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SITE INDEX EQUATION FOR *PINUS CARIBAEA* PLANTATION *IN* EROSION PRONE ENUGU NGWO, NIGERIA

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ABSTRACT
Site index equation was developed for estimating the site quality and timber production potential of an existing site of *Pinus caribaea* plantation in Enugu Ngwo, Nigeria. Site index is a term that is used in forestry to describe the potential for forest tree to grow at a particular location or site or a measure of a forest's potential and productivity. The site quality assessment of *Pinus caribaea* plantation at Enugu Ngwo has never been quantitatively evaluated for many years now despite the plausible potentials of the erosion prone plantation in the Ngwo Community of Enugu State, Nigeria. Measurements of the total height and diameter at breast height data were taken from twenty temporary sampled plots (TSPs) of 20m × 20m in the pine plantation stand of different age series. The quantitative data collected from these TSPs were subjected to both linear and non-linear regression analyses for models fitting and evaluation. Adjusted coefficient of determination (R^2_{Adj}), root mean square error (RMSE) and scatter diagram were used in model evaluation and for choosing the best model. The model ($\beta_0 + \beta_1 (A) + \beta_2 (A^{-1}) + e_1$) was chosen as the best fit model having the highest Adjusted R^2 (0.911) and the lowest RMSE (0.023) in plot 4. The results from scatter plots of residual against predicted values of dominant height for the best model significantly agrees with the trend of model fitting and evaluation; which shows that the models selected gave reasonable relationships between the response and predictor variables. The results of this study showed that the index age of 50 was used to determine the site index of *Pinus caribaea* at Enugu Ngwo, Nigeria. This site index equation developed is presumably suitable for the site index studies on any *Pinus caribaea* plantation in Nigeria. The study finally revealed that site index equation developed can be applicable for reasonable assumptions on site index studies on any *Pinus caribaea* plantation in Nigeria and thus proffer ample estimates and appropriate site index for the determination of the site quality of the *Pinus caribaea* plantation, that can be relevant in assessing the productivity of the pine stands for sustainable valuation and management in Nigeria.

KEYWORDS: site quality, optimum timber production, sustainable management

INTRODUCTION

Site index is a term used in forestry to describe the potential for forest tree to grow at a particular location or site or a measure of a forest's potential productivity. Site index is usually defined as the height of the dominant or co-dominant trees at a specific age in a stand. Common methods used to determine site index are based on tree height, plant composition and the use of soil maps. Also it can be achieved by measuring and averaging the total height and age of the trees found on that site (Avery and Burkhart 2002). Height is obtained from dominant or codominant trees in an even aged stand usually from an instrument called Clinometers, and age is calculated from an instrument called an increment borer or from planting or harvest record (Avery, and Burkhart 2002). The estimated height model describes tree heights as a function of diameter at breast height, site index, dominant height and dominant diameter. Total tree height and diameter at breast height (1.3m above ground, DBH) outside bark are essential measurements in forest management and are used for predicting total and merchantable tree volume, estimating site index and other important variables in forest growth and yield (Zhang and Hill 2001). Since tree heights are relatively more difficult and time consuming to obtain, measurement of all sample trees for DBH and a portion of these trees for height is an exceedingly common practice with both permanent and temporary sample plots. Height diameter models are then used to estimate the heights of trees measured only for diameter. Site index is the essential tool for forest management to estimate the productivity of forest land generally. Site index equation is developed and used by relationship between stand and age and dominant tree height. However, there are limit to the use of the site index equation in the application of variable ages, environment influence and estimation of site index for unstocked land. Prediction methods of site index have been of interest to many researchers because of the limitations associated with ground-based measurement of the index, such as the destructive nature of the stem analysis. Additional limitation occurs because there is a certain age for trees below which site factors will not reflect actual condition. The site quality assessment of *Pinus caribaea* plantation at Enugu–Ngwo has never been quantitatively evaluated since the establishment of plantation despite the plausible potential of the erosion – prone plantation in the Ngwo community of Enugu state. The development of site index equations and models will therefore facilitate proper assessment of the site quality of the plantation for determination of optimum productivity. The objective of this study therefore is to develop site

index equations for *Pinus caribaea* plantation. The study also will determine the dominant height of *Pinus caribaea* for prediction purposes, as well as determine the best fit model for the site index evaluation.

MATERIALS & METHODS

Ngwo town is located in the south-eastern state of Enugu, Nigeria, with a population of about 50,000 people. Enugu-Ngwo is situated on Udi escarpment, at an altitude of about 396.24m, longitude $07^0\ 27^1$ East and latitude $06^0\ 26^1$ North of the equator (Ainslic 1935). The annual rainfall ranges between 32 and 87 degrees centigrade while it is hottest between May and October each year.

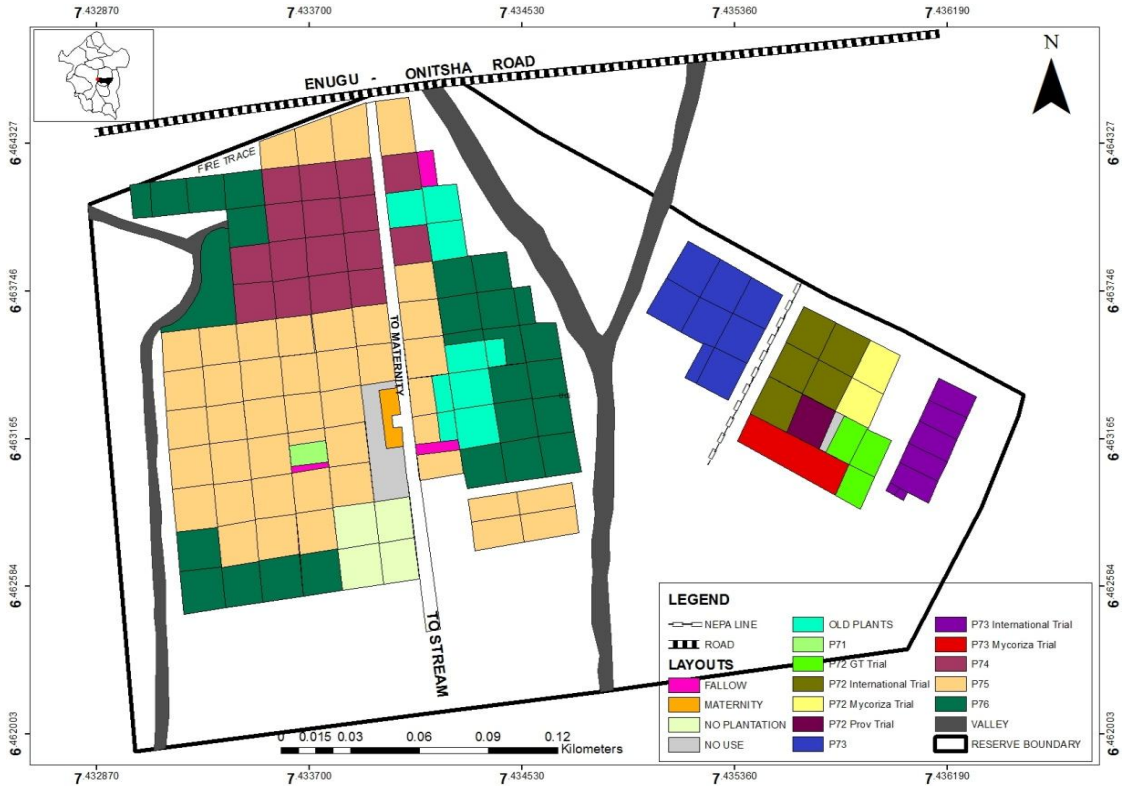

FIGURE 1: Map of the study area (Source: Google Earth, 2011)

The sampling technique that was employed in this study is systematic sampling. Sampling is that part of statistical practice concerned with the selection of a subset of individuals from within a population to yield some knowledge about the whole population, especially for the purposes of making predictions based on statistical inference. Systematic sampling is a form of probabilistic sampling in which the target is divided into equal-sized blocks (for example, a series of squares covering a survey region) and a sample taken at a predetermined point in each block (example, on the grid intersection or in the middle or each square). This method is useful for sampling unevenly distributed populations but runs the risk of missing thing that is regularly spaced. The population variance can be expressed as:

$$S^2 = \frac{1}{N-1}\sum_{i=1}^{N}(Yi - \overline{y_k})^2 = \frac{1}{N-K}\sum_{K-1}^{K}(Nk-1)\,S_k^2 \quad \text{.....i}$$

Where ykm refers to individual number in sample number K. the variance within samples can be expressed as S^2 within =

$$\frac{1}{N-K}\sum_{K=1}^{K}\sum_{m=1}^{NK}(ykm - \bar{y}k)^2 = \frac{1}{N-K}\sum_{k-K}^{k}(Nk-1)\,S_k^2 \quad \text{.....ii}$$

Where S_k^2 is the population variance in sample k. the variance between samples is expressed as S_k^2 between =

$$\frac{1}{K-1}\sum_{K-1}^{K}NK(\overline{y_k} - \overline{y})^2 \quad \text{.....iii}$$

Using this variance simplification it can be show that

$$\text{Var}\ (\bar{y}\ sy) = \frac{k-1}{N} s^2 Between \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ .iv$$

Or

$$\text{Var}\ (\bar{y}\ sy) = \frac{B-1}{N} S^2 - \frac{n-1}{n} S^2\ within \quad \ldots\ldots\ldots\ldots\ldots\ldots v$$

Using that $\text{var}(\bar{y}\ si) = \frac{N-n}{nN} s^2$, it follows that

$$\text{Var}(\bar{y}\ sy) > \text{var}\ (\bar{y}\ si) > \frac{\text{N - n}}{nN} S^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots vi$$

Method of data collection

Data collection is a term used to describe process of preparing and collection data. The purpose of data collection is to obtain quantitative data for the site index equations to be developed. The data on the tree parameters that will be collected are height, age, diameter at breast height (DBH) and crown diameter using recent modern measurement equipments.

Development of site index equation

This study adopted proportional or guide curve method of site index development method using the data from temporary sample plots (TSP_s). This method permits the usage of both linear and non-linear regression equation for the estimation of site index as used by numerous authors (Clutter *et al* 1983, Akindele 1991, Onyekewlu and Fuwape 1998, Teshome and Petty 2000). These equations or models would follow the order:

$H_d = \beta_o + \beta_1 (age) + \beta_2 (age)^2 + e_1$…….……vii
$H_d = \beta_3 + \beta_4 (age) + \beta_5 (1/age) + e_1$…… ……....viii
$H_d = \beta_6 + \beta_{7n\ 1n} (age)_+ e_1$……ix
where H_d = total height of dominant trees
$\beta_0 - \beta_7 =$ regression coefficients

Data analysis and data validation

The underlining statistical analysis procedure for this study was regression analysis (linear and non-linear). The developed model was subjected to validation procedure for arriving at the best model of fit using goodness of fit parameters such as coefficient of determination (R^2) and root mean square error (RMSE). The coefficient of determination is given v

$$R^2 = 1 - \frac{SS_{error}}{SS_{total}}$$

$$= 1 - \frac{\sum_{v=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{n} (y_i - y)^2}$$

$$y = \quad \text{---------- x}$$

where $y^i_=$ modelled value
y_i = observed value, y = mean of the observed data =

$$\frac{1}{n} \sum_{1-1}^{n} yi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots xi$$

n = number of observation

RESULT AND DISCUSSION

Dominant trees (site index) and growth characteristics

Summaries of the growth parameter for the 160 site index samples trees (dominant trees) are presented in Table 1, Table 2 and Table 3 in respect to the different year series which are 1976, 1975 and 1974 respectively.

TABLE 1: Summary statistic for the dominant sampled trees in 1976

		Dominant height (m)			DBH(cm)		
Plot No.	No. of tree per plot	Min	Max	Mean*	Min	Max	Mean*
1	6	11.9	14.8	12.9±0.45	9.58	15.15	11.07±0.89
2	6	13.9	16.8	15.2±0.48	7.29	12.15	9.89±0.80
3	6	13.4	15.4	14.07±0.32	6.43	12.15	9.03±0.78
4	6	11.2	11.4	11.25±0.34	27.89	41.63	34.56±2.13
5	6	11.1	11.2	11.15±0.22	30.48	46.73	38.24±2.35
6	6	11.1	11.2	11.15±0.22	30.32	52.06	37.03±3.56

*Mean ± Standard error
Source: Field survey 2011

TABLE 2: Summary statistic for the dominant sampled trees in 1975

Plot No.	No. of tree per plot	Dominant height(m)			DBH(cm)		
		Min	Max	Mean*	Min	Max	Mean*
1	6	10.8	11.4	11.2±0.09	9.48	14.23	12.39±0.82
2	6	11.4	11.7	11.58±0.40	13.37	39.12	36.26±1.13
3	6	11.1	11.8	11.33±0.10	32.34	58.2	42.24±1.31
4	6	13.9	15.2	14.45±0.19	8.12	13.75	11.24±0.88
5	6	12.1	13.7	12.82±0.27	6.75	13.3	10.83±0.95

*Mean ± Standard error (Source: Field survey, 2011)

TABLE 3: Summary statistic for the dominant sampled trees in 1974

Plot No.	No. of tree per plot	Dominant height(m)			DBH(cm)		
		Min	Max	Mean*	Min	Max	Mean*
1	6	13.2	15.4	14.03±0.30	4.93	9.29	7.41±0.61
2	6	13.9	16.1	14.5±0.35	3.6	9.96	6.9±1.02
3	6	14.1	15.8	14.6±0.27	7.7	12.16	9.8±0.65
4	6	12.8	13.4	13.2±0.09	32.5	43.01	36.6±1.68
5	6	9.6	10.6	10.9±0.17	19.81	30.56	25.7±1.73
6	6	13.8	15.9	14.7±0.37	7.7	12.35	9.5±0.72
7	6	10.4	11.3	10.9±0.15	29.26	41.31	35.2±2.00
8	6	13.16	14.8	14.2±0.20	10.28	13.84	11.1±0.57
9	6	12.8	14.1	13.3±0.21	6.84	12.57	9.1±0.82

*Mean ± Standard error (Source: Field survey, 2011)

Table 1 revealed the summary statistics for the dominant sampled tree in 1976 stand in plots two (2) having the highest mean dominant height (15.2m) the highest mean diameter at breast height (dbh) is found in plot five (5) (38.24cm). Similarly, summary of the growth parameters of the sampled trees in 1975 stand of *Pinus caribaea* showed that the highest mean dominant height (14.45m) was found in plot four (4) while the highest dbh of the sampled dominant trees is found in plot three (3) with dbh of 42.24cm (Table 2). Correspondingly, the summary of the dominant sampled trees in 1974 stand indicated that the highest mean dominant height (14.50m) was found in plot three (3) while the highest mean dbh was recorded in plot four (4) with 36.60cm (Table 3). These variables and their variations were in consonant with findings of several authors on site index equations and site curves development (Akindele, 1991; Smith and Watts 1987; Onyekwelu, 2005; Onyekwelu 2003).

TABLE 4. Estimated parameters and statistics for the dominant height models for *Pinus caribaea* in the study area

Age	Plot No.	Model	Regression Coefficient	Estimated parameter	Adjusted R^2	RMSE
37	4	1	β_o	-0.696		
			β_1	0.676	0.813	0.974
			β_2	-0.008		
37	4	2	β_o	44.344		
			β_1	-0.375	0.791	0.103
			β_2	-639.542		
37	8	3	β_o	29.230	0.757	0.236
			β_1	-4.009		
36	2	1	β_o	6.035		
			β_1	0.277	0.760	0.048
			β_2	-0.003		
36	2	2	β_o	23.980		
			β_1	-0.153	0.727	0.051
			β_2	-247.983		
35	4	1	β_o	16.286		
			β_1	-0.232	0.883	0.029
			β_2	0.003		
35	4	2	β_o	2.694		
			β_1	0.097	0.911	0.025
			β_2	186.067		

Model 1= $\beta_o + \beta_1 (age) + \beta_2 (age)^2 + e_1$, Model 2= $\beta_3 + \beta_4 (age) + \beta_5 (1/age) + e_1$, Model 3= $\beta_6 + \beta_{7n\ 1n} (age) + e_1$, adjusted R^2 –coefficient of determination, RMSE-Root Mean Square Error. (Source: Field survey, 2011)

Regression Parameters and Models Evaluation

The parameter and statistics of regressing model 1, 2 and 3 generated are being presented in Table 4.4. The initial observation was that all models used had the highest Adjusted R^2 and a low Root Mean Square Error (RMSE), which showed that all the models screened were significantly related with their respective dependent variables (site index). However, a critical comparison of the three model 1,2 and 3 among the three age series (1976, 1975 and 1974) revealed that model 2 was the best it model in this study, having the highest Adjusted R^2 and the lowest RMSE of 0.911and 0.023 respectively in plot 4. This model was particular of models 2 of 1976 *Pinus caribaea* stand (Table 4).

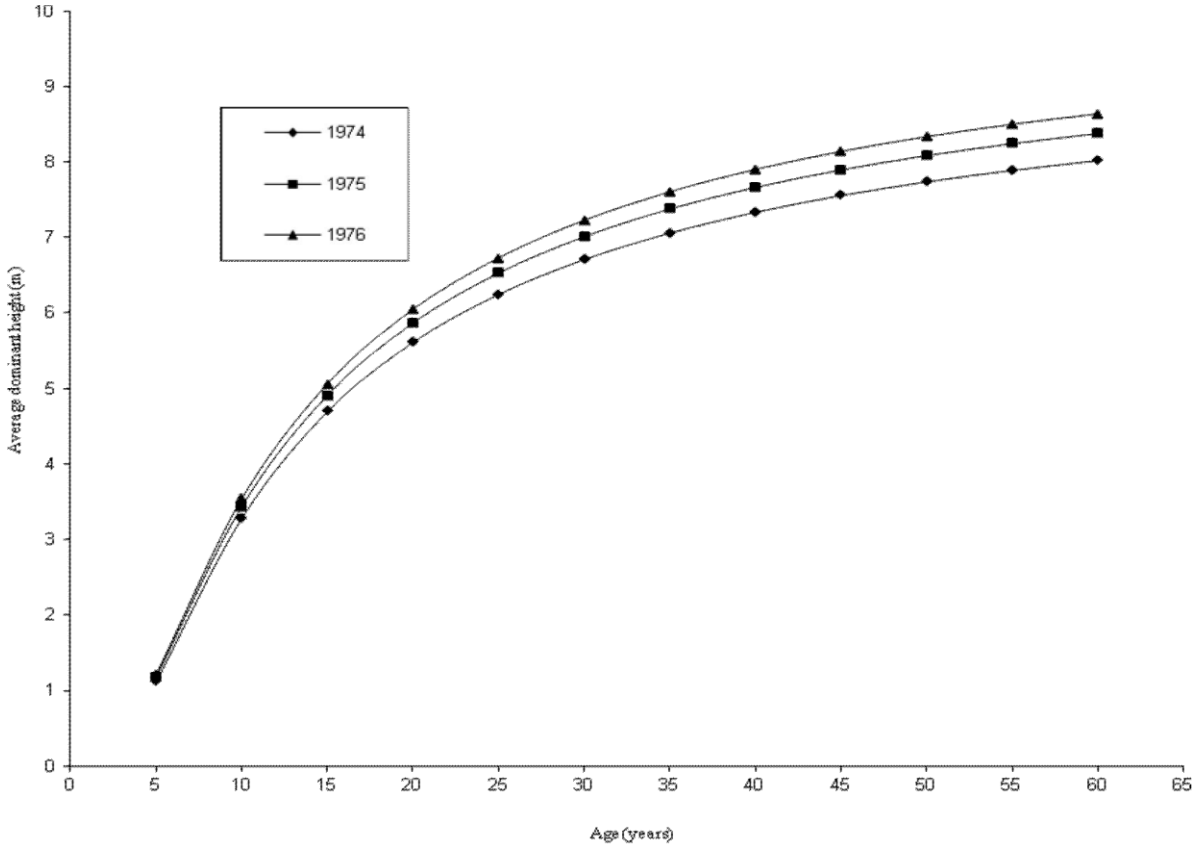

Fig 2: Site index curve of *Pinus caribaea* for the different stands in Enugu-Ngwo plantation, Nigeria

The site curves generated for the *Pinus caribaea* plantation in the study area shows the height development patterns that dominant trees of *Pinus caribaea* in the area are expected to follow throughout the rotation, as shown in Figure 2. The site index curves reveals that at 50 years old of the *Pinus caribaea* plantation will attain a dominant height of 10m. The guide curve method was used to produce anamorphic site index curves in this study. The anamorphic index curves which are a family of parallel lines with constant slope but varying intercepts, achieve by holding the shape parameters constant and varying the asymptote parameter to obtain the required dominant height value when stand age (A) equals the index age (A_0), which is 50 years in this study as proposed by Clutter *et al.,* (1983) and Teshome and Petty (2000). Similarly, this trend was observed in the findings of Onyekwelu (2005), when developing site index curves for Opepe (*Nauclea didderichii*) plantation is Southwestern Nigeria. Akindele (1991) also constructed similar site index curve for *Tectona grandis* (Teak) in the dry high forest areas of southwestern Nigeria. The result of this finding compares significantly with growth of other plantation species in other ecological zones in Nigeria and according to Akindele (1989) plausible factors for this development might be traceable to factor of climate and relatively good soil. Therefore, the site index and site productivity of the study area could be estimated using the best site equation screened.

CONCLUSION

From the results of this study, it can be concluded that the index age of 50 was used to determine the site index of *Pinus caribaea* at Enugu Ngwo, Nigeria. This site index equation developed should be suitable for the site index studies on any *Pinus caribaea* plantation in Nigeria. Similarly, the site index equation developed was appropriate for the determination of the site quality of the *Pinus caribaea* plantation, and thus can be relevant in assessing the productivity of the pine stand. This will enhance the proper management of the stand's sustainable timber yield production. Therefore, it is recommended that quantitative and qualitative assessment of the sites should

be done using site index equation for evaluation and monitoring of stand parameters which is very relevant in any other pine plantations in Nigeria for sustainable improvement and assurance of sound decision making in the management of the plantations.

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