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Tree basal area models and density for selected plantation species in swamp forest zone of Rivers State, Nigeria

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ABSTRACT

Individual-tree models of basal area growth and density were developed for seven plantation species in swamp forest zone of Rivers State, Nigeria. Tree growth data were collected from pure permanent sample plots of seven plantation species within the study area with measurements of diameter at breast height (cm), diameter at the base (cm), total height of tree (m), and also the number of tree per plot was taken and obtained from plantation records. The Quantitative data collected from these selected plantation species were subjected to descriptive analysis, correlation and regression analyses. Linearized models for description of relationship between BA and other growth attributes were developed. The results of the major growth variables by species in the study area showed that *Treculia africana* has the highest dbh mean value 30.804 ±2.031 (cm) with density 0.0022 and basal area per hectare 1.79×10^{-4} (m^2). Similarly, the results also showed that *Nauclea dedirrichii* has the lowest dbh mean value 08.484 ±0.339 (cm) with basal area 3.92×10^{-5} (m^2) and density 0.0063 per hectare. The results of correlation analyses showed general associations between basal area and the growth attributes by species with coefficients of correlation ranging from –0.023 to 0.999. The results similarly revealed distinct variations by species in density, basal area and tree number in the study area. The results of relationship between basal area and other growth variables showed significant model fit (best fit) with diameter attributes with model order: $LNBA = b_0 + b_1 lnDb + b_2 Dbh^2$ in *Enthandrophragma angolense* (R^2 - 0.964, RSME – 0.837). The results of the study revealed that there were significant variations in the growth attributes by species in the study area; with significant associations between the basal area and major growth variables evaluated in the study, while the selected best adjudged fit model in the study area could be reasonably used for predicting basal area which is critical in cubical volume estimation and sustainable management of the study area.

Keywords**:** basal area, modeling, stand density, management, *Nauclea diderrichii, Entandrophragma angolense, Khaya ivorensis, Terminalia ivorensis, Treculia africana, Tectona grandis*

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1. INTRODUCTION

Forest is a highly complex, constantly changing environment made up of a variety of living things (wildlife, trees, shrubs, wildflowers, ferns, mosses, lichens, fungi and microscopic soil organisms) and non-living things (water, nutrients, rocks, sunlight and air). Trees are the biggest part of this complex community. Forestry is the scientific study of the forest for continuous production or supply of goods and services to meet human needs [29-33].

Forests play critical roles in maintaining and providing important ecosystem services and functions. However, these important roles are under threat due to the combined effects of deforestation, forest fragmentation and degradation. Alarms about these threats have mainly focused on their impacts on habitat quality, climate change and particularly biological diversity. Tree diversity of forested ecosystems has important consequences on carbon storage, decomposition or mineral cycling, nutrient acquisition, communities of biota, and growth and productivity [15]. A plantation is a large piece of land (or water) usually in the tropical or semitropical area where one crop is specifically planted for a widespread commercial sale or research purpose and usually tended by resident laborers. Species, such as *Nauclea diderrichii (opepe), Entandrophragma angolense, Khaya ivorensis, Terminalia ivorensis, Treculia africana* and *Tectona grandis* plantation are among the most economically important hardwood species in tropical Africa, particularly Nigeria.

A tree is a perennial plant with an elongated stem, or trunk, supporting branches and leaves in most species. Like many aspects of nature, a tree's existence revolves around competition. However, trees grow poorly if there are too many or too few trees per acre. According to [8], the largest trees can produce an expanded crown which, in turn, produces the largest amount of food. The tallest trees receive the direct sunlight. Therefore, the fastest growing trees are often the winning competitor. Stand density greatly influences the diameter growth. Stand density or stocking is a quantitative measure of the area occupied by trees, usually measured in terms of well-spaced trees or basal area per hectare, relative to an optimum or desired level of density. Stand structure is an important element of stand biodiversity. Also to produce an adequate amount of food, a tree must retain at least one-third of its height in live crown. The optimum number of trees per acre at a given age depends upon their size. Due to this, foresters prefer to use basal area to describe stand density [2].

One defines the basal area of a tree as area of a given section of land that is occupied by the cross-section of tree trunks and stems at their base. The basal area of a stand is the average cross-sectional area of all trees per unit of stand surface, normally measured at the breast height. It is also useful to guide thinning operations, particularly during the latter stages of development of the selected specie plantation. According to [8], a hectare of land is defined as a unit of area equal to 10,000 square meters. To compare and examine a forest's growth rate and productivity, basal area measurements are usually made for one hectare (ha) of land. Several studies had been done on individual tree basal area and basal area increment (BAI) models which are commonly used within the growth modeling; with perception that such derive tree growth according to tree size, crown size, level of competition and site specific characteristics [11, 18, 26], but few information is particularly recorded on basal area modeling related to swamp forest zone of Rivers State, Nigeria.

According to [10] such growth models are importantly developed to predict future yield and to explore silvicultural options, and within growth models, diameter growth of a tree is determined by diameter increment or the corresponding tree basal area increment.

Indeed, numerous writers had reported the essentiality of basal area models and their applications to sustainable forest science and management. According to them, the last two decades had witnessed a rapid development of advanced mathematical statistics and computing technologies and information on basal area modeling methodology and technology at the stand level have progressed a great deal in many parts of the world; and many mathematics-based basal area models including simultaneous equation methods [6], difference models [1, 3, 4, 9], artificial neural network techniques [14], linear/nonlinear regression models [7, 19, 21, 28] and matrix models [12, 13, 22, 27] have been developed and found their great applications in forest management.

It is therefore imperative to carry out this study to evaluate the tree basal area and density of selected plantation species (*Nauclea diderrichii*, *Entandrophragma angolense, Khaya ivorensis*, *Terminalia ivorensis*, *Treculia africana*, and *Tectona grandis*) in swamp forest zone of Rivers State, Nigeria. The study also determined the relationship between the basal area and density of trees in the study area.

2. METHODOLOGY

2. 1. Study area

The study area is located at the Forestry Research Institute of Nigeria, Swamp Forest Research Station, Onne. Onne is a part of Nchia clan in Eleme Local Government Area of Rivers State in Nigeria, situated on latitude 4º44' N and longitude 7º15' E (at an altitude of 1440 feet) to Bonny River (**Fig. 1**). The closest ethnic groups to which the Onne people have been associated with are the Ogonis. With an approximate population of 190,884 persons on a land area of over 138 km^2, the area is described as amongst one of the many large wetlands in Africa as well as beehive of oil and gas activities. The area consists of rivers, creeks and estuaries while stagnant swamp covers about 600 km^2 with the area dotted with mangrove swamps. The ecosystem of the area is highly diverse and supports numerous species of terrestrial and aquatic flora and fauna including human life. It is one of the richest regions in the world, and could be said to be an ecologically sensitive region. Large resources of oil and gas are extracted from the region (which is the main source of revenue for the Nigerian state, accounting for about 97% of the country's total export), has dominated the Nigeria's economy.

2. 2. Data Collection

Quantitative data were collected from the selected plantation species located at swamp forest zone of Rivers State, Nigeria. Total enumeration of the selected plantation species was carried out with measurements on growth variables on diameter at the breast height (cm), diameter at the base (cm), total height of tree (m), as well as the number of trees per plot obtained from plantation records.

2. 3. Data Analysis

Descriptive analysis and inferential statistics were used in this study. Various regression analysis options were also used to develop a suitable tree basal area and density models while the product moment correlation analysis was used to evaluate association between tree basal area and the density and tree growth characteristics.

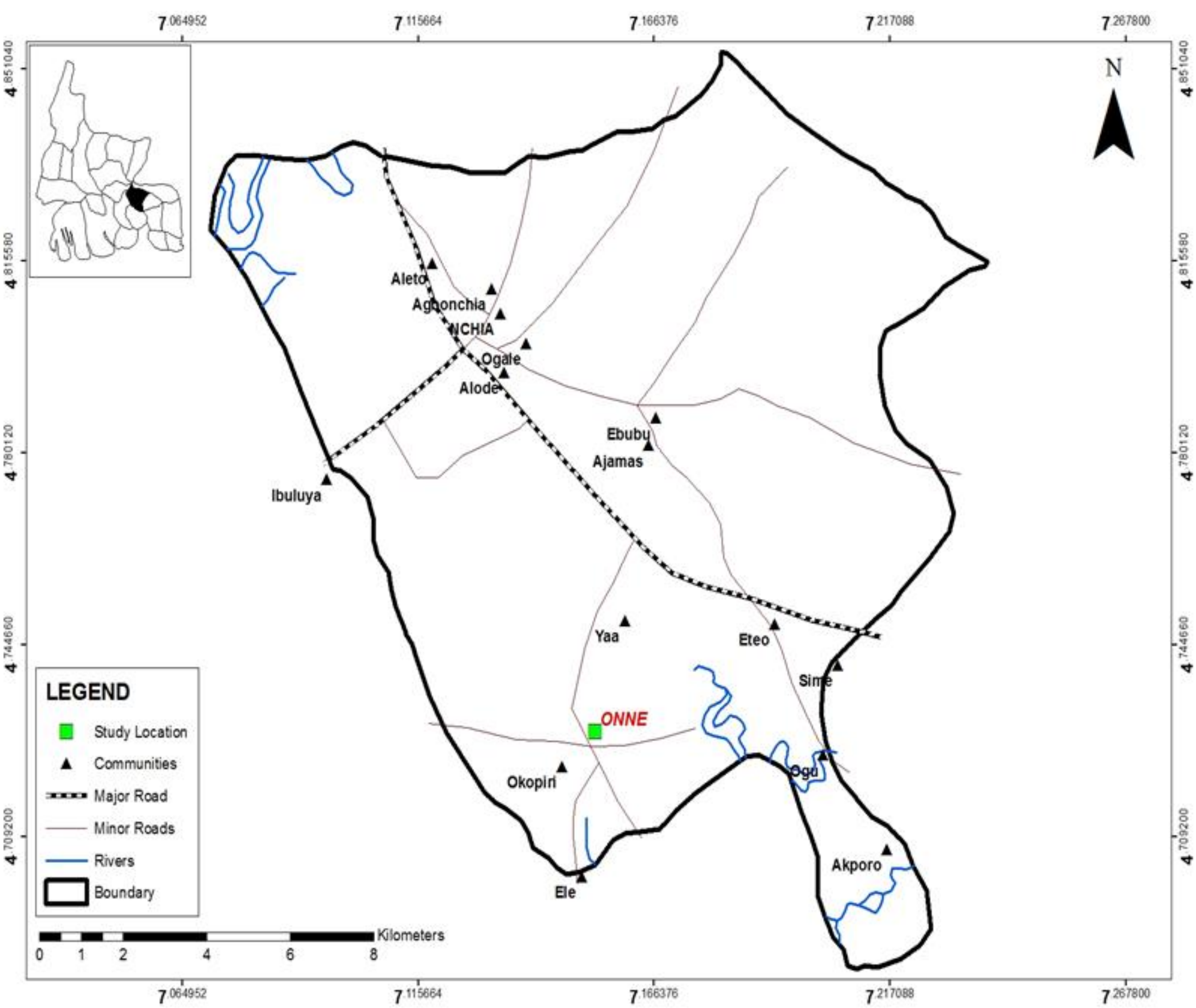

Figure 1. Map of Eleme Local Government in Rivers State Showing the Study Location

2. 3. 1. Basal Area Estimation

Tree basal area (TBA) is the cross-sectional area (over the bark) at breast height (1.3 metres or 4.5 ft above the ground), measured in square metres (m^2). TBA can be used to estimate tree volumes and stand competition.

The basal area for each tree in each sample plot was estimated using the formula:

$$BA = \frac{\pi}{4} D^2 \qquad \text{………..…….(1)}$$

where: BA = Basal Area (m^2)
D = dbh, π = 3.1415925535.

The total basal area of all the trees and density were also estimated and their estimates were used for per hectare estimates.

2. 3. 2. Correlation and Regression analysis

The coefficient of correlation (r) was estimated to determine the associations between basal area and some common growth variables while simple regression method was explored to measure the relationship between variables.

The correlation coefficient (r) and simple regression empirical equation are expressed respectively below (2).

2. 3. 3. Correlation

The strength of the linear association between two variables is quantified by the correlation coefficient. Given a set of observations (x_1, y_1), (x_2, y_2)…. (x_n, y_n), the formula for computing the correlation coefficient is given by

$$r = \frac{1}{n-1} \Sigma \left(\frac{x-\bar{x}}{Sx}\right)\left(\frac{y-\bar{y}}{Sy}\right) \qquad \text{………..……. (2)}$$

2. 3. 4. Regression

The regression equations follow the simple and multiple orders as:
Simple or Linear regression

$$Y = \alpha + \beta X_1 \qquad \text{………..……. (3)}$$

where: Y = dependent, X = independent while α and βare regression parameters.

Multiple regression:

$$Y = a + bx_1 + cx_2 + \ldots\ldots dx_n \qquad \text{…………. (4)}$$

Y = dependent variable, a, b, c, d are regression parameters, x_1, x_2 … x_n are the multiple independent variables.

2. 3. 5. Stand density

Number of tree stem per unit ground area is expressed as:

$$N = \frac{\bar{n}}{a} \quad [17] \qquad \text{………………….(5)}$$

where:

N = Density (number of stems per hectare)
$\bar{n}$ = average of the counts
a = Area of plot per hectare,

3. RESULTS

3. 1. Statistics of growth variables by species in swamp forest zone

Table 1 below shows the summary statistics of the growth variables of species (*Nauclea dedirrichii*, *Khaya ivorensis*, *Enthandrophragma angolense*, *Terminalia ivorensis*, *Tectona grandis* and *Treculia africana*) in the study area. The major growth variables shown in the Table below includes basal area, diameter at breast height (dbh), diameter at the base (db), total height (THT), density and basal area/ hectare (ba/ha) of the plantation.

The result of the growth variables showed that variations exist between basal area, diameter at breast height, diameter at the base, total height, density and basal area per hectare of the by species of the study area.

Table 1. Summary statistics of the growth variables by species in the study area

	Variable	**N**	**Mean ± SE**	**Min**	**Max**	**Density (Num/ ha)**	**Basal area/hect (m^2/ha)**
Nauclea dedirrichii	Dbh (cm)	63	08.484±0.339	3.264	14.5263	0.0063	3.92×10^{-5}
	Db (cm)		10.301±0.282	4.282	15.7378		
	THT (m)		6.701±0.25	3.26	11.41		
	BA (m^2)		0.066214±0.000468	0.000837	0.016575		
Khaya ivorenses	Dbh (cm)	57	19.206±0.5007	2.54	20.32	0.0057	1.43×10^{-4}
	Db (cm)		48.783±1.2718	6.4516	51.6128		
	THT (m)		10.769±0.35308	4.89	17.59		
	BA(m^2)		0.02505±0.001819	0.003709	0.066653		
Enthandrophragma angolense	Dbh(cm)	14	20.32±9.85E-16	20.32	20.32	0.0014	7.61×10^{-5}
	Db (cm)		32.781±1.11935	24.575	39.0458		
	THT (m)		16.2536±0.919435	11.41	22.82		
	BA (m^2)		0.05437±0.005179	0.020739	0.08503		
Terminalia ivorenses	Dbh (cm)	20	21.091±0.4059	17.138	24.171	0.002	7.041×10^{-5}
	Db (cm)		24.8422±0.4135	22.716	29.668		
	THT (m)		18.58±0.0904	18	19.7		
	BA (m^2)		0.035188±0.00133	0.02307	0.04589		

Tectona grandis	Dbh (cm)	59	18.674±0.99033	3.2336	38.15659	0.0059	1.88×10^{-4}
	Db (cm)		24.1658±1.177507	11.07511	56.58816		
	THT (m)		12.0005±0.5384	3.2	19.56		
	BA (m^2)		0.03186±0.003066	0.000821	0.114363		
Treculia africana	Dbh (cm)	22	30.8038±2.030819	14.0662	46.40229	0.0022	1.79×10^{-4}
	Db (cm)		37.14609±1.78254	17.05729	52.8695		
	THT(m)		10.4859±0.30738	8.15	13.04		
	BA(m^2)		0.081337±0.00932	0.01554	0.16913		

N-Number of trees, Dbh (cm) - diameter at breast height, Db (cm) - diameter at the base, THT (m) - total height, BA (m^2) - basal area.

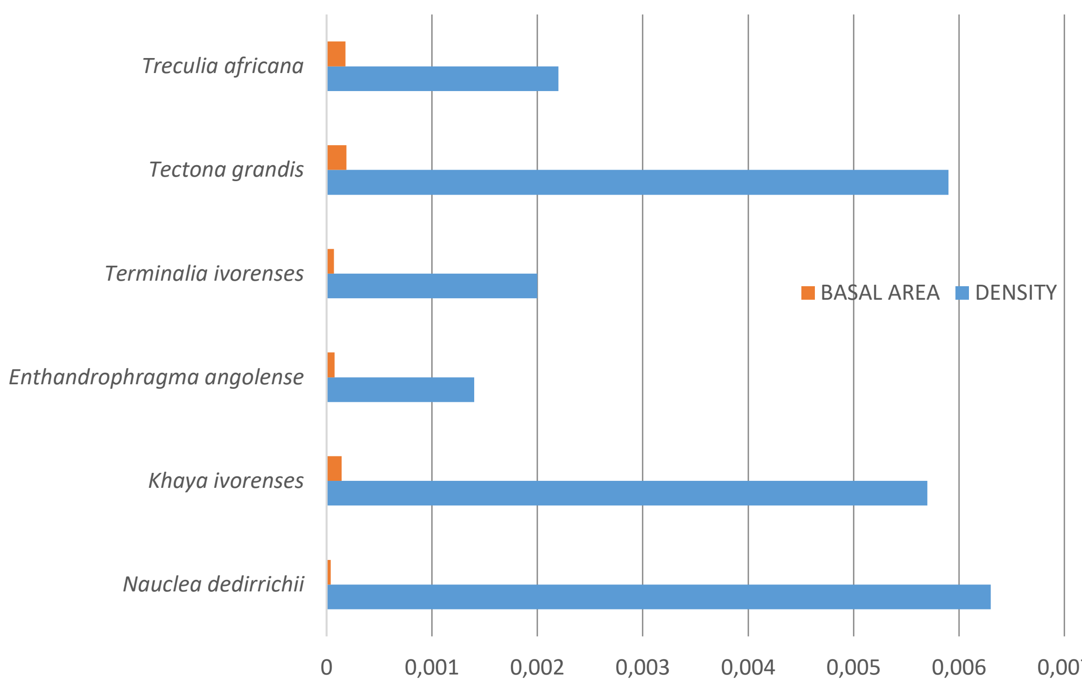

Fig. 2. Pattern of variation in basal area and density by species in the study area

Treculia africana having the highest basal area mean value 0.081337 ±0.00932 with density 0.0022 and basal area per hectare 1.79×10^{-4}, *Khaya ivorensis* having the highest basal area mean value 0.02505 ±0.001819 with density and basal area 0.0057 and basal area per hectare 1.43×10^{-4}. *Treculia africana* having the highest dbh mean value 30.8038 ±2.030819 with density 0.0022 and basal area per hectare 1.79×10^{-4} and *Nauclea dedirrichii* having the lowest dbh mean value 08.484 ±0.339 with density 0.0063 and basal area 3.92×10^{-5}. *Khaya* *ivorensis* having the highest db mean value 48.783 ±1.2718 with density and basal area 0.0057 and basal area per hectare 1.43×10^{-4}. *Nauclea dedirrichii* having the lowest db mean value 10.301 ±0.282 with density 0.0063 and basal area per hectare 3.92×10^{-5}.

Likewise *Terminalia ivorensis* having the highest total height mean value18.58±0.0904 with density 0.002 and basal area per hectare 7.041×10^{-5}, *Nauclea dedirrichii* having the lowest total height mean value 6.701±0.25 with density 0.0063 and basal area per hectare 3.92×10^{-5}. *Enthandrophragma angolense* having the highest basal area per hectare 7.61×10^{-5}, density 0.0014, Dbh Min. 20.32. Max. 20.32; Db Min. 24.575, Max. 39.0458, THT Min. 11.41, Max. 22.82. *Terminalia ivorensis* also having high basal area per hectare 7.04×10^{-5}, density 0.002, Dbh Min. 12.138, Max. 24.171, Db Min. 22.716, Max. 29.668, THT Min. 18, Max. 19.7. *Khaya ivorensis* having the lowest basal area per hectare 1.43×10^{-5}, density 0.0057, Dbh Min. 2.54, Max. 20.32, Db Min. 22.716, Min. 29.668, THT Min.18, Max. 19.7.

As a means of verifying, the growth variables chart was plotted for the variation between basal area and density. **Fig. 2** shows the pattern of variation of basal area and density by species in the study area with *Nauclea dedirrichii* having the highest density and *Enthandrophragma angolense* having the lowest density while *Treculia africana* and *Tectona grandis* having the highest basal area while *Nauclea dedirrichii* having the lowest basal area.

3. 2. Result of the correlation analyses

Table 2 shows correlation matrixes between basal area and growth attributes of by species in the study area. Correlation analysis defines the relationship that exists among the variables in consideration. The results as shown in the table revealed general associations between basal area (BA) and the growth attributes by species (*Nauclea dedirrichii*, *Khaya ivorensis*, *Ethandrophragma angolense*, *Terminalia ivorensis*, *Tectona grandis*, *Treculia africana*) in the study area.

The associations between the basal area and diameter at breast height (DBH), diameter at the base (DB) of tree and total height of tree (THT) shown in the Tables have a high correlation with coefficients of correlation (r) 0.986, 0.791, 0.676 for *Nauclea dedirrichii*; 0.986, 0.825, 0.643 for *Khaya ivorensis*; 0.995, 0.408, 0.222 for *Enthandrophragma angolense*; 0.999, 0.743, –0.115 for *Terminalia ivorensis*; 0.964, 0.896, 0.418 for *Tectona grandis* and 0.988, 0.803, 0.200for *Treculia Africana*, respectively. The associations between tree basal area and the growth attributes (THT, DBH and DB) of *Terminalia ivorensis* were low and having negatively correlated with coefficients of correlation (r) –0.115, –0.117, and –0.023, respectively.

However, there are elements of similarity among the associations that exist among DBH, DB and THT with high values of coefficients of correlation, such that the association between dbh and db gave coefficient of correlation (r), 0.787 for *Nauclea dedirrichii*, 0.854 for *Khaya ivorensis*, 0.369 for *Enthandrophragma angolense*, 0.733 for *Terminalia ivorensis*, 0.866 for *Tectona grandis*, and 0.773 for *Treculia africana*, while a basal area coefficient is negatively correlated with THT, Dbh and Db in *Terminalia ivorensis* –0.115, –0.117, –0.023 among the by-species. This shows that an increase in the tree growth causes a decrease in diameter at breast height (Dbh) in *Terminalia ivorensis* with a negative coefficient of correlation (r) of –0.115, –0.117, –0.023; indicating that tree growth increases, the basal area and diameter at breast height decreases in (**Table 2**). Furthermore, **Fig. 3** shows a pattern of variations in the density per hectare, as well as the tree number by species, while **Fig. 4** shows variations among density, basal area and tree number by species in the study area.

Table 2. Correlation matrixes between basal area and other growth variable for the tree species in the study area

Tree Species	***Growth variables***	**Basal area (m^2)**	**Dbh (cm)**	**Db (cm)**	**THT (m)**
Nauclea diderrichii	Basal area (m^2)	1			
	Dbh (cm)	0.986	1		
	Db (cm)	0.791	0.787	1	
	THT (m)	0.676	0.680	0.747	1
Khaya ivorensis	Basal area (m^2)	1			
	Dbh (cm)	0.987	1		
	Db (cm)	0.825	0.854	1	
	THT (m)	0.643	0.681	0.678	1
Enthandrophragma angolense	Basal area (m^2)	1			
	Dbh (cm)	0.995	1		
	Db (cm)	0.408	0.369	1	
	THT (m)	0.222	0.226	0.488	1
Terminalia ivorensis	Basal area (m^2)	1			
	DBH (cm)	0.999	1		
	DB (cm)	0.743	0.733	1	
	THT (m)	–0.115	–0.117	–0.023	1
Tectona grandis	Basal area (m^2)	1			
	DBH (cm)	0.964	1		
	DB(cm)	0.896	0.866	1	
	THT(m)	0.418	0.524	0.436	1
Treculia africana	Basal area(m^2)	1			
	DBH(cm)	0.988	1		
	DB(cm)	0.803	0.773	1	
	THT(m)	0.200	0.195	0.237	1

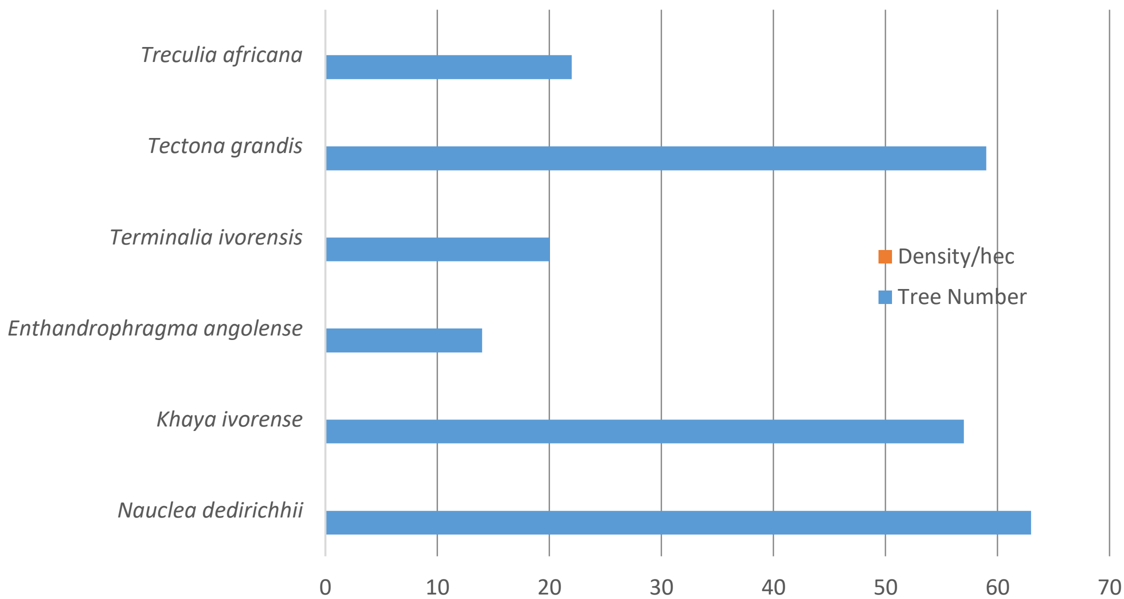

Fig. 3. Density and tree number by species in the study area

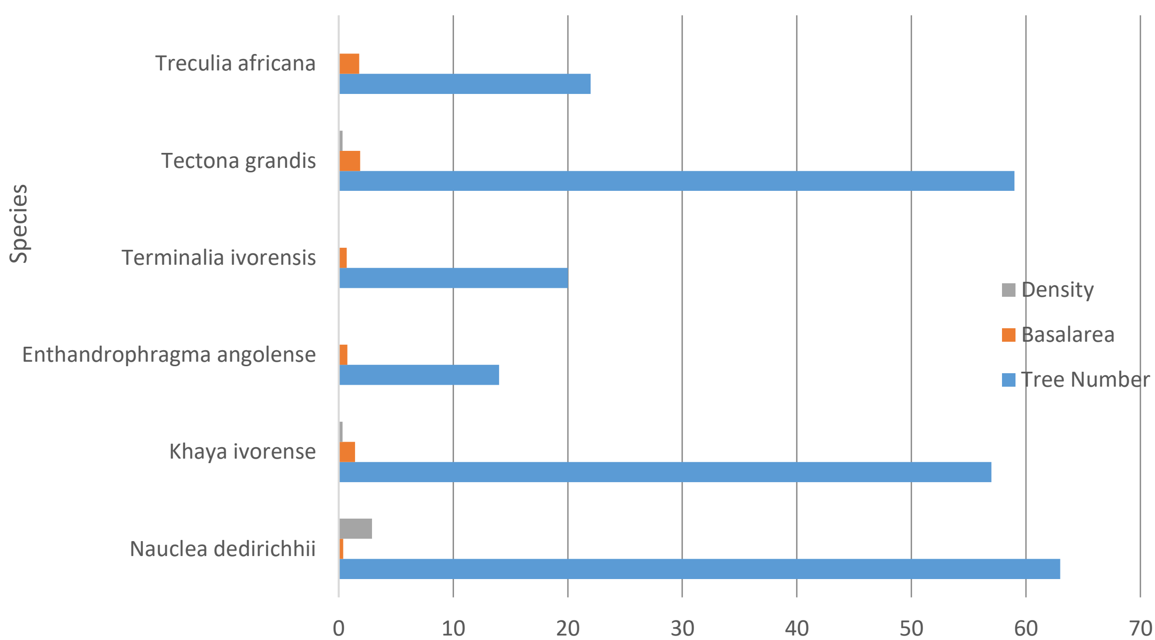

Fig. 4. Species variation in density, basal area and tree number in the study area

3. 3. Regression Basal Area Models

The results of estimated basal area models parameters of by-species (*Nauclea dedirrichii*, *Khaya ivorensis*, *Enthandrophragma angolense*, *Terminalia ivorensis*, *Tectona grandis* and *Treculia africana*) in the study area are shown in **Table 3**.

Table 3. Estimated linear model parameters and summary statistics for basal area equation by species in the study area

Species	b_0	b_1	b_2	R^2	RSME	P-value
Equation 1: (LNBA=b_0+b_1LnDb+b_2LnTHT)						
Nauclea dedirrichii	−10.162	1.678	0.543	0.605	0.439	0.000
Khaya ivorensis	−10.631	1.778	0.511	0.783	0.270	0.000
Ethandrophragma angolense	−6.134	0.800	0.133	0.96	0.420	0.573
Terminalia ivorensis	−7.018	1.991	−0.941	0.567	0.137	0.001
Tectona grandis	−11.349	1.956	0.592	0.726	0.556	0.000
Treculia Africana	−10.058	2.009	0.059	0.502	0.543	0.002
Equation 2: (BA+b_0+b_1Db+b_2THT^2)						
Nauclea dedirrichii	−0.006	0.001	0.2579×10^{-5}	0.643	0.002	0.000
Khaya ivorensis	−0.26	0.002	0.3123×10^{-5}	0.690	0.008	0.000
Ethandrophragma angolense	−0.006	0.002	0.8561×10^{-6}	0.168	0.019	0.363
Terminalia ivorensis	−0.012	0.002	-0.3477×10^{-5}	0.561	0.004	0.001
Tectona grandis	−0.025	0.002	0.6724×10^{-6}	0.803	0.011	0.000
Treculia africana	−0.079	0.004	0.2491×10^{-5}	0.632	0.028	0.000
Equation 3: (LNBA=b_0+b_1LnDb+b_2Dbh^2)						
Nauclea dedirrichii	−7.231	0.431	0.12	0.888	0.235	0.000
Khaya ivorensis	−7.188	0.854	0.002	0.920	0.164	0.000
Ethandrophragma angolense	−3.296	−0.240	0.002	0.964	0.837	0.000
Terminalia ivorensis	−9.604	1.972	−0.005	0.557	0.139	0.001
Tectona grandis	−8.354	1.256	0.002	0.747	0.534	0.000
Treculia Africana	−7.231	0.431	0.012	0.888	0.235	0.000
Equation 4: (BA=b_0+b_1LnDbTHT)						
Nauclea dedirrichii	−0.16	0.005	-	0.555	0.003	0.000
Khaya ivorensis	−0.106	0.024	-	0.599	0.088	0.000
Ethandrophragma angolense	−0.072	0.02	-	0.101	0.019	0.268
Terminalia ivorensis	−0.298	0.054	-	0.471	0.004	0.001
Tectona grandis	−0.012	0.004	-	0.010	0.024	0.445
Treculia Africana	0.076	0.001	-	0.000	0.045	0.971
Equation 5: (BA=b_0+b_1THT^2)						
Nauclea dedirrichii	0.002	0.8844×10^{-5}	-	0.447	0.003	0.000
Khaya ivorensis	0.007	0.000	-	0.391	0.011	0.000
Ethandrophragma angolense	0.44	0.3732×10^{-5}	-	0.050	0.020	0.441
Terminalia ivorensis	0.049	-0.4064×10^{-5}	-	0.012	0.006	0.643
Tectona grandis	0.018	0.8715×10^{-5}	-	0.148	0.022	0.003
Treculia Africana	0.052	0.000	-	0.038	0.044	0.397

The results, as indicated in the Table, show the linear empirical models were fitted into individual tree data. The results of the estimates were evaluated using coefficient of determination (R^2), root standard mean error (RSME) and probability of significance (P-value). The R^2 among the linear models ranges from 0.605, 0.783, 0.96, 0.567, 0.726, 0.502 in equation one (1), 0.643, 0.690, 0.168, 0.561, 0.803, 0.632 in equation two (2), 0.888, 0.920, 0.964, 0.557, 0.747, 0.888 in equation three (3), 0.555, 0.599, 0.101, 0.471, 0.010, 0.000 in equation four (4), and 0.447, 0.391, 0.050, 0.012, 0.148, 0.038 in equation five (5) of *Nauclea dedirrichii*, *Khaya ivorensis*, *Ethandrophragma angolense*, *Terminalia ivorensis*, *Tectona grandis* and *Treculia Africana*, respectively; with *Ethandrophragma angolense* having the highest R^2 value 0.96 and RSME 0.420, while *Treculia africana* having the lowest R^2 value 0.502 and RSME 0.543 in equation one (1).

Tectona grandis is having the highest R^2 value 0.803 and RSME 0.011 in equation two (2), *Enthandrophragma angolense* having the highest R^2 value 0.964 and RSME 0.837 in equation three (3), *Khaya ivorensis* having the highest R^2 value 0.599 and RSME 0.088 in equation four (4), and *Nauclea dedirrichii* having the highest R^2 value 0.447 and RSME 0.003 in equation five (5). *Nauclea dedirrichii* and *Treculia africana* is having R^2 value 0.888 and P-value 0.235, respectively, in equation three (3).

The relationship between the basal area and other growth variables showed a significant model fit (best fit) with diameter attributes with model order: LNBA = $b_0 + b_1\ln Db + b_2 Dbh^2$ in *Enthandrophragma angolense* (R^2 - 0.964, RSME – 0.837).

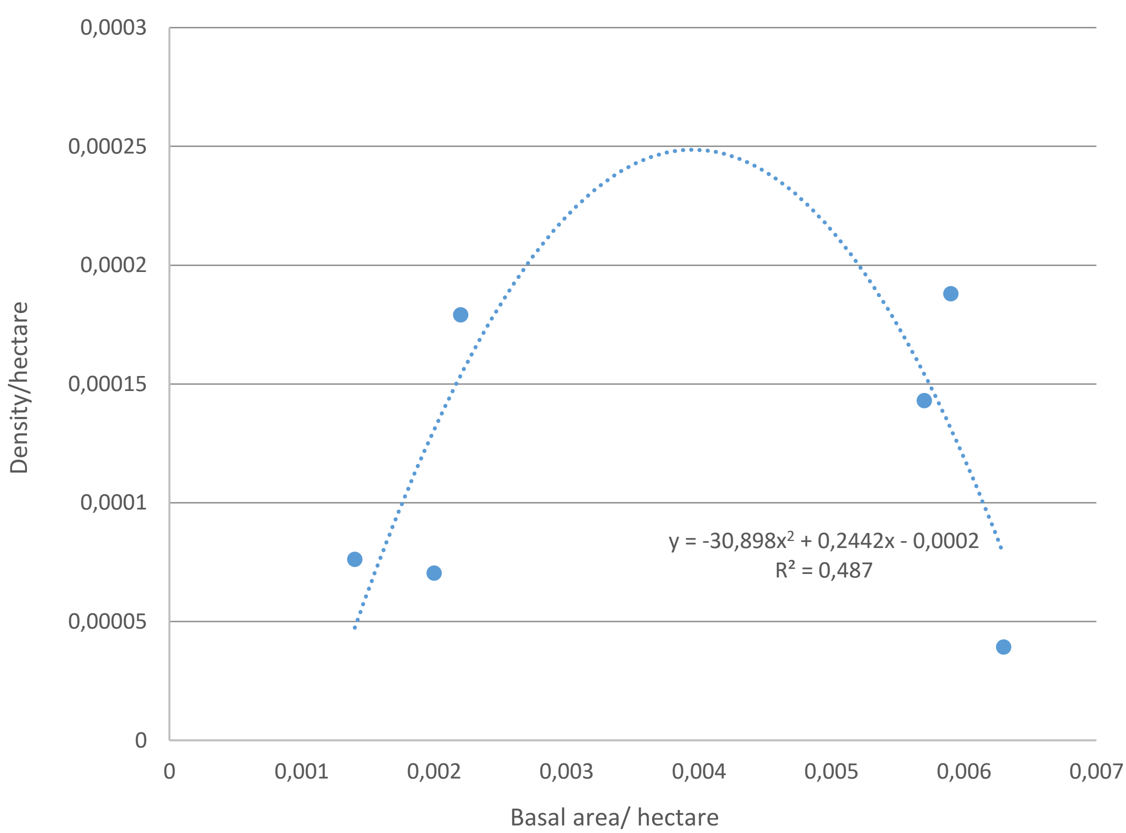

Fig. 5. Relationship between basal area and density by species in the study area

Figure 5 shows the growth curve presenting the relationship between the basal area per hectare and density per hectare by species in the study area. The fit curve developed for the relationship between the density/hectare and basal area/hectare by species plantation in the study area attained the R^2 value of 0.487 (Fig. 5).

4. DISCUSSION

4. 1. Growth variables

The results of the major growth variables by species plantation in the study area shows that *Treculia africana* has the highest dbh mean value. This was as a result of the species being well spaced and does not compete with other species for growth, while *Nauclea dedirrichii* has the lowest dbh mean value and having the highest density, with *Terminalia ivorensis* having the lowest density, *Khaya ivorensis* having the highest basal area mean value. *Enthandrophragma angolense* has the highest basal area per hectare. *Treculia africana* had the highest dbh mean value and *Nauclea dedirrichii* having the lowest dbh mean value. *Khaya ivorensis* is having the highest db mean value. *Nauclea diderrichii* has the lowest db mean value. Basal area growth by species differs significantly. Trees existence revolves around competition. Trees grow poorly if there are too many or too few trees per hectare. Stand density greatly influences diameter growth. Ref. [2] reported that the basal area and density are related when examining the total basal area and density values, of the coastal plain data which were extreme that it could not be included when determining the line of best fit.

The growth variables charts were plotted for the variation between basal area and density. Fig. 2 shows the pattern of variation of basal area and density by species in the study area with *Nauclea dedirrichii*, having the highest density and *Enthandrophragma angolense*, having the lowest density while *Treculia africana* and *Tectona grandis* are having the highest basal area, while *Nauclea dedirrichii* has the lowest basal area. Also an increase in the tree growth causes a decrease in diameter at breast height (Dbh) in *Terminalia ivorensis* with a negative coefficient of correlation (r), indicating that when tree growth increases, the basal area and diameter at breast height decreases (Table 2). Other researchers observed the variation in the changes of plant density along the succession trajectory [5, 20, 24]. This study did observations with some research which found out that the plant density increases as the fallows ages, or increases and then stabilizes. Other studies have found that stem density increases initially, but then declines in early or intermediate stages, that it varies among age classes, or that it decreases with fallow age.

Furthermore, Fig. 3 shows a pattern of variations in density per hectare, as well as the tree number by species, while Fig. 4 shows variations among density, basal area and tree number by species in the study area.

4. 2. Correlation and Regression analyses on basal area

The results of correlation analysis among growth variables by species and basal area revealed significant variations and the results were all in a diagonal shape indicating that the results or values which supposed to be above the constant are the same with the values below the constant seen in Table 2. There are elements of similarity among the associations that exist among DBH, DB, and THT with high values of coefficients of correlation such that the association between dbh and db gave a negative coefficient of correlation among the species, indicating that the tree growth increases, the basal area and diameter at breast height decreases (Table 2). *Nauclea dedirrichii* and *Treculia africana* are having R^2 value 0.888 and P-value 0.235, respectively, in equation three (3), showing element of covariance in the relationship by equation among the species. As a basal area increases, so does density increases in the relationship between basal area and density per hectare (Fig. 5). The graph shows that when the density and basal area are compared, they form relatively a curve which increases from the zero (0) point, gets to the maximum, and decreases slowly. When the basal area was compared to density, the coefficient of determination in, R^2 value was 0.487 per hectare (Fig. 5). Similarly, other researchers also reported an increase in stem density [16], but this study observed a decline after reaching a peak in early to intermediate successional stages [20, 24, 25].

5. CONCLUSIONS

This study has provided a quantitative information on the basal area and density by species (*Nauclea dedirrichii, Khaya ivorensis, Enthandrophragma angolense, Terminalia ivorensis, Tectona grandis, and Treculia africana*) in swamp forest zone, Onne, Rivers state.

The results of relationship between the basal area and other growth variables showed a significant model fit (best fit) with diameter attributes with model order: LNBA = $b_0 + b_1$lnDb + b_2Dbh^2 in *Enthandrophragma angolense*. The study also revealed that the residual curve which represents the relationship of basal area and density per hectare showed inverted-U-shaped residual curve; and indicative of non-linear relationship that may exist when expressing the basal area and density on per hectare basis. The revelations from the study can significantly be used for a reasonable management objective on the tree basal area and density by species for determining sustainability and productivity of any selected plantation in Nigeria. This would also give valuable quantitative silvicultural options for a well-managed plantation in other ecological zone of Nigeria. Basal area is indeed a measure used for management because it can represent the size of individual trees and the density of forest stands, and it can describe wildlife habitat. Assessed either with special instruments, or through prediction or by estimation, basal area is an important forest measurement. Basal area is used to determine more than just forests stand density; it is also linked with timber stand volume and growth. Therefore, it is often the basis for making important forest management decisions, such as estimating forest regeneration needs and wildlife habitat requirements. The manipulation of stand basal area to achieve forest management goals can be as important as the use of prescribed fire or other vegetation treatments. More research to compare more stands from other ecological zone in Nigeria should be done.

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