Chapter 11
Assessment of Tree Growth Competition Indices for Biodiversity Conservation in IITA Forest Ibadan, Nigeria

P. O. Ige and O. O. Komolafe

Abstract Forest growth assessment is a key tool for sustainable forest management. Understanding relative contributions of competition in the growth of the forest is of great important which determines the forest structure and also gives an insight to various influences of tree response to climate. There is dearth of information on forest growth using Competition Indices (CI). Hence, this study assessed CI effects on stand growth in International Institute of Tropical Agriculture (IITA) Forest, Ibadan, Nigeria, towards improving the forest health status and biodiversity conservation. Data were collected from the forest using four systematic line transect (270 m each) at 200 m apart for plot demarcation. Sixteen sample plots of 25 m × 25 m were alternately laid to collect data. All trees with diameter at breast height (DBH) ≥ 10 cm were estimated. Characterizing the joint influence of tree size, climate and competition in each plot, overtopped trees were considered subject trees and 10 m search radius was used in identification of competitor's tree for distance dependent (DD). Measurement of influence of neighbouring trees for distance independent (DI) was based on plot-centred. Eight Competition Indices were assessed (CI_1-CI_8). Best DD and DI were adapted each into Basal Area Increment model (BAI) before and after adding competition measures. Best model was selected using Root Mean Square Error (RMSE), Coefficient of Determination (R^2), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Data were analysed using descriptive statistic and regression at $\alpha_{0.05}$. The stand comprises 389 stem ha^{-1}. The diameter at breast height (DBH), tree total height (THt), numbers of tree per hectares (N/ha) and volume (V) ranged from 25.12 ± 1.023 cm, 18.548 ± 0.324 m, 442 and 1.035 ± 0.136m^3, respectively. The computational analysis shows that basal area increment (BAI) model is a function of neighbourhood interactions and the best spatial indices were better growth predictors than the best non-spatial indices. The best CI growth model was: $BAI = \exp(-3.769 + 0.026DBH + 0.012C_6)$ (RMSE = 0.064, AIC = −774.031, BIC = −759.324 and R^2 = 0.912). This implied that DD CI predicted the growth predictability well compared to DI indices.

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Introduction

Nigeria tropical rain forest has a large numbers of species, which are been represented by few tree and their growth pattern and rates varies (Aigbe et al. 2013). Growth is an irreversible process which takes place in all living things. Tree growth simply means the increase in magnitude and quantity of the vegetative structures. As trees grow in the forest, competition sets in for photosynthesis, space and resources. Competition is an interaction between individual for survival for limited resources resulting to decrease for survivorship, reproduction and growth of the competing individual (Ige and Adesoye 2017). However, it was asserted by Ige (2017), that tree height and tree diameter within a forest will be constrained by the pressure of adjacent trees. Competition or growth rate in the forest often determines the shape and the structures of the forest stand (Coomes and Allen 2007). Individual tree growth competition is also an essential environmental process that plays substantial roles in population dynamics, survival, growth and species replacement on forest composition and stand structure (Amiri and Naghdi 2016; Ige 2017). However, trees growing in a given population usually exhibit large variation in growth. Coomes and Allen (2007) emphasized on the need for understanding the different variation in growth which is the basis for forest structures and biomass and also noted that tree growth declined with altitude. It was ascertain by Pelemo et al. (2011) that some trees grows poorly in the forest not as a result of competition but due to the influence of some other disturbances such as floods, windstorms, fire and human inflicted damages which make the forest to be instable and make the tree less favourable to grow properly. Various attempt of predicting the tree growth as accurate and precisely basically brought out the study of effect of competition on individual tree, two general methods are widely used for tree growth competitor indices which are the distance-independent indices and distance-dependent indices (Tome and Burkhart 1989; Amiri and Naghdi 2016).

Distance-independent indices or non-spatial indices generally measure and portray the competition status of trees in the stand which requires not the trees coordinate or the relative location of the neighbouring trees with the dimension of the subject tree not required as ascertained by (Tome and Burkhart 1989; Contreras et al. 2011). Obtaining distance-independent indices variables are relatively easy, and the calculation is less demanding in terms of data and time.

Distance-dependent indices try to explain a tree's competitive status based on the direct conditions of their neighbouring tree (Contreras et al. 2011). This generally measures the zones of influence of the neighbouring trees which best improve estimates of individual tree growth (Ige 2017). In estimating the tree growth competition using distance-dependent and distance-independent indices, strong positive correlation has been proven to exist between tree growth and basal area. Basal areal basically deals with the average amount of an area occupied by tree stem, thus making diameter at breast height (Dbh) a good predictors of forest dynamics which also improve the dependability of timber volume, growth and yield models (Brooks et al. 2008; Onyekachi and Osho 2018).

Materials and Method

Study Area

This study was carried out in International Institute of Tropical Agriculture (IITA) Forest (Fig. 11.1). International Institute of Tropical Agriculture forest is geographically located in Akinyele Local Government Area of Oyo State Nigeria. It lies between latitudes 7° 30′ 5.1264" and 7° 28′ 55.52" North and longitudes 3° 54′ 47.50" and 3° 52′ 44.49" East in the city of Ibadan. IITA forest has a humid tropical climate with well-known wet and dry seasons, with the wet season commencing from March and ends in October and dry season that lasts from November to February, and it has an average daily temperature of about 21–23 °C and the maximum temperature ranges from 28–34 °C. The forest used to experience bimodal rainfall pattern between 1300 and 1500 mm, which falls between the month of May and September. The mean daily relative humidity ranges between 64 and 83% (Ariyo et al. 2012). The forest reserve has a low lying and gentle undulating topography with an elevation ranges between 243 and 292 m. The parent rock materials of the soil are been forms through the underlying crystalline and banded gneiss which weathers to form site-specific soils. In the upland areas clay, quartz gravel and sand are predominant soil types, while the bottom of the valley has poorly drained clay and sandy soils (Oluyinka 2020). Some part of IITA forest has a highly diverse plant species. The vegetation of this area could be classified as tropical semi-deciduous forest with diverse of vegetation types ranging from derived savanna, secondary forest and riparian types (Osunsina et al. 2012).

Sampling Techniques and Data Collection

Reconnaissance was carried out so as to assess the forest stand and see the different changes that are currently taken place at the reserve. The survey carried out revealed that there was no evidence of logging in the forest, though the forest is a secondary forest that is currently undergoing reservation phase for biodiversity conservation. The sampling procedure used for the research work was adopted after the visitation to the study area. Simple systematic line transect was adopted for this study for plot laying and data collection. A total of 16 temporary sample plots were used for this research work. In laying of plots for data collection, simple systematic line transect

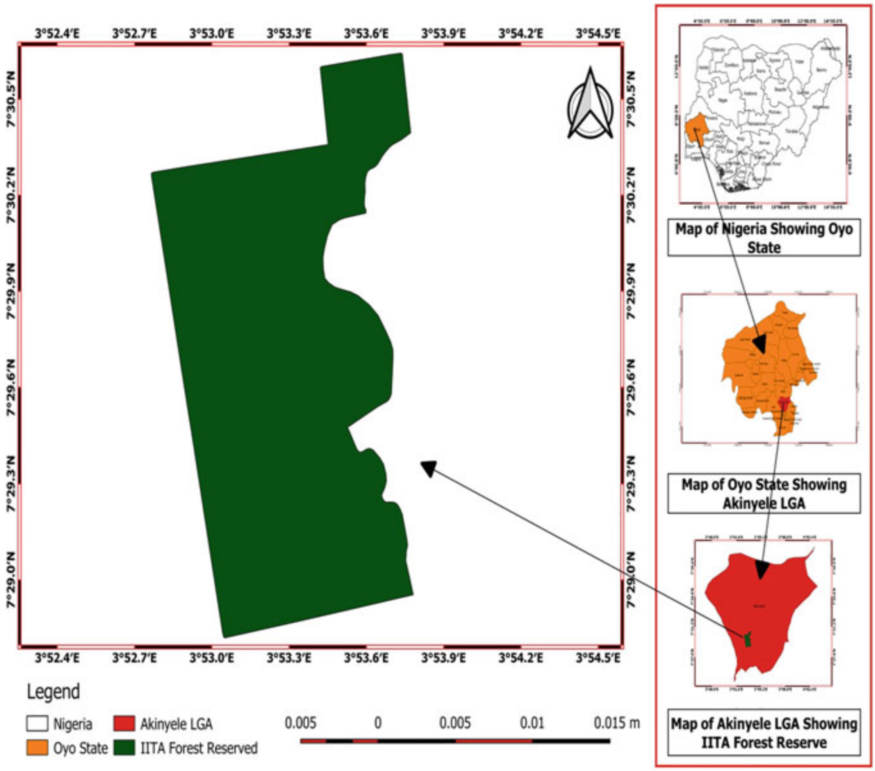

Fig. 11.1 Map of IITA forest reserve

has used by Adekunle et al. (2013) was adopted and modified for plot laying, and four parallel transects of equal distance (300 m) were delineated at 200 m apart for this study. A total number of 4 sample plot of equal size (25 m × 25 m) were laid alternatively on each transect and 50 m interval distance offset away from each sample plot was observed so as to decrease replication of tree species. To minimize the edge effect, 20 m offset was measured at the beginning of each transect (Fig. 11.2).

Data Collection

On each sample plot, all trees with diameter at breast height (DBH) ≥ 10 cm variables were identified and measured as used by Adekunle et al. (2013). To estimate volume per stand, the diameters at the base, middle and top were measured using Spiegel relaskop, while merchantable height and the total height of all the tree were measured using Haga Altimeter. Competitors tree was been identified by weighing the dimension of the subject tree and its neighbouring tree. Tree that are completely

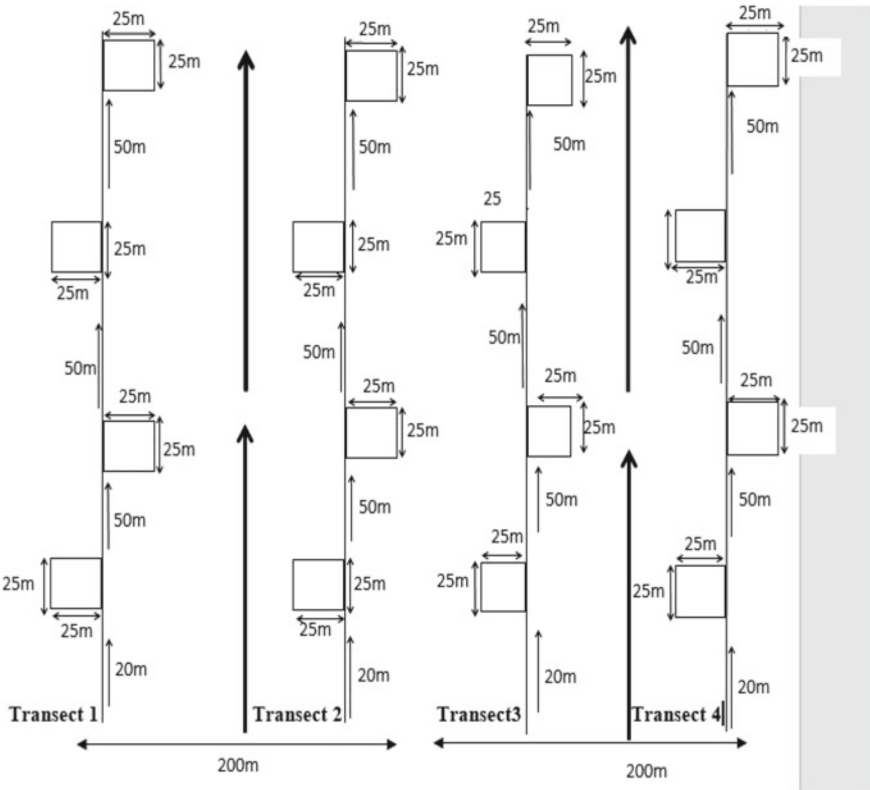

Fig. 11.2 Systematic line transects sampling technique for Plot layout

suppressed are considered subject tree. All the relevant information for computational evaluation of the competition indices of each subject tree and its neighbouring trees such as the horizontal distance, height and diameter of the entire subject tree to its competitors within the search radius of 10 m were measured and recorded.

Tree Growth Competition Indices

All the tree growth variables were assessed. Distance-dependent and distance-independent indices that are generally used were adopted to examining the tree growth competition indices.

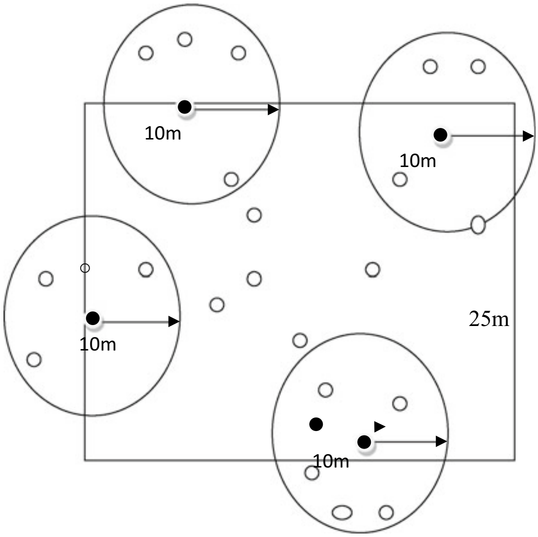

Fig. 11.3 Sample plot with four subject trees (solid dots) with various numbers of neighbours (open dots) within their respective competition plots of fixed radius of 10 m

Distance Dependent

Distance dependent was carried out by spatial location of the affected subject tree for their computations. Diverse method have been adopted to determine the pressure of the potential competitor trees over the subject tree such as fixed radius, crown-influence-zone overlap, DBH angle-gauge and height gauge method (Ige 2017). On the sample plot trees that are completely overtopped were considered as the core tree, and fixed radius of 10 m was used to measure the dimension of trees considered as neighbour trees (Figs. 11.3 and 11.4).

Distance Independent

Measurements were based on plot-centred rather than tree-centred neighbourhood data as used in distance-dependent indices.

Competition of each subject tree was quantified using four distance-independent competition indices (CI 1–4) and four distance-independent competition indices (CI 5–9) as given in Table 11.1 were used respectively for the competition indices. The indices used for this study were selected from the literature, taking into consideration the availability of tree variables for this study with their simplicity to describe the competition situation of a tree.

Relative spacing was computed using this equation:

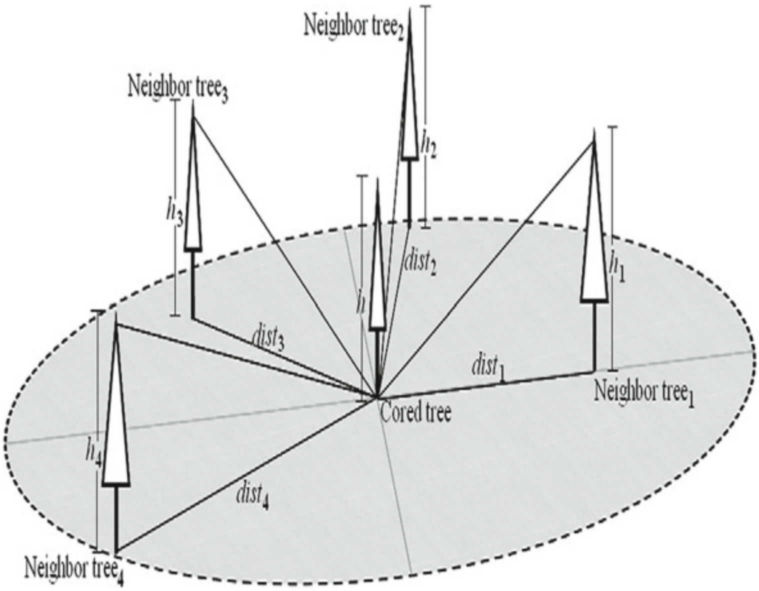

Fig. 11.4 Measurement of distance of each competitor trees to the core or subject tree

Table 11.1 Competition indices evaluated in this study

Equation no	Competition indices	Source
Distance-independent competition indices		
11.1	$\frac{\sum_{j=1}^{n} {d_j}^2}{{d_i}^2}$	Corona and Ferrara (1989)
11.2	$\frac{\left(1-\left[1-\left(\frac{BAL}{G}\right)\right]\right)}{RS}$	Schröder and Gadow (1999)
11.3	$\frac{\sum_{d_i<j\neq i}^{n}(g_j)}{S}$	Wykoff et al. (1982)
11.4	$\sum_{j\neq i}^{n}\left(\mathrm{g}_{j;d_j>d_i}\right)/\mathrm{G}$	Daniel (1976)
Distance-dependent competition indices		
11.5	$\sum_{i=1}^{n} h_i\, arctan\left(\frac{d_i}{dist_i}\right)$	Rouvinen and Kuuluvainen (1997)
11.6	$\sum_{i=1}^{n} h_i\left(\frac{h_j}{dist_i}\right)$	Braathe (1980)
11.7	$\sum_{i=1}^{n} \mathrm{d}_i\left(\frac{d_j}{dist_i}\right)$	Daniel (1976)
11.8	$\sum_{j=1}^{n} \frac{d_j}{\mathrm{d}_i\,(\mathrm{l}_{ij}+1)}$	Daniel (1976), Ige and Adesoye (2017)

Where: n = number of neighbours within the 10 m radius competition plot; BAL basal area of neighbour trees larger than the cored tree $\left(m^2h^{-1}\right)$; G is total basal area of the trees within plot $\left(m^2h^{-1}\right)$; g_j is basal area of competitor tree ; $dist_i$ is the horizontal distance from the ith neighbour tree to the subject tree (m); h_i height of the subject tree (m); h is height of the competitor tree (m); l_{ij}, distance between competitor (j) and subject (i) tree (m), S is plot area

Model Evaluation of the Tree Growth Competition Indices

Mathematical calculations were carried out on all the competition indices (CI 1–8) specified above, and the value gotten from each of the indices was included in the basal area growth model (Eqs. 11.10 and 11.11) so as to predict tree growth competition function as used by Contreras et al. (2011) and Ige and Adesoye (2017). All the values gotten from each of the competition indices (CI 1–10) were incorporated into the basal area increment model.

$$BAI = \exp(b_0 + b_1\ln(DBH) + b_2CI) \quad (11.9)$$

$$\ln BAI = b_0 + b_1DBH + b_2H + b_3CI \quad (11.10)$$

where: BAI = basal area increment, DBH = diameter at breast height, H = tree height, CI = competition indices, and b_0, b_1, b_2 and b_3 = regression parameters.

The entire models were assessed based on graphical and numerical analysis of the residuals. Four statistical fit indices used to evaluate the model are:

Coefficient of Determination (R^2): The (R^2) measures the proportion of variation in the dependent variable based on the behaviour of the independent variable. R^2 value must be higher for the model to be considered valid. The formula below was used to compute it.

$$R^2 = \frac{\boldsymbol{SSregression}}{SSTotal} \times 100 \quad (11.11)$$

Root Mean Square Error (RMSE): This is the sum square of the vertical distances between the data point and its corresponding data point on the regression line. The RMSE must be relatively small for the model to be considered valid.

$$\text{Rmse} = \sqrt{\frac{\sum (Y_i - Y')^2}{N}} \quad (11.12)$$

Bayesian Information Criterion (BIC): For a model to be considered valid, its BIC must be relatively low.

$$\text{BIC} = \text{n ln}\left(\frac{rss}{n}\right) + \text{p ln n} \quad (11.13)$$

Akaike Information Criteria (AIC): This estimates the amount of information lost by a model, thereby estimating the quality of the model. For a model to be considered good fit, its AIC value must be relatively low.

$$\text{AIC} = \text{n ln}\left(\frac{rss}{n}\right) + 2\text{p}$$

where SS = Sum square, rss = residual sum square, n = sample size, p = number of model fixed parameters, Y_i = the observed value and Y^i = the theoretical value predicted by the model.

Model Validation

Validating of the model was based on the qualitative assessment of the model outputs compared with the data set kept aside for validation. The 25% data set kept aside for model validation was used for this purpose. This was done by examining the significant different between the predicted value and the actual value using two sample t-tests for paired samples. Confidence level of 5% alpha was also used to test for statistical significance. There is no significant different between the observed value and the predicted value when the p-value is greater than 0.05 ($p > 0.05$), and the model is considered acceptable.

Tree Growth Competition Indices

Table 11.2 gives the statistical summary of the growth characteristics obtained for this study. The diameter at breast height (DBH) for the study area ranges from 10 to 170 cm with mean value of 25.12 ± 1.03 cm. The tree height ranges from 7.70 to 38.10 m with a mean value of 18.55 ± 0.32 m.The numbers of tree per hectare in a sample plot ranges from 96 to 704 with a mean value of 442. The mean volume and basal area were1.04 ± 0.14m^3 and 0.08 ± 0.01 m^2, respectively, with minimum and maximum values of 0.003 and 24.676 m^3; and 0.007 and 2.270m^2. The crown diameter had a mean value of 5.89 ± 0.08 m with respective minimum and maximum values of 3 and 13.7 m. The crown length and crown ratio had respective mean value of 2.97 ± 0.06 and 0.17 ± 0.004 with their minimum and maximum values of 1 and 7.8 m; and 0.05and 0.51.

Table 11.3 gives the correlation matrix between the basal area and the various competition indices. There was a strong positive correlation between basal area and competition indices 3(CI_3), and this was as a result of the similarities in the indices formulation and the association among the input variables (the basal area in the CI_3) and the sample plot (S). All competition of each subject tree in the study area was quantified using four (4) spatial (dependent) and non-spatial (independent) indices. The results of the competition indices estimated in this study area are presented in Table 11.4. The value of CI_1 ranges from 0.0203 ± 0.0183 to 1.4972 ± 0.0183. Indices estimated with CI_2 ranges from 0.00006 ± 0 0.0002 to 0.0435 ± 0 0.0002, CI_3 had a value range of 0.1087 ± 0.1575 to 36.3215 ± 0.1575, CI_4 and CI_5 had

Table 11.2 Statistical summary of the tree growth characteristics

Stand growth variable	Mean	Count	MIN	MAX
DBH (cm)	25.123 ± 1.026	389	10	170
THT (m)	18.548 ± 0.324	389	7.7	38.1
MHT (m)	15.038 ± 0.336	389	3.8	36
VOL (m^3)	1.035 ± 0.136	389	0.003	24.676
BAL (m^2)	0.083 ± 0.010	389	0.007	2.270
CL (m)	2.9688 ± 0.059	389	1	7.8
CR (m)	0.174 ± 0.004	389	0.051	0.506
SC	93 0.140 ± 1.896	389	22	225
N/ha	442	389	96	704
Dq (cm)	31.488 ± 0.406	389	18.047	52.655
CD (m)	5.894 ± 0.083	389	3	13.7

where: DBH = diameter at breast height, THT = Tree Total Height, MHT = Merchantable Height, VOL = Volume, BAL = Basal Area, CL = Crown Length, CR = Crown Ratio, SC = slenderness Coefficient, N/ha = numbers of tree per hectare, Dq = Quadratic Mean Diameter, CD = Crown Diameter

a range value 0.55726 ± 0.0058–0.9960 ± 0.0058 and 0.110604 ± 0.0044–0.4325 ± 0.0044, respectively. There was a change pattern in the estimate of competition indices 6 (CI_6), where the range value was higher compared to other competition indices the range value is between 22.425 ± 0.8775 and 87.7998 ± 0.8775, while CI_7 and CI_8 had their values ranges from 0.002 ± 0.0039–0.3704 ± 0.0039 and 0.1075 ± 0.0393–2.7669 ± 0.0393, respectively. In order to asses and compare the competition indices equation for tree growth competition in the study area, a basal area model was used. The best model was been selected using four goodness of fit which are Root Mean Square Error (RMSE), Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC) and Coefficient of Determination (R^2). Table 11.5 gives the summary of the models fit indices and the rank of all the fit indices.

In Table 11.6, the model selected for distance-independent competition indices for Model $BAI = \exp(b_0 + b_1(DBH) + b_2CI)$ is the model with competition indices 3 (CI_3) while for the distance dependent was model with CI_6. The second model which the dependent variable is the natural logarithm of BAI (lnBAI) the model selected for distance-independent indices is model with CI_3 and for distance dependent is model with CI_7 ($\ln BAI = b_0 + b_1DBH + b_2H + b_3CI\ _7$). Further analysis which included model verification and residual analysis was carried out to select the best from the four selected CI model from the two BAI and lnBAI models used (selected on basis of distance-dependent competition indices and distance-independent CI indices).

It was observed that all the models had a p-value greater than the alpha level, which thus indicates that the models are not significant. Figures 11.5, 11.6, 11.7, and 11.8 show the residual analysis carried out on the selected competition indices models. It was revealed that only Fig. 11.5 met the assumption of homoscedasticity. The error where randomly and evenly distributed with zero means and constant variance along

Table 11.3 Correlation matrix between basal area increment and various competition indices

	DBH	THt	lnBAI	BAI	C1	C2	C3	C4	*C5*	*C6*	*C7*	*C8*
DBH	1											
THt	0.595	1										
lnBAI	0.925	0.659	1									
BAI	0.926	0.441	0.731	1								
C1	0.108	0.072	0.127	0.081	1							
C2	0.826	0.460	0.691	0.828	-0.137	1						
C3	0.926	0.4409	0.731	1	0.081	0.828	1					
C4	0.210	0.024	0.243	0.149	0.510	0.076	0.149	1				
C5	0.139	0.131	0.208	0.055	−0.005	0.041	0.055	0.214	1			
C6	0.154	0.181	0.209	0.071	0.149	0.066	0.071	0.341	0.356	1		
C7	0.057	0.089	0.055	0.0372	−0.042	0.087	0.037	0.238	−0.104	0.553	1	
C8	0.101	0.005	0.103	0.075	0.616	−0.033	0.075	0.367	−0.104	0.328	−0.087	1

C1–C4 are distance-independent competition indices (non-spatial), while C5–C8 are distance-dependent competition indices (spatial)

Table 11.4 Estimated mean for the competition indices

	Mean	Min	Max
CI_1	0.36867 ± 0.0183	0.0203 ± 0.0183	1.4972 ± 0.0183
CI_2	0.0017 ± 0 0.0002	0.00006 ± 0 0.0002	0.0435 ± 0 0.0002
CI_3	1.3266 ± 0.1575	0.1087 ± 0.1575	36.3215 ± 0.1575
CI_4	0.8917 ± 0.0058	0.55726 ± 0.0058	0.9960 ± 0.0058
CI_5	0.2958 ± 0.0044	0.110604 ± 0.0044	0.4325 ± 0.0044
CI_6	50.3021 ± 0.8775	22.425 ± 0.8775	87.7998 ± 0.8775
CI_7	0.0334 ± 0.0039	0.002 ± 0.0039	0.3704 ± 0.0039
CI_8	0.7408 ± 0.0393	0.1075 ± 0.0393	2.7669 ± 0.0393

Where CI = competition indices, ± Standard error

Table 11.5 Models parameters and fit Indices

Basal Area Model + CI_i	B_0	B_1	B_2	B_3	*RMSE*	*AIC*	*BIC*	R^2	*Rank*
	$BAI = exp(b_0 + b_1(DBH) + b_2(CI)$								
CI_1	−3.046	0.023	0.072	–	0.072	−703.245	−688.538	0.8874	369.068
CI_2	−3.014	0.0212	14.75	–	0.069	−724.873	−710.1664	0.895	368.373
CI_3	−4.173	0.055	−0.120	–	0.021	−1437.97	−1423.263	0.991	343.164
CI_4	−9.382	0.024	6.738	–	0.063	−780.688	−765.981	0.914	385.087
CI_5	−3.830	0.025	2.314	–	0.066	−751.016	−736.309	0.904	365.620
CI_6	−3.769	0.026	0.012	–	0.064	−774.031	−759.324	0.912	364.759
CI_7	−3.077	0.024	1.063	–	0.071	−715.026	−700.319	0.892	367.896
CI_8	−3.208	0.024	0.172	–	0.069	−731.929	−717.222	0.898	367.322
No CI	−3.0141	0.0234			0.072	−704.455	−693.425	0.887	368.041
	$lnBAI = b_0 + b_1DBH + b_2H + b_3CI$								
CI_1	−5.131	0.0455	0.032	0.004	0.431	342.536	360.919	0.868	773.653
CI_2	−5.254	0.055	0.031	−66.011	0.403	303.149	321.533	0.85	773.747
CI_3	−5.448	0.094	0.004	−0.306	0.228	−29.005	10.622	0.963	750.423
CI_4	−5.763	0.043	0.035	0.699	0.424	333.043	351.426	0.872	774.543
CI_5	−5.471	0.044	0.030	1.367	0.415	320.839	339.223	0.877	769.365
CI_6	−5.275	0.044	0.031	0.004	0.426	336.639	355.022	0.870	783.513
CI_7	−5.126	0.045	0.032	−0.234	0.430	342.025	360.408	0.868	772.314
CI_8	−5.158	0.044	0.032	0.036	0.429	341.285	359.669	0.868	777.869
No CI	−5.130	0.045	0.032		0.867	344.539	361.246	0.868	772.443

Note CI = Competition indices, C_1–C_8 are the competition indices equation numbers, C_1–C_4 are the distance-independent indices, while C_5–C_8 are the distance-dependent indices

Table 11.6 Fitted model validation for the selected models with competition indices incorporated

Models form	CI	Types of indices	Mean of predicted value	Mean of observed value	Validation T-Value	P-value	Shapiro wilk
$BAI = \exp(b_0 + b_1(DBH) + b_2CI)$ $BAI = \exp(-5.448 + 0.094DBH + 0.004$	C3	DD	0.067583	0.07400361	−0.40072	0.6891	2.2×10^{-16}
$BAI = \exp(b_0 + b_1(DBH) + b_2CI)$ $BAI = \exp(-3.7687 + 0.0255DBH + 0.0117CI$	C6	DD	0.06758328	0.092105	−1.7371	0.08424	2.2×10^{-16}
$\ln BAI = b_0 + b_1DBH + b_2H + b_3CI$ $\ln BAI = -5.448 + 0.094DBH + 0.004H - 0.306$	C3	DID	−3.432653	−3.436474	0.024624	0.9804	4.672×10^{-11}
$\ln BAI = b_0 + b_1DBH + b_2H + b_3CI$ $\ln BAI = -5.448 + 0.045DBH + 0.032H - 0.306CI$	C7	DID	−3.432653	−3.462242	0.20646	0.8367	1.397×10^{-9}

where CI = competition indices, C3, C6 and C7 are the competition indices equation numbers, DD = distance-dependent indices, DID = distance-independent indices

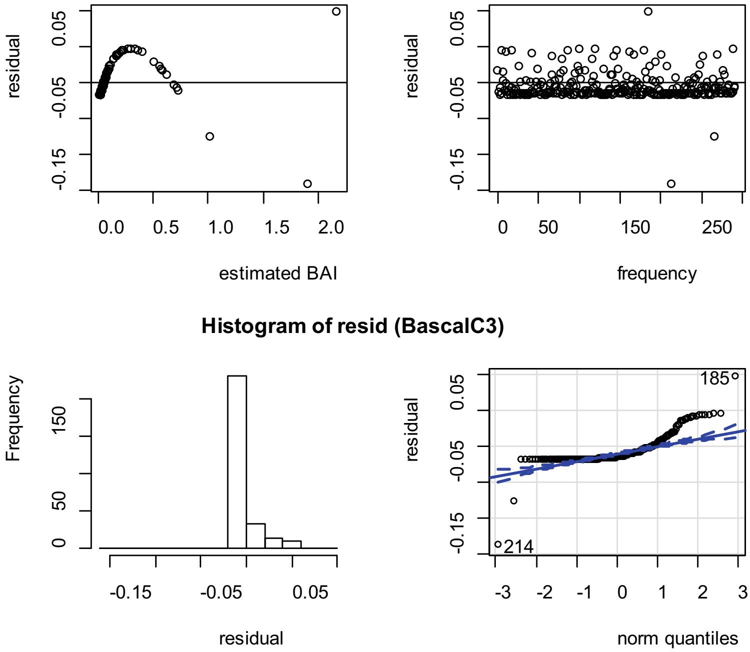

Fig. 11.5 Residual analysis for model 1 distance-independent CI_3

the positive and negative region of the X-axis. The distribution pattern was uniform and this thus implies that Model 1 distance-dependent competition indices CI_6 is good and superior to other models used in the study area.

Discussion

Model is now a daily routine used in forestry for predicting growth and yield, modelling diameter distributions, basal area model and tree crown model and many more (Ogana et al. 2015). Models are simply used for prediction and projection. Tree growth competition model was developed for this study in order to examine the competitive effect on each tree. Several studies had opined that decision of the management of the forest is often predetermined on information about current and future resources condition. As such, this study has directed effort in obtaining prediction models on tree growth competition with special focus on incorporation of spatial and non-spatial indices in the basal area growth model. The distance dependent involves spatially location of the subject tree to the competitors tree, while the distance independent examined the effect of the subject trees in relative to the stand measured at the centre of the plot. Studies have shown that adding of competition indices to tree growth improves the predictability of the model due to inclusion of

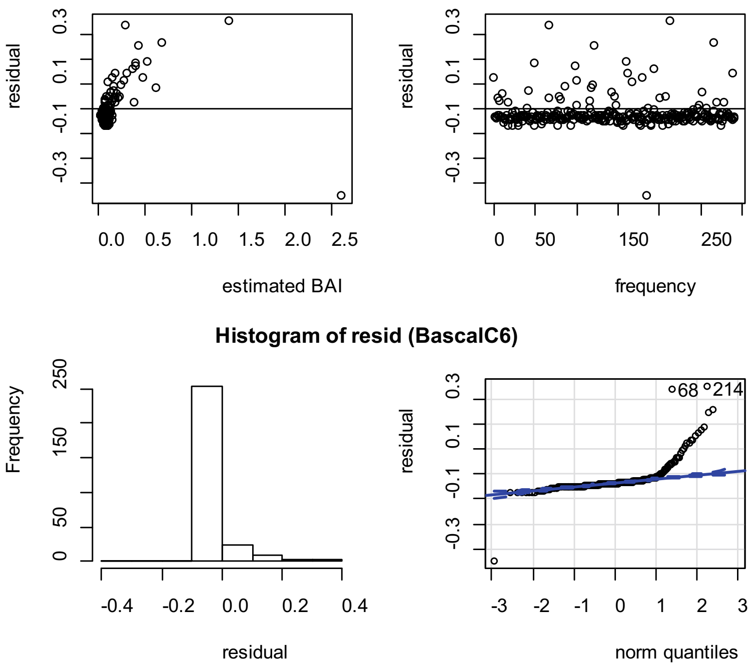

Fig. 11.6 Residual analysis for model 1 distance-dependent CI_6

trees variables in the competition indices (Contreras et al. 2011; Maleki et al. 2015; Ige 2017). For the study area, it was observed that distance-dependent competition indices C6 gave better estimation of tree growth competition and its effect on the growth of neighbouring trees. This study was in contrast with what was reported by Biging and Dobbertin (1992) that estimation of crown parameter improved the performance of distance depend indices measure, because competition indices that performed best for this study only uses height and distance in is computational competition index. However, Fraver et al. (2014) noted that inter-tree competition significantly affects growth rates as observed in better performance of model with competition indices when compared to models with no competition indices. Examining the effect of competition on tree growth, basal area model as used by Contreras et al. (2011) was used with four goodness of fit being used in selecting the best model for predicting the tree growth competition indices for the study area. For distance-dependent competition indices model, CI_6 gave better estimates for tree growth competition, while CI_3 gave better estimate for tree growth competition using the distance independent. Further analysis was however carried out on the DD CI_6 and DID C_3model. The residual analysis carried out on CI_6 and CI_3 shows that the spread residual above and below the zero line for model with CI_6 follows the law of homoscedasticity this indicates that the distance-dependent indices are more superior to distance-independent indices. Values gotten for the Root Mean Square Error of all the models are very small and high values gotten from the adjusted coefficients

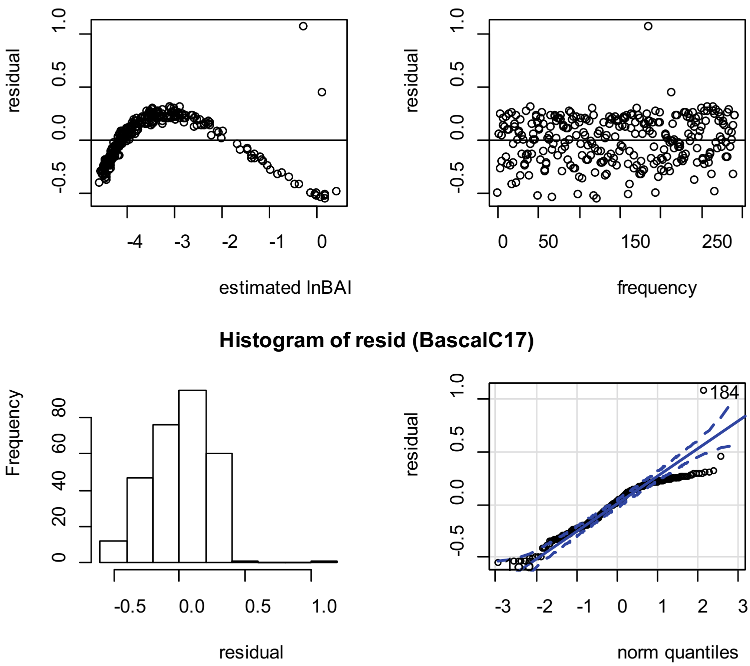

Fig. 11.7 Residual analysis for model 2 distance-independent CI_3

of determination shows that the model form is well adapted and biological realistic which is an indication that one of the major factors contributing to individual tree growth variation is the inter-tree competition as such, this finding also agrees with what was reported by Ige and Adesoye (2017).

Conclusions and Recommendations

The result of this study revealed the present assessment of stand growth characteristics and evaluation of tree growth competition indices in the study area. The study area has an estimated number of 389 tree stem per hectare which compares well with what is been observed in tropical forest ecosystem. Tree growth competition indices are not often address in many natural forests. Tree growth competition evaluated for this study involves using eight measures of tree competition index examined in terms of their effectiveness as growth predictor for the study area. This study demonstrated that one of the factors that influence forest processes and structure is competition. The inclusion of distance-dependent indices described the effects of tree neighbourhood

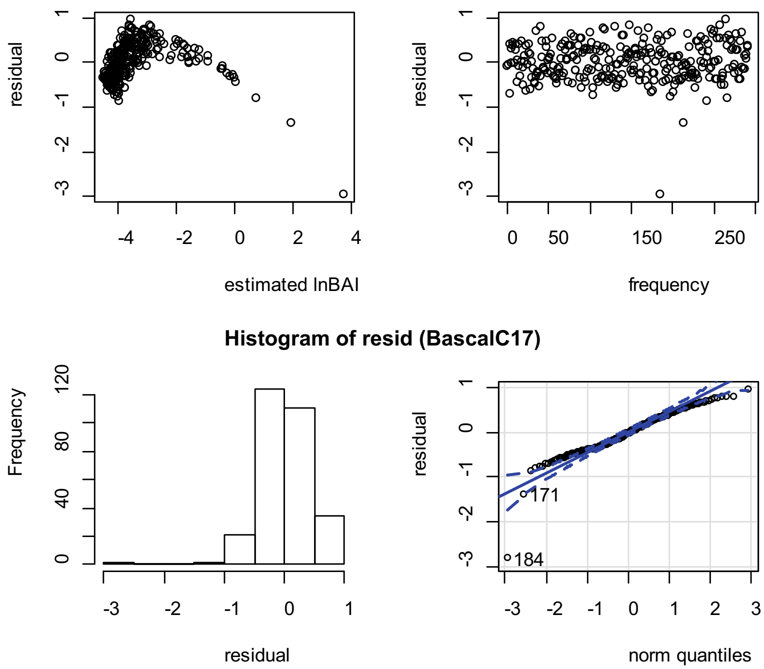

Fig. 11.8 Residual analysis for model 2 distance dependent with CI_7

maintained in the complex stand structure compared to distance-independent indices in the study area. One major constrain to use of distance dependent is the acquisition of tree attributes such as location and distance measurement which are time consuming and labour intensive. A positive strong correlation was found between two competition indices and tree growth variables, and this is an indicator that competition exists between trees. The growth model examined in this study revealed that model form of $BAI = \exp(-3.7687 + 0.0255DBH + 0.0117CI_6$ of distance-dependent competition indices predicted the growth predictability well compared to distance-independent indices. Therefore, for basal area increment growth model, competition index computed with the sum of ratio of height of subject tree multiplies with the ratio of height of competitor tree to the distance of the subject tree in a plot that are recommended so as to increase tree growth predictability for the study area.

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