DEVELOPMENT OF MODELS FOR ASSESSING THE SLENDERNESS OF *TRIPLOCHITON SCLEROXYLON* K. SCHUM STANDS IN ONIGANBARI FOREST RESERVE, NIGERIA.

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Abstract

Tree slenderness coefficient is an index of tree stability and its ability to resist wind throw. Hence, this study evaluated the use of selected linear and nonlinear slenderness coefficient function for *Triplochiton scleroxylon* stands in Onigambari forest reserve, Nigeria as predictive models. Data were collected from a total of 10 temporary sample plots (size 20 x 20m) randomly laid in 1979, 1988 and 1992 stands and fitted to eight slenderness coefficient. The functional models were evaluated with the least values of Akaike information criterion (AIC) and standard error of the estimate (SEE). The significance of the estimated parameters was also verified with the plots of residuals against the predicted values to ascertain the goodness of fit of for the selection of the best models. The results revealed that 78.41%/ha of *Triplochiton scleroxylon* stands in this study area were of good vigour and could withstand wind throw. Modified exponential models had the least AIC and SEE values and were therefore recommended for predicting slenderness coefficient in the stands with plausible potentials for enhancing reasonable quantification of the stands' stability. Sustainable management of this plantation is also recommended for continuous stability and productivity.

Keywords: Modified exponential model, slenderness coefficient, *Triplochiton scleroxylon*, estimated parameters and Akaike information criterion.

Introduction

Forests provide habitat for plants and animals, clean water, places for outdoor recreation, and many other benefits. Irrespective of these benefits, they are subject to multiple threats which can jeopardize their health, ecology, biodiversity, and resources. These threats can be natural or anthropogenic. Natural disturbances include wildfire, catastrophic wind events, drought, insect infestation, fungal/pathogen outbreaks and invasive plants. Anthropogenic disturbances include pollution, forest fragmentation, and urbanization. The stability of a stand is mainly affected by biological and physical factors (Nivert, 2001). The physical factors are mainly related to the wind components, the topography and the site properties while the biological factors include the species characteristics. Wind is a natural phenomenon in all forest landscapes and some amount of wind damage to forest stands is normal. Wind damage, sometimes referred to as blow down, is the breaking or uprooting of live trees by strong winds (Navratil, 1996). Vulnerability of individual trees and stands to wind is based on a combination of tree attributes (species, age, health, total height, crown size, rooting characteristics), stand conditions (species, density, and structure of surrounding stands), local topography, soils (texture, depth, soil moisture level), and predominant wind patterns (Ruel, 2000).

Trees show considerably variation and flexibility in their shape and size of crowns, height and trunk diameters (Givnish, 2002). These are governed by an inherited developmental tendency, which may in turn be modified by the environment where the tree grows. The size of a tree canopy and its height above the ground is significant to a tree in that it determines the total amount of light that the tree intercepts for photosynthesis (Midgley, 2003). The adaptive significance of tree height, have been through a mathematical model, that the higher a tree is the more light it intercepts during the course of the day (Jahnke and Lawrence, 1965). The tree trunk size also has its own adaptive significance to a tree. It must be strong enough to withstand the forces that act on it and the force exerted on it by the wind. These forces are the weight of the tree and the drag exerted on it by the wind, as noted by Fraser (1962). Experimentally, wind has been found to be much more important than weight in determining what thickness of trunk is necessary for a tree (Alexander, 1968). The slenderness coefficient of a tree is defined as the ratio of total height (H) to diameter at breast height (DBH) outside bark at 1.3m above ground when both H and DBH are measured in the same units (i.e. H/DBH, with both H and DBH measured in metres) (Onilude and Adesoye, 2007). It has been widely used as an index of tree to resistance from wind throw. Tree slenderness coefficient often serves as an index of tree stability, or the resistances to wind throw (Navratil, 1996). A low slenderness coefficient value usually indicates a longer crown, lower centre of gravity, and a better developed root system. Therefore, trees with higher slenderness coefficient values (that is slender trees) are much more susceptible to wind damage. Actions improving the stability of trees and stands could considerably limit these damages. Tree slenderness coefficient is important for indexing tree resistance to wind throw. Therefore, it is important to study the slenderness of trees, as well as developing models that can predict these values.

One of the major challenges of forestry development in Nigeria is the dearth of periodic information on stand conditions. However, sustainable management of forest stands can only be ensured if current and reliable information on growth condition of the stand is available which can be used by forest managers/management to provide accurate and timely information on the current growing stock. Forestry, like any other business venture, requires effective management of its resources. As a result, it requires quantifiable information on the trees not only for the management decision but also to show the growth, productive capabilities and resistance capability of the trees. Good forest management requires accurate and up to date information on the current growing stock and future growth potential. The objective of this study is therefore to develop models for estimating slenderness coefficient for *Triplochyton scleroxylon* stands in Onigambari forest reserve, Nigeria.

Methodology

The Study Area

This study was carried out in Onigambari Forest Reserve (Figure 1). The reserve is located on latitude 7^0 25' and 7^0 55'N and longitude $3^0$53' and 3^0 9'E within the low land semi-deciduous forest belt of Nigeria and covers a total land area of 17,984ha. The reserve is divided into two: natural and plantation forests. The natural forest is made up of indigenous species such as *Terminalia spp*, *Irvingia garbonensis, Treculia africana,* among others while the plantation forest is made up of species such as *Triplochiton scleroxylon,* G*melina arborea* and *Tectona grandis*. The topography of the study area is generally undulating, lying at altitude between 90m and 140m above sea level. The annual rainfall ranges between 1200mm and 1300mm, spreading over March to November. The dry season is severe and the relative humidity is low. The average annual temperature is about 26.4^{0}C (Larinde and Olasupo, 2011**).**

Sampling Techniques and Data Collection

Three age series (1983 (5ha), 1988 (3ha) and 1992 (6ha)) of *Triplochiton scleroxylon* stands in the reserve were assessed. A total of 10 temporary sample plots (size 20 x 20m) were randomly laid in each age series. Complete enumeration of all trees in each plots were carried out. The following variables were measured: diameters (cm) at breast height (dbh) measured at 1.3m above ground level with the aid of girth tape, base (Db) with the aid of girth tape, middle (Dm) with the aid of relaskope and top (Dt) with the aid of relaskope, total height (H (m)) with the aid of relaskope, stem quality (SQ (m)) with the aid of relaskope as the length of clear bole without defect, crown length (CL (m)) at the corresponding length or expanse of the crown on the ground surface at two directions with the aid of meter tape while crown diameter (CD (m)) was estimated as the difference between the total height and merchantable height.

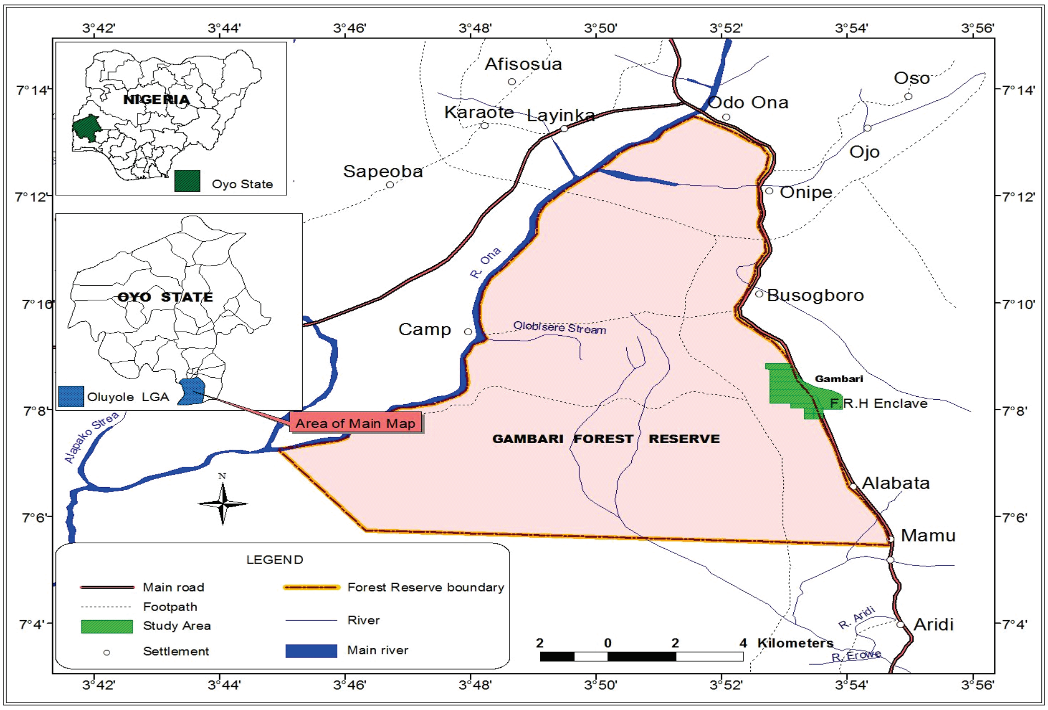


Fig 1: Map of Onigambari forest reserve (Larinde and Olasupo, 2011)

Data Analyses

- Basal Area Estimation

  The Basal Area (BA) of individual trees was estimated using the formula in equation 1 (Husch *et al*, 2003)

$$BA = \frac{\pi}{4} D^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where BA = Basal area (m^2), D = dbh (cm).

- Volume Estimation

The volume of individual trees were estimated using Newton equation developed for trees volume estimation (Husch *et al*, 2003)

$$V = \pi H \left[\frac{Db^2 + 4Dm^2 + Dt^2}{24} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where V = Total volume (m^3), H = height (m), Db = Diameter at the base, Dm = Diameter at the middle, Dt = Diameter at the top and Π = 3.142

- Tree Slenderness coefficient (TSC)

$$TSC = \frac{THt}{dbh} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

According to Navratil*et al*, (1996), slenderness coefficient values were classified into three categories.

TSC values > 99…………… High slenderness coefficient
70 < TSC values > 99……….Moderate slenderness coefficient
TSC values < 70 …………….Low slenderness coefficient
Crown variables estimation

- Crown ratio (CR)

$$CR = \frac{CL}{THt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

- Crown projection area (CPA)

$$CPA = \frac{\pi \left(CD^2\right)}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where THT = Total height and CL = Crown length and CD = Crown diameter

Development of the Models

Linear and nonlinear models were developed and tested in this study for tree slenderness coefficient prediction using CurveExpert Professional 2.3. The models were to express slenderness as a function of some tree growth characteristics. The model functions are of the form of simple linear, exponential and growth models as shown in table 1

Table 1: List of selected model functions

Model No	Model Name	Model
1	Simple linear	$TSC = a + b*D$
	Exponential functions	
2	Exponential	$TSC = a*\exp^{bD}$
3	Modified exponential	$TSC = a*\exp^{b/D}$
4	Natural logarithm	$TSC = a + b*\ln(D)$
5	Reciprocal logarithm	$TSC = \frac{1}{a + b*\ln(D)}$
	Growth functions	
6	Exponential association 2	$TSC = a\left(1 - \exp^{-b*D}\right)$
7	Exponential association 3	$TSC = a\left(b - \exp^{-c*D}\right)$
8	Saturation growth rate	$TSC = \frac{a*D}{(b + D)}$

TSC = Tree slenderness coefficient, D = dbh (m), exp = exponential, ln = natural logarithm and a,b&c = regression coefficient/parameter estimate.

Model Evaluation

The models developed were evaluated with a view of selecting the best estimator for tree slenderness coefficient. The evaluation was based on the following criteria:

The Mean Square Error (MSE). This is a measure of the spread of the data and therefore an indication of the precision of the predicted response. MSE is expressed as:

$$MSE = {RSS}/{n - p} \quad \text{...} \; 6$$

a. Akaike information criterion (AIC). The AIC is of the form:

$$AIC = = 2 - 2*\ln(L) AICk \text{...} \; 7$$

Where: K = number of estimated parameters in the model, Ln = Natural logarithm and L = the maximized value of the likelihood function for the model.

The significance of each regression coefficient in the models was tested using the Student t-test. The t-value was compared with the critical value of t at $\alpha = 0.05$ level. Where t-calculated for the regression coefficient exceeded the critical value of t, the independent variable was considered significant and vice-versa. Suitable models are those with least AIC and MSE values.

Results and Discussion

The statistical summary of the tree growth variables is presented in table 2. It was revealed that there were steady growths in the plantations. The dbh was able to explain the relationship that existed within the growth variables. Basal area and volume per hectare among others throughout the period of assessment followed the same trend with the tree dbh. The mean dbh for 1979, 1988 and 1992 stands were 61.51±0.65cm, 23.15±0.43cm and 21.50±0.31cm respectively. According to Husch *et al* (2003), basal area per hectare is computed from the dbh of the standing trees. The basal area (m^2/ha) were 0.30±0.007, 0.04±0.002 and 0.04±0.001 for 1979, 1988 and 1992 stands respectively. Meanwhile, the stand volume (m^3/ha) were 14.38±0.40, 0.62±0.09 and 0.48±0.02 for 1979, 1988 and 1992 stands respectively. The TSC was observed to be minima in 1988 plantation (31.42) while it was highest in 1992 plantation (186.32). This might be as a result management efforts on these plantations. Most of the trees in 1979 plantation

(61.03%) have moderate TSC whereas 52.55% of trees in 1988 plantation can withstand wind throw while only 17.51% of trees/ha in 1992 plantation are prone to wind throw (Table 5).

The correlation coefficients between tree slenderness coefficients and tree DBH, basal area, volume and age were negative (Table 3). This result indicates that the tree slenderness coefficient tends to decrease for larger trees, and the largest slenderness coefficient occur for the trees with small DBH. The correlation coefficients between tree slenderness coefficient and DBH were higher than those between it and the other tree growth variables. This indicates that tree DBH is a better predictor of the slenderness coefficient than age or volume. The results confirm that slenderness coefficient generally decreases with increasing stand age. This trend was in agreement with the reports of Onyekwelu (2001), Onyekwelu *et al*., (2003) and Eguakun and Oyebade (2015) on growth attributes and management scenarios for plantation species in Southwest, Nigeria. Tree height, crown length and crown diameter also showed a negative low correlation with slenderness coefficient. The results of this study were similar with the findings of Wang (1998) where the relationship of tree slenderness coefficients and tree characteristics for major species in boreal mixed forests were evaluated using empirical models.

Assuming that a slenderness coefficient value over 99 is considered to be at the high risk of wind throw as suggested by Navratil (1996), the result of this study indicated that these stands do not belong to the high risk category of wind throw. The relationship of wind throw and slenderness coefficient is indirect. Lower slenderness coefficient can be an indicator of larger crowns, lower centre of gravity and a better developed root system. The desirable height/dbh ratios for adequate wind resistance vary according to species and country. In general, trees with a higher slenderness coefficient (low taper) are much more susceptible to damage than trees with low slenderness coefficient (high taper). Since smaller slenderness coefficient is usually indicating a higher resistance to wind throw, the relationships suggest that silvicultural treatments, such as producing long-crowned trees and maintaining appropriate stand density through spacing, thinning, or gradually harvesting overstory trees, can be helpful in reducing the risk of wind throw (Wang *et al*., 1998; Eguakun and Oyebade, 2015).

Eight candidate models were selected to predict TSC in this study using dbh that it has the highest correlation coefficient as the major predictor and practically, it (dbh) is the easiest variable that can be measured. All the models show strong fit to the tree slenderness coefficient. The observed goodness of fit of the models was in agreement with the previous works on the relationship between tree slenderness coefficient and tree or stand characteristics (Orzeł, 2007; Orzeł and Socha 1999; Wang, 1998; Eguakun and Oyebade, 2015). Hence, least values of AICC and standard error were used to select the best model that explains this relationship. Based on these criteria, modified exponential model was adjudged the best among the candidate models. Hence, this model is therefore recommended for predicting slenderness coefficient of the stand.

Table 2: Summary of growth variables

Growth variables	1979			1988			1992		
	Min	**Max**	**Mean±S.E**	**Min**	**Max**	**Mean±S.E**	**Min**	**Max**	**Mean±S.E**
DBH (cm)	40.50	100.00	61.51±0.65	11.46	59.70	23.15±0.43	11.46	30.01	21.50±0.31
THt (m)	41.60	81.00	57.58±0.58	8.50	57.00	16.26±0.43	8.00	25.50	16.08±0.27
SQ (m)	33.10	74.30	51.00±0.59	6.20	41.59	11.78±0.32	5.50	17.53	11.29±0.20
CL (m)	2.90	13.10	6.57±0.12	2.30	15.40	4.49±0.12	2.36	7.97	4.79±0.08
CD (m)	5.51	27.51	13.47±0.25	4.25	28.50	8.97±0.24	4.00	15.14	8.64±0.144
BA (m^2/ha)	0.13	0.79	0.30±0.007	0.01	0.28	0.04±0.002	0.01	0.07	0.04±0.001
VOL (m^3/ha)	6.12	42.34	14.38±0.40	0.08	13.02	0.62±0.09	0.11	1.18	0.48±0.02
TSC	61.47	144.44	95.00±1.17	31.42	144.01	78.46±1.90	32.77	186.32	72.02±1.92
CPA (m^2)	23.85	594.47	152.32±5.96	14.19	638.02	69.50±5.09	12.57	180.07	61.54±1.98
CR	0.04	0.24	0.12±0.002	0.27	0.29	0.28±0.001	0.28	0.31	0.30±0.001

Table 3: Correlation matrix between TSC and growth variables

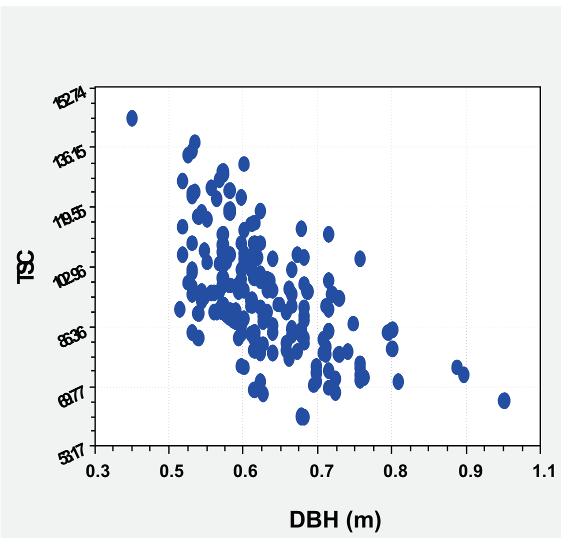
	TSC	*DBH*	*THt*	*SQ*	*CL*	*CD*	*BA*	*Vol*	*CR*	*CPA*	*Age*
TSC	1										
DBH	-0.999*	1									
THt	-0.563	0.999*	1								
SQ	-0.465	1.000*	1.000*	1							
CL	-0.318	0.986	0.991	0.990	1						
CD	-0.477	0.999*	0.998*	0.999*	0.981	1					
BA	-0.762	0.999*	0.999*	0.999*	0.991	0.998*	1				
Vol	-0.865	0.999*	0.999*	0.999*	0.990	0.999*	1.000*	1			
CR	-0.781	0.999*	0.997*	0.998*	0.977	0.999*	0.997	0.998*	1		
CPA	-0.385	-0.998*	-0.995	-0.996	-0.972	-0.999*	-0.995	-0.996	-0.999*	1	
Age	-0.892	0.964	0.995	0.957	0.905	0.970	0.954	0.956	0.975	-0.979	1

Table 4: Developed models

Model	Parameters	AICC	r	SEE	P-value	Ranking
Simple linear ($TSC = a + b*D$)	a = 159.362 b = -104.630	1008.913	0.583	13.289	0.000	6th
Exponential ($TSC = a*\exp^{bD}$)	a = 198.281 b = -1.206	1004.513	0.595	13.140	0.000	5th
Modified exponential ($TSC = a*\exp^{b/D}$)	a = 43.858 b = 0.463	998.972	0.610	12.954	0.000	1st
Natural logarithm ($TSC = a + b*\ln(D)$)	a = 60.727 b = -69.087	1003.416	0.598	13.103	0.000	4th
Reciprocal logarithm ($TSC = \frac{1}{a + b*\ln(D)}$)	a = 0.015 b = 0.008	999.120	0.610	12.959	0.000	2nd
Exponential association 2 ($TSC = a(1 - \exp^{-b*D})$)	a = 95.004 b = 43.168	1089.813	0.000	16.352	0.000	8th
Exponential association 3 ($TSC = a(b - \exp^{-c*D})$)	a = 695.047 b = 1.224 c = -0.137	1011.557	0.581	13.344	0.000	7th
Saturation growth rate ($TSC = \frac{a*D}{(b + D)}$)	a = 54.290 b = -0.255	999.358	0.609	12.967	0.000	3rd

Table 5: Tree slenderness coefficient classification

TSC Range	Value (%/ha)			Overall result (%)	Implication
	1979	1988	1992		
> 99	34.87	12.41	17.51	21.60	Prone to wind throw
70 – 99	61.03	35.04	42.94	46.34	Moderate
< 70	4.10	52.55	39.55	32.07	Withstand wind throw



2: Relationship between TSC and dbh (m)

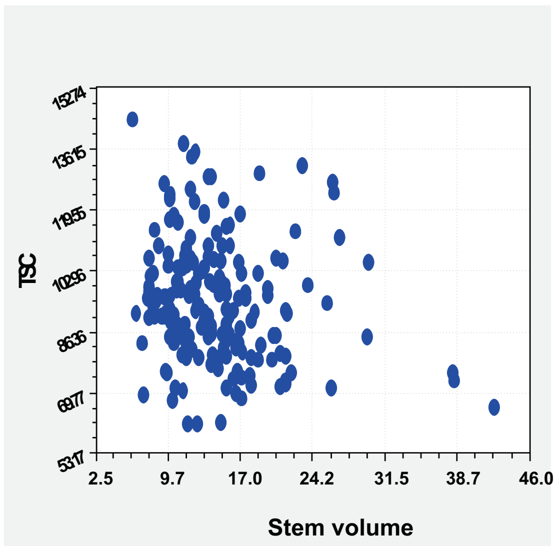


Fig 3: Relationship between TSC and stem volume (m^3)

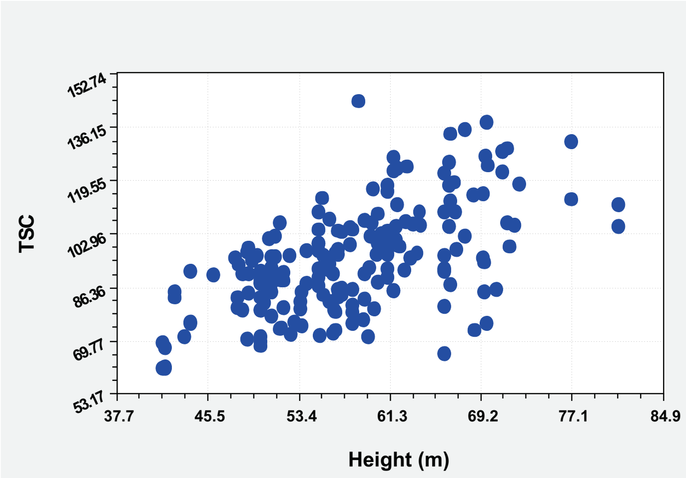


Fig 4: Relationship between TSC and height (m)

Conclusion

This study revealed significant variations among the tree growth characteristics (dbh, height and volume) and relationship between these variables and tree slenderness coefficient (TSC) of *Triplochyton scleroxylon* plantations in Onigambari Forest Reserve, Nigeria. The study has projected the possibility of occurrence of wind throw among this species and advances the need for enhancing stability among other species to reduce susceptibility to wind throw and other environmental degradation within the plantations in Nigeria. Diameter at breast height was observed to be the most useful independent variable in all the selected models. Based on the evaluation of the models, the modified exponential model was recommended as tree slenderness model for *Triplochyton scleroxylon* stand in Onigambari Forest Reserve for further use.

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