Original Research Article

ALLOMETRIC MODELS FOR ESTIMATING SITE INDEX OF TEAK (*Tectona grandis* Linn F.) IN KANYA FOREST PLANTATION, KEBBI STATE, NIGERIA

ABSTRACT

This study was conducted in order to develop site index for Teak (*Tectona grandis)* in Kanya Forest Plantation, Nigeria. Site index is defined as the total height of the dominant or co-dominant trees at an arbitrary index age, it is a method used for quantifying site quality for pure even aged stands which is essential in growth and yield modeling. The data used in this study were obtained from six different age classes. Five sample plots each were selected across all age classes in which a total of 712 trees were measured, variables measured include total height, diameter at the base, middle, top, and diameter at the breast height were taken from 30 temporary sampled plots of 25x25m approximately from the center, 180 dominant trees were selected from 712 trees. Basal area and volume of sampled trees were computed. Yield values obtained from the dominant trees are (B=249.312m^3/ha, D=196.128m^3/ha, F=134.976m^3/ha, C=119.328m^3/ha, E=100.320m^3/ ha and A=86.976m^3/ha). The results showed that B was the best and A was the poorest. Seventeen models were generated and paired sampled t-test was used for model validation, comparing the actual and predicted height. Two out of 17 were rejected (significant $P<0.05$). The first model $Hd=12075.346-354.809(Age)+3.448(Age)^2-135193.126(1/Age)$ is the recommended height estimation of Teak in Kanya Forest plantation for its best performance.

Keywords: Site; Site Index; Site Quality; Dominant Trees; Teak.

1. INTRODUCTION

Site index is defined as the average total height of dominant and co-dominant trees (site trees) at a specified reference or base age, which is commonly selected to lie close to the rotation age [1]. The top height is the arithmetic mean height of the 100 trees ha^{-1} with the greatest diameters [2]. However, the most common objective of site index is to determine the height development pattern that a stand is expected to follow throughout rotation [1]. It is little affected by varying densities and species composition, relatively stable under varying thinning intensities and is strongly correlated with volume.

Site index is a quantitative measure of site quality, and it is generally a reflection of the potential timber productivity of a stand of trees [3]. Dominant and co-dominant trees are used to describe site index because they are assumed to have grown freely throughout their life; thus, the growth of these trees is somewhat independent of other vegetation. A base age is usually used as a reference so that stands of different site quality can be compared. These characteristics of plantation forest - uniformity of crop, intensity of production, high density, fast growth rate and high productivity have raised concerns that many of the sites on which the plantations are established may be incapable of sustaining their productivity [4]. Site quality assessment is the evaluation of innate productive capacity of an area of forest land for one or more tree species. Site quality assessment is very important in forest management because a site could support one species excellently, while supporting another species poorly.

According to 2000-2005 Global Forest Resources Assessment of the Food and Agricultural Organization of the United Nation (FAO), Nigeria has the world's highest annual deforestation rate of primary forest at 55.7%. The country is one of the largest losers of annual natural forest in Africa at 11.1%. Nigeria's annual deforestation rate of natural forest is the highest in the world and put it in the pace to lose virtually all its primary forest within few years. There is a growing concern about the uncontrolled exploitation of Nigeria's forest resources in accordance to the recent observations that deforestation poses a great risk to sustainable land use and the wellbeing of the people [5].

For more than 100 years, site index has remained the world's most widely used measure of site productivity, many decisions in forestry rely on estimates of the land's inherent ability to grow trees and yield timber. These site productivity estimates serve as a baseline for land-use decisions, land appraisals, silvicultural investment analyses, and growth and yield predictions. The importance of site quality assessment remains imperative in quantitative forestry, simply for its potential and possibility of determining the productive capacity of the plantations area for sustainable management [6]. The main objective of this research is to develop site index for Teak (*Tectona grandis* Linn F.) in Kanya Forest Plantation

2. MATERIALS AND METHODS

2.1 The Study Area

The study was conducted in Kanya Forest Plantation in Danko Wasagu Local Government, Kebbi State is located on Latitude 11.339^0N to 11.348^0 and Longitude 5.606^0E to 5.641^0E, occupying about 4,208km^2. It is bordered in the South by Sakaba Local Government, in the West by Zuru Local Government both in Kebbi State and in the North by Bukkuyum Local Government Area of Zamfara State. Danko Wasagu has an estimated population of about 265,271 people [7]. The vegetation falls under Northern Guinea Savannah. The topography is said to be flat or low land with fertile soil covered by sandy soils, sometime coarse in texture with fadama and alluvial plain suitable for agricultural activities. The weather is marked by single rainy season and long dry season; the average rainfall is 720mm, the rainy season is about four to five months, the mean temperature ranges from 31^0C and 38^0C. From the month of November to February cold weather is usually experienced due to the dry harmattan wind and from March to May, the weather is generally hot and wet as in the tropics [8].

2.2 Sampling Procedure

The area was stratified in to different age classes based on the years of establishment (1979, 1980, 1981, 1982, 1983, and 1989) on which five temporary sample plots of 25 x 25m

(0.0625ha) were marked at random from each age block close to the center. Measurements were taken on all trees within the selected plots. Stand age was obtained from plantation records.

2.3 Data Collection

The data obtained include: Counting and recording of individual trees per plot, Measuring the total height of six dominant trees in all selected plots using Haga Altimeter (this represented the 100 largest trees per ha), Diameter at breast height (DBH) of all individual trees was measured at 1.3m above ground level. Flexible measuring tape was used to determine the circumference of the boles, Diameters at three different points (Base, middle, Top) were determined with the aid of Spiegel Relascope.

2.4 Development of Site Index Equations

After due consideration of the rotation age and the age of culmination of mean annual increment as recommended by various researchers [9,10,11] 30 years was adopted as the appropriate base age for the determination of site index of Teak plantations in the study area. Among the various techniques for developing site index equations, the proportional or guide curve method was adopted for this study because the data were obtained from temporary sample plots, thus permitting only the use of this method [1,12]. Various linear and non-linear equations commonly used for site index studies in forestry were selected from forestry literature [13,1,14,15,16,11,17,18,19]. These equations or models followed the order as follows.

$$Hd = a_0 + a_1\,(Age) + a_2\,(age)^{2} + e_i \qquad (4)$$

$$Hd = a_3 + a_4\,(Age) + a_5\,(1/Age) + e_i \qquad (5)$$

$$Hd = a_6 + a_7 1n\,(Age) + e_i \qquad (6)$$

2.5 Model Selection and Validation

Different criteria for choosing the best model are available; the highest coefficient of determination (R^2) and the lowest root mean square error (RMSE) were considered appropriate criteria in selecting the best model. Model validation was achieved by dividing the data into two sets; (75%) of the data to calibrate the models and the other set (25%) to validate the models, testing for the significant differences in mean predicted and observed values of the dependent variables in all cases was achieved using paired sample T-test.

3. RESULTS

The summaries of growth and yield characteristics of 180 sampled dominant trees are presented in Tables 1and 2. Mean, minimum and maximum values of Dbh, height, BA and volume are recorded for all the age series. The standard error of the mean was also attached to all the mean values in order to see the variability distribution of the sampled data from the population.

Table 1: Summary Statistics of Dominant Trees (Sampled Trees)

			Dbh (cm)			Height(m)		
Age (years)	Plots	Trees	Min	Max	Mean*	Min	Max	Mean*
38	5	6	12.51	36.98	23.77±0.29	9.85	15.25	15.61±0.44
37	5	6	20.53	27.05	25.10±0.75	11.30	19.60	15.19±0.51
36	5	6	19.26	37.91	26.62±0.93	10.70	20.00	15.58±0.42
35	5	6	16.23	37.91	30.07±1.39	11.55	19.60	22.61±0.46
34	5	6	19.89	48.09	24.91±0.89	18.80	28.25	15.07±0.39
28	5	6	16.87	39.15	25.59±0.41	12.90	19.80	16.06±0.29

*Mean± standard error

Table 2: Summary of yield characteristics of Dominant Trees (Sites Trees)

			Basal Area (m^2)				Volume (m^3)			
AC	P	Trees	Min	Max	Mean	Mean BA/ha	Min	Max	Mean	Mean volume/ha
A	5	6	0.01	0.11	0.04±0.01	4.29	0.240	0.980	0.906±0.04	86.976

B	5	6	0.03	0.06	0.50±0.03	8.03	0.410	1.310	2.597±0.20	249.312
C	5	6	0.29	1.11	0.11±0.04	10.34	1.260	5.630	1.243±0.18	119.328
D	5	6	0.02	1.11	0.08±0.01	7.20	0.480	5.470	2.043±0.18	196.128
E	5	6	0.03	0.18	0.05±0.01	4.70	1.150	5.300	1.045±0.08	100.320
F	5	6	0.02	0.12	0.14±0.02	13.14	0.580	2.290	1.406±0.08	134.976

*Mean± standard error

3.1 Site Index Parameter Models.

Different model forms/structures were considered in developing site index equations and estimated regression parameters are presented in Table 3.

Table 3: General models

	Model Expression	**Estimated parameters**			
		a	**b**	**c**	**d**
1	Hd = a + b (Age)	23.84	-0.225	-	-
2	Hd = a + b $(Age)^2$	20.821	-0.004	-	-
3	Hd = a + b ln (Age)	38.441	-6.311	-	-
4	Hd = a + b ln $(Age)^2$	27.990	-0.948	-	-
5	Hd = a + b (Age) + c $(Age)^2$	-238.092	15.996	0.248	-
6	Hd = a + b (Age) + c (1/Age)	597.471	-9.017	9225.302	-
7	Hd = a + b (1/Age) + c $(Age)^2$	296.410	-5903.004	-0.089	-
8	Hd = a + b (1/Age) + c ln (Age)	2716.098	-19260.413	-604.20	-
9	Hd = a + b $(Age)^2$ + c ln (Age)	-772.306	-0.129	266.731	-
10	Hd = a + b ln (Age) + c ln $(Age)^2$	-3452.704	2004.657	-289.249	-
11	Hd = a +b (Age) + c (1/Age) + d $(Age)^2$	-238’183	15.999	10.00	-0.248
12	Hd = a + b (Age) + c(1/Age) + d ln (Age)	-1349.746	-17.299	15.000	555.0.78
13	Hd = a + b (Age) + c ln (Age) + $(Age)^2$	-545.676	-23.907	15.000	110.529
14	Hd = a + b (Age) + c ln $(Age)^2$	-544.228	-23.919	110.729	-
15	Hd = a + b (1/Age) + c ln $(Age)^2$	1287.809	-14801.435	-66.976	-
16	Hd = a + b (Age) + c ln $(Age)^2$	-3427.703	1990.238	-287.173	-
17	Hd = a + b (Age) + c $(Age)^2$ + d (1/Age)	12075.346	-354.809	3.448	1351.126

Hd = dominant height, a, b, c, d = Regression coefficients, Age = Age of the plantation

3.2 Model Evaluation and Validation

Fifteen equations were ranked based on some statistics generated in the course of modelling. Models with the highest coefficient of determination (R^2) and Smaller Root mean square error (RMSE) were considered as the better fit models and were subsequently ranked higher than those with lower R^2 and higher RMSE values (Table 4). The selected candidate models were equations 1,2, and 3 based on ranking with equation 1 having the highest R^2 and lowest RMSE of 0.760 and 1.384. Furthermore, plots of residual values of dominant height for the selected models are shown in Figures 1, 2, and 3. The selected models have their scatter plot normally distributed having perfect prediction of the estimated dominant height.

Table 4: General Equations Developed for Site Index Estimation

Developed Equations	**R^2**	**RMSE**	**Ranking**
$Hd = 12075.346 - 354.809\ (Age) + 3.448\ (Age)^2 - 135193.126\ (1/Age)$	0.760	2.384	1
$Hd = 2716.098 - 19260.413\ (1/Age) - 604.020\ln\ (Age)$	0.634	3.592	2
$Hd = 1287.809 - 1401.435\ (1/Age) - 66.976\ln\ (Age)^2$	0.632	3.607	3
$Hd = -\ 3452.704 + 2004.657\ln\ (Age) - 289.249\ln\ (Age)^2$	0.627	3.657	4
$Hd = -\ 597.471 - 9.017\ (Age) - 9225.302\ (1/Age)$	0.627	3.660	5
$Hd = -\ 3427.703 + 1990.238\ln\ (Age) - 289.173\ln\ (Age)^2$	0.626	3.695	6
$Hd = 296.410 - 5903.004\ (1/Age) - 0.089\ (Age)^2$	0.620	3.730	7
$Hd = -\ 1349.746 - 17.299\ (Age) + 15.00\ (1/Age) + 555.078\ln\ (Age)^2$	0.620	3.745	8
$Hd = -\ 772.306 - 0.129\ (Age)^2 + 266.731\ln\ (Age)$	0.613	3.794	9
$Hd = -\ 238.092 + 15.996\ (Age) - 0.248\ (Age)^2$	0.607	3.860	10
$Hd = -\ 238.183 + 15.999\ (Age) + 10.00\ (1/Age) - 0.248\ (Age)^2$	0.607	3.882	11
$Hd = 20.821 - 0.004\ (Age)^2$	0.071	9.055	12
$Hd = 23.884 - 0.225\ (Age)$	0.055	9.216	13
$Hd = 27.990 - 0.498\ln\ (Age)^2$	0.045	9.315	14
$Hd = 38.441 - 6.311\ln\ (Age)$	0.041	9.352	15

Hd = dominant height (m) Age = Age of the plantation, R^2 = coefficient of determination, RMSE = Root mean square error.

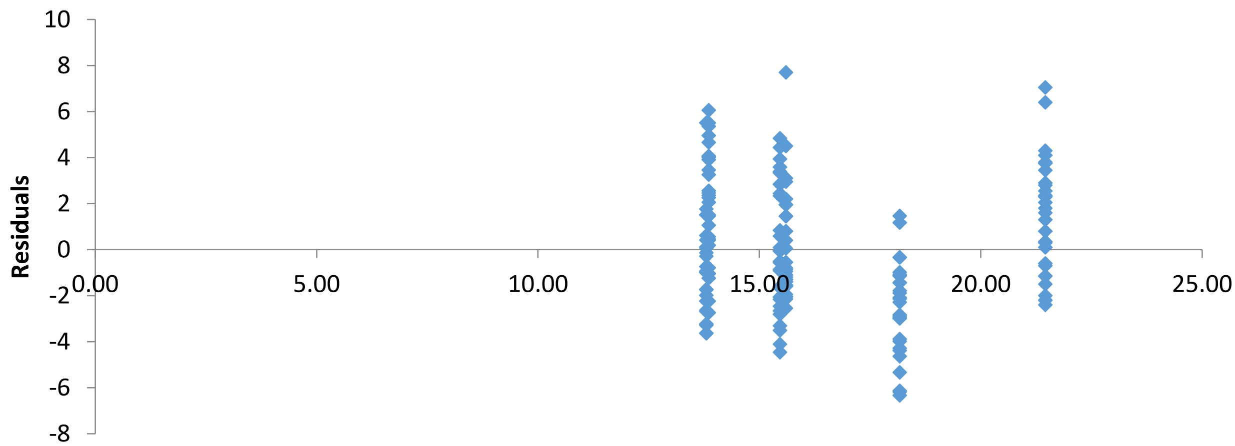

Figure 1: Residual plots for dominant height using first equation

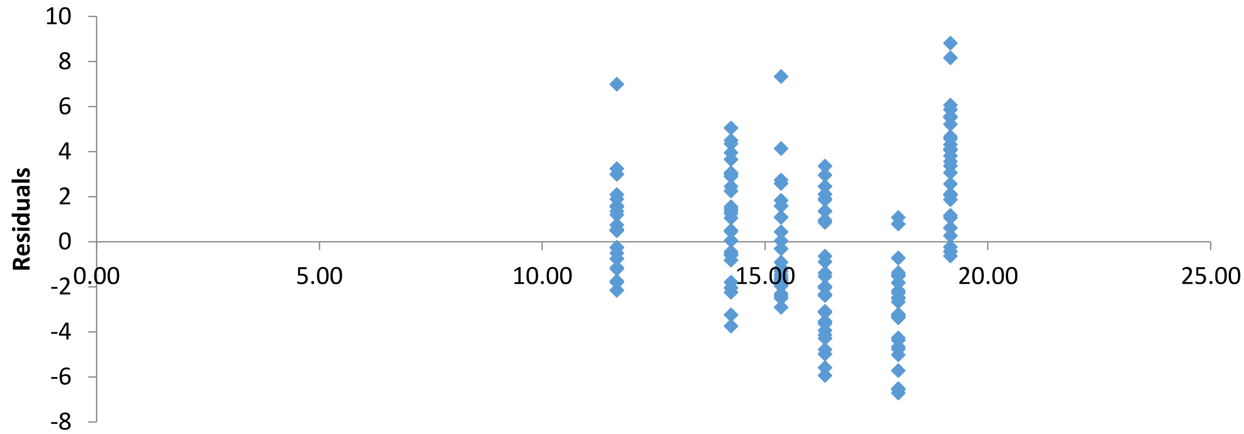

Figure 2: Residual plot for dominant height using second equation

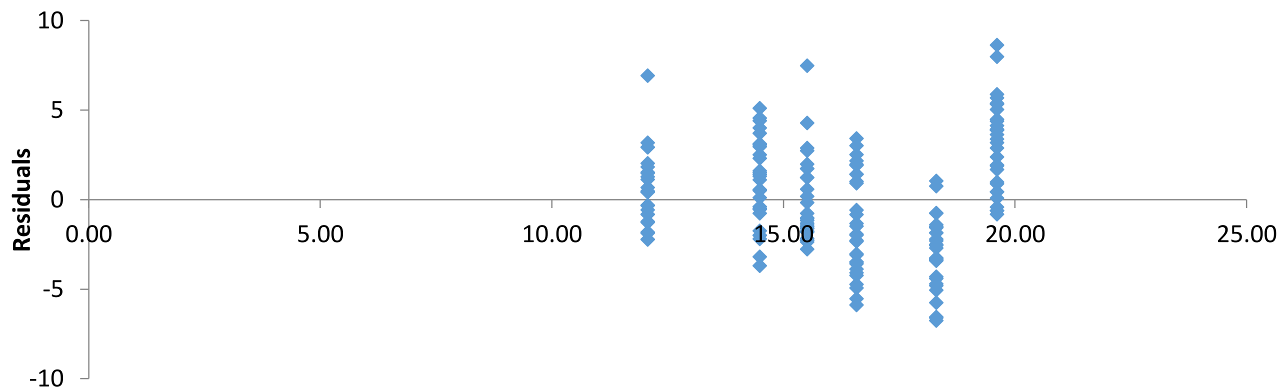

Figure 3: Residual Plot for Dominant Height using third Equation

In order to validate the selected models, paired sample T-test was carried out comparing heights of dominant trees measured from the field and the estimated values from the equations generated (Table 5). Pairs that showed non-significant difference were considered as valid models for application, while pairs that yielded significant differences were rejected ($p<0.05$).

Table 5: Results of Model Validation for Site Index Estimation

Paired Samples	Mean difference	T-Value	P-Value	Decision
Hd(m) v Eqn 1	0.00789	0.028	0.978 ns	Accepted
Hd(m) v Eqn 2	0.12022	0.425	0.671 ns	Accepted
Hd(m) v Eqn 3	-0.00193	-0.007	0.995 ns	Accepted
Hd(m) v Eqn 4	-0.00203	-0.007	0.994 ns	Accepted

Hd(m) v Eqn 5	0.31456	1.391	0.166 ns	Accepted
Hd(m) v Eqn 6	0.00181	0.008	0.994 ns	Accepted
Hd(m) v Eqn 7	0.00033	0.001	0.999 ns	Accepted
Hd(m) v Eqn 8	0.29726	1.319	0.189 ns	Accepted
Hd(m) v Eqn 9	0.00039	0.002	0.999 ns	Accepted
Hd(m) v Eqn 10	-0.42848	-1.908	0.058 ns	Accepted
Hd(m) v Eqn 11	0.01019	0.045	0.96 ns	Accepted
Hd(m) v Eqn 12	-3.59844	-16.004	0.00 sig	Rejected
Hd(m) v Eqn 13	-49.59120	-199.945	0.00 sig	Rejected
Hd(m) v Eqn 14	0.01658	0.074	0.941 ns	Accepted
Hd(m) v Eqn 15	-0.00152	-0.007	0.995 ns	Accepted
Hd(m) v Eqn 16	0.00317	0.140	0.989 ns	Accepted
Hd(m) v Eqn 17	-0.30048	-1.454	0.145 ns	Accepted

Hd = Dominant height (m), Eqn = Equations, Ns = No significant different, Sig.= Significant difference.

4. DISCUSSION

4.1 Site Index Models

The parameter and statistics of regression models 1-17 generated are being presented. Parameters (a, b, c, d,) varied with the model. The selected height-age models are presented according to criteria for selecting the most suitable prediction model, model 17 (Ranked 1st) performed better than all for height-age prediction in Kanya Forest Reserve having highest R^2 and the lowest RMSE of 0.760 and 2.384. Although, the R^2 value was higher than that reported by [20] in height-diameter models and slightly lower R^2 in volume-Dbh models R^2 = 0.51and R^2 = 0.85 respectively. The result implies greater accuracy for dominant height prediction due to higher modeling efficiency. [18] carried out similar study on Site Index Equation for *Pinus caribaea* Plantation in Erosion Prone Enugu Ngwo, Nigeria having R^2_{adj} 0.911 and RMSE 0.023 respectively. [21] Site Quality Assessment for *Tectona grandis* Linn.F Plantations in Gambari Forest Reserve, Nigeria reported R^2 value of 0.95 and SEE value of 0.0835 this shows higher accuracy than the best model in this research. A study by [22] on Site Quality Assessment of Degraded *Quercus fraianetto* stand in central Greece obtained slightly higher R^2 values (0.799, 0.788, and 0.700) for the first two equations and the third equation reporting lower R^2 value, two of the equations have higher accuracy than the best equation in this study and the third equation having low accuracy in predicting dominant height than what was presented in this study. Paired sampled t-test was used to validate the models by comparing the height estimated by the equations and actual height measured. The validation showed mean differences, T-value, P-value and also decisions on the accepted and rejected models. All equations with higher P-values ($P>0.05$) showed no significant difference between the actual measured and estimated dominant height and are accepted, while those with P-value ($P<0.05$) showing significant differences were automatically rejected. [20] also used paired sampled t-test to validate the models comparing actual measured and estimated volume of the stand recording three equations that were significantly different ($p<0.05$).

5. Conclusion and Recommendation

From the results of the study, it can be concluded that the index age of 30 was used to determine the site index of *Tectona grandis* in Kanya Forest Planation, Nigeria. Similarly, the site index equation developed was appropriate for the determination of the site quality of the *Tectona grandis* plantation, and thus can be relevant in assessing the productivity of the Teak stand. This will enhance the proper management of the stand for sustainable timber yield production. It is therefore recommended based on the that: Equation 1. $Hd = 12075.346 - 354.809\,(Age) + 3.448\,(Age)^2 - 135193.126\,(1/Age)$, should be used for site index estimation of teak plantation in Kanya Forest Plantation for its best performance and simple structure

REFERENCES

1. Clutter, J.L., Fortson, J.C., Pienaar, L.V., Brister, G.H. and Bailey, R.L. (1983). *Timber Management: A Quantitative Approach*; John Wiley & Sons.: New York, NY, USA, 30–62.
2. Hagglund, B. (1981). Evaluation of forest site productivity. *Forest Abstracts*, 42(11): 515–527.
3. Hanson, E.J., D.I. Azuma, and B.A. Hiserote. (2002) *Site Index equations and mean annual increment equations for Pacific Northwest Research Station Forest Inventory and Analysis Inventories*, 1985 2001. USDA Forest Service Research Note PNW-RN-533.
4. Onyekwelu J.C, Mosandl, R. and Stimm, B. (2006) Productivity, site evaluation and state of nutrition of Gmelina arborea plantations in Oluwa and Omo forest reserves, Nigeria. *Forest Ecology and Management*, 229: 214-227
5. Schulte-Bisping, H., Bredemeier, M. and Beese, F. (1999). Global availability of wood and energy supply from fuel wood and charcoal. *Ambio*, 28(7): 592–594
6. Skovsgaard, J.P. and Vanclay, J.K. (2007). *Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands.* Forestry Advance Access published November 22, 2007.
7. National Population Commission, (2006). *Provisional Census Figure*. Abuja Nigeria. 1-3.
8. Girma, S.A. (2008). Agro-climatology of Millet Production in Desert Fringe Zone of Nigeria, A Case Study of Kebbi State. M.Sc. dissertation.; Federal University of Technology Minna, Niger state: 1-97.
9. 9. Curtis, R.O., Demars, D.J. and Herman, F.R. (1974). Which dependent variable in site index-height-age regression? *Forest Science*, 20: 74–87.
10. Trousdell, K.B., Beck, D.E. and Lioyd, F.T. (1974). Site index for loblolly pine in the Atlantic Central Plain of the Carolina and Virginia. USDA Forest Service Research. Paper SE-115.
11. Teshome, T. and Petty, J.A. (2000). Site index equation for *Cupressus lusitanica* stands in Munessa, Ethiopia. *Forest Ecology and Management* 126: 339–347.
12. Nanang, D.M. and Nunifum, T.K. (1999). Selecting a functional form for anamorphic site index curve estimation. *Forest Ecology and Management*, 118: 211–221
13. Carmean, W.H. (1972). Site index curves for upland oaks in the Central States. *Forest Science*, 18: 109–120.
14. Malende, Y.H. and Temu, A.B. (1990). Site index curves and volume growth of teak (*Tectona grandis*) at Mtibwa, Tanzania. *Forest Ecology and Management*, 31: 91–99
15. Akindele, S.O. (1991). Development of a site index equation for teak plantations in south-western Nigeria. *Journal of Tropical Forest Science*, 4(2): 162–169.
16. Onyekwelu, J.C. and Fuwape, J.A. (1998). Site index equation for *Gmelina arborea* pulpwood plantations in Oluwa Forest Reserve, Nigeria. *Journal of Tropical Forest Science*, 10(3): 337–345.
17. Onyekwelu, J.C. (2003). Choosing appropriate index age for estimating site index of *Gmelina arborea* timber plantations in Oluwa forest reserve, Nigeria. *Journal of Food, Agriculture and Environment*, (3&4): 286–290.
18. Oyebade, B.A., Popo-ola, F.S. and Aguma Samuel (2012) Site Index Equation for *Pinus Caribaea* Plantation *in* Erosion Prone Enugu Ngwo, Nigeria. *International journal of science and nature*, 3(3): 586-591

19. Kitikidou, K., Milios, E., Tsirekis, E., Pipinis, E. and Stampoulidis, A. (2014). Site quality assessment of degraded *Quercus frainetto* stands in central Greece. *iForest – Biogeosciences and Forestry*: e1-e6.
20. Adeyemi, A.A. (2016). Site Quality Assessment and Allometric Models for Tree Species in Orban Forest, Nigeria. *Journal of Sustainable forestry,* 36(4): 280-289
21. Ige, P.O and Akinyemi, G.O. (2015) Site Quality Assessment for *Tectona grandis* Linn.f Plantations in Gambari Forest Reserve, Nigeria. *Journal of Forestry Research and Management*. 12: 58-67