in measuring fronds' lengths due tothe inclined position of most of the fronds. Dbh is the most common predictor variable in allometric models (Munishiet al., 2001; Munishi and Shear, 2004) and has been adopted by several studies as the only independent variable for predicting the aboveground biomass of mangroves (Fromardetal., 1998; Ong et al., 2004; Soares et al., 2005). According to Hossain(2016), allometric models with dbh as single independent variable might be more practical and user friendly in the field than those with other independent variable like total height.

The 8 models fitted to the dataset consisted of both linear and power functions expressed in various forms. The power functions were transformed to linear equations using natural logarithms to make possible the use of linear regression methods in fitting the equations. Three models (6, 7 and 9) fitted the dataset reasonably, judging from the evaluation results of both thestatistical and graphical analysis of their residuals. In addition, the validation results of paired sample t-test, andthe test for bias (Tables 4) showed that the three equations are valid for predicting the biomass of individual fronds of Nipa palmin Cross River State mangrove forest. All the tests' results demonstrated that the predictions of the equations were close to the actual observations. However, model 9, a power model transformed to linear equation with natural logarithms, performed best, having the lowest AIC, FI, and RMSE, the highest R^2 and F-Val (Table 3) and optimal performance in the graphical analysis of the residuals (Figure 2). Therefore, equation 9 was selected because it fitted the dataset best, as indicated by the evaluation and validation results. The selected equationwas transformed back to its original power function and corrected for bias, with acorrection factor of1.015878, so as to yield its results in arithmetic units. The correction for bias was necessary, since logarithmic transformation changes the original scale and introduces a slight negative bias when data are transformed back to arithmetic units (Baskerville,1972; O'Hara and Kotze, 2010; Packard, 2009) and to account for this bias, the back-transformed results from logarithmic unit are usually multiplied by a correction factor (Addo-Fordjour and Rahmad, 2013).

Conclusion

The biomass of Nipa palm fronds can be estimated using allometric relationship. Frond dbhis a good predictor of frond biomass as shown by the results of theanalysis of the relative error rates between the measured and the simulated values in this study.The predictions of the three equations that fitted the dataset reasonably were close to the actual observations. Theequations are valid for predicting the biomass of individual fronds of Nipa palm in Cross River State mangrove forest. However, the selectedequationisthe most valid and is recommended for predicting the biomass of only individual fronds of Nipa palm whose sizes range from5 cm to 14.1cm in dbh within the study area. It is also recommended that a wider study on this, with a larger sample size that may cover a wider range of dbh, should be carried out in the study area.

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