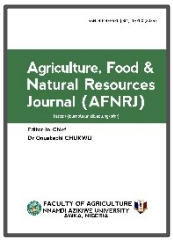
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Original Article

Influence of elevation and wood specific gravity on tree structure in a Nigerian university forest

OPEN ACCESS

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ABSTRACT

Elevation and wood specific gravity variables are used to understand forest growth and its various responses to climate. Despite this, the relationship among various forest structures, wood specific gravity, and elevation remains poorly understood. This study investigated the influence of elevation and wood specific gravity on the tree structure of a natural forest in Nnamdi Azikiwe University, Nigeria. Using a line transect, fifteen plots of 50 m x 50 m were alternately laid at 50 m intervals on three transects. Diameter at breast height (DBH, cm), tree total height (TH, m), and elevation (elev., m) were measured, while basal area (BA, m^2) and wood specific gravity (WSG g/cm^3) were derived. Data were analyzed using descriptive statistics and regression. Six (6) regression models were fitted and evaluated using the adjusted coefficient of determination (Adj.R^2) and standard error of estimate (SEE). Results revealed that Dst had a mean and standard error of 49.0±1.80. Elevation (81.7±0.33), WSG, and BA had 0.51±0.01 and 0.14±0.01, respectively. The highest number (136) of trees was observed in the elevation class of 76-85, 86-95 had 32 trees, and <75 had the lowest (1). Elevation class (76-85) had the highest number (26) of species distribution, 86-95 had 16, and <75 had the lowest (1) number. From evaluation results, models 2 and 3 had the same and highest Adj.R^2 and lowest SEE values of 0.87 and 0.08 and were selected. This study concludes that elevation and WSG influenced tree species distributions and structure. Therefore, it is recommended for further research using a larger forest area.

KEYWORDS: *Basal area, Forest, Forest structure, Mixed forest, Tree growth*

INTRODUCTION

Variability in wood density and specific gravity along elevation gradients is driven by multiple factors. These factors directly impact tree growth and species distribution by pushing species beyond their eco-physiological limits, affecting photosynthesis and other biological processes (Rowe & Lidgard, 2009). Given wood specific gravity's role in all woody tissues from roots to canopy, and studying both above and belowground wood structures is crucial for understanding whole-plant patterns (Fortunel *et al.,* 2012). Elevation, along with its associated environmental and climatic conditions, shapes forest dynamics, including stand recovery, composition, and structure (Lieberman *et al.,* 1996)."

Forest structure is known to vary with many factors such as water and temperature (Larjavaara, 2014). These factors shape forest structure along elevation gradients (Venter *et al.,* 2017). As elevation changes, so does tree structure, often due to variations in wood density. Studying how elevation and wood density affect tree structure can inform conservation efforts and climate change mitigation strategies. Since tree species and size play critical roles in supporting ecosystem functions and services, understanding these dynamics is key.

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Elevation and climatic factors are the governing factors for regional differences in species composition (Lee & Chun, 2016). Elevation changes can significantly impact various tree structures (Mao *et al.,* 2015). Tree growth rates vary with elevation and wood density due to differences in soil properties and climate (Sharma *et al.,* 2020). Research has shown mixed results on the relationship between tree species richness and elevation; some studies found a unimodal pattern, peaking around 100 m (Lee *et al.,* 2013), while others reported a steady decline in species richness with increasing elevation (Kraft *et al.,* 2011; Zhu *et al.,* 2015). This study, therefore, aimed at assessing the influence of elevation and wood specific gravity on the tree structure of the natural forest in Nnamdi Azikiwe University, Awka, for its proper management and conservation strategies.

MATERIALS AND METHODS

The study area

The study site (6.245 – 6.283° N and 7.115 – 7.1219° E) is a Nigerian University established in the southeastern zone in 1991 with a mean elevation of 136 meters above sea level. The climate of the area is tropical, indicating that it is basically within the tropical rainforest ecological zone with a mean temperature of 26.3°C. Awka has seasonal climatic harmattan as well as a precipitation array of 1828 mm-2002 mm (Ezenwaji *et al.,* 2013).

Data collection

Sampling technique

The sampling technique used for this study was a systematic random sampling technique (line transect). It is a probability sampling method that involves the random selection of a sample of the same population at a regular interval. It helps to minimize biased samples and poor inventory data. In this study, the natural forest on Nnamdi Azikiwe University's main campus was used. Three (3) transect lines of 600 m long were laid at 50 m apart from each other in the forest. Five (5) temporary sample plots of 50 m × 50 m were laid alternately alongside each other at 50 m intervals on each transect to ensure coverage of the forest variations. Within each plot, all trees with DBH ≥ 10 cm were measured and recorded. A total of 15 (fifteen) sample plots were used for this study. The following tree growth characteristics were measured: stump diameter (Dst, cm), diameter at breast height (DBH, cm), tree total height (TH, m), and crown diameter (CD, m). while individual tree basal area and wood specific gravity were derived. This study was done in a small forest area. According to Sanders & Rahbek (2012), assessing climate's impact on vegetation through field sampling across vast areas using standardized methods can be tough, and inconsistent environmental factors often complicate the process. Another approach is to conduct studies in smaller areas with varying elevations, essentially using elevation as a stand-in for latitude (Jump *et al.,* 2009).

Data Processing and computation

The data collected for this study were carefully handled, processed, and analysed.

***Basal area computations*:** This is mathematically expressed as:

$$BA = \frac{\pi(DBH)^2}{4} \quad (1)$$

Where, BA = basal area, π = 3.142, DBH = diameter at breast height per tree.

Data Analysis

Exploratory analysis: The data obtained from the field were prudently processed and analysed. Descriptive statistics were employed to summarize the growth variables. Correlation matrix analysis was done to investigate the linear association existing among the variables collected.

Graphical analysis was used to show the composition and distributions of tree species based on the elevation classes. Regression analysis was used to investigate the influence of elevation and wood specific gravity on tree basal area.

In this study, six (6) basal area models were fitted and examined using Basal area as the dependent variable and Dst (stump diameter), WSG (wood specific gravity), and elevation (Elev.) as independent variables. The candidate functions used are simple linear, multiple linear, and reciprocal. These models were compared using the following fit statistics criteria: values of standard error of estimate (SEE) and adjusted coefficient of determination (Adj.R^2). The model with the highest value of Adj.R^2 and the lowest value of S.E.E. was chosen as the best predictive model. The selected models are mathematically expressed in Table 1.

Table 1. Model functions

Model No	Model Functions	Equation No.
1	$BA = \beta_0 + \beta_1 Dst$	(2)
2	$BA = \beta_0 + \beta_1 Dst + \beta_2 Elev$	(3)
3	$BA = \beta_0 + \beta_1 Dst + \beta_2 WSG$	(4)
4	$BA = \beta_0 + \beta_1 \frac{1}{Dst}$	(5)
5	$BA = \beta_0 + \beta_1 \frac{1}{Dst} + \beta_2 \frac{1}{Elev}$	(6)
6	$BA = \beta_0 + \beta_1 \frac{1}{Dst} + \beta_2 \frac{1}{WSG}$	(7)

BA= basal area, Dst= stump Diameter Elev= elevation, WSG= wood specific gravity, β_0, β_1, β_2 are parameters estimated.

The fit statistics criteria expressions are as follows: Adjusted coefficient of determination (Adj. R^2) and standard error of estimate (SEE).

$$Adj.R^2 = 1 - \frac{1-(1-R^2)(n-1)}{n-p} \quad (8)$$

$$SEE = \sqrt{\sum_{i=1}^{n} \frac{e_i^2}{n-k}} \quad (9)$$

Where k and p = the number of model parameters in the test, n=total number of observations

R^2= coefficient of determination, RSS= regression sum of square, e_i= error sum of square

RESULTS AND DISCUSSION

Results

Assessment of tree growth characteristics

The results of the summary of descriptive statistics of tree growth characteristics measured in the study area are presented in Table 2. The results indicated that Dst ranged from 13.4 cm – 115.2 cm with a mean and standard error of 49.0±1.80. DBH ranged from 10 cm – 102.2 cm with a mean and standard error of 37.3±1.54. The total height ranged from 10.3 m – 24.1 m with a mean and standard error of 13.5±0.76. The elevation varied from 72 m – 92 m, with a mean and standard error of 81.7±0.33. While the WSG and BA varied from 0.23 g/cm^3 – 0.9 g/cm^3 and 0.0072 m^2 – 0.82 m^3, with mean and standard error of 0.51±0.01 and 0.14±0.01, respectively.

Table 3 presents the summary of the Pearson correlation analysis. It was discovered that the relationship between DBH and BA had the highest and significant positive correlation (r) of 0.978, followed by the relationship between Dst. and DBH, and Dst and BA, showing significant positive correlation (r) of 0.942 and 0.897, respectively. The relationship between elevation and BA had the lowest and significant positive correlation (r) of 0.176.

Table 2: Descriptive statistics

Growth variables	Min.	Max.	Mean	Std. Error
Dst (cm)	13.4	115.2	49.0	1.80
DBH (cm)	10.0	102.2	37.3	1.54
Total height (m)	10.3	24.1	13.5	0.76
Elevation (m)	72	92	81.7	0.33
WSG g/cm^3	0.23	0.9	0.51	0.01
BA (m^2)	0.0072	0.82	0.14	0.01

Dst= Stump diameter, DBH = diameter at breast height, WSG= wood specific gravity, BA= basal area.

Table 3: Correlation Analysis

Growth var.	Dst (cm)	DBH (cm)	TH (m)	E (m asl)	WSG kg/m^3	BA (m^2)
Dst (cm)	1					
DBH (cm)	0.942*	1				
TH (m)	-0.023	-0.024	1			
E (m asl)	0.229*	0.207*	0.045	1		
WSG (g/cm^3)	0.084	0.101	-0.086	0.011	1	
BA (m^2)	0.897*	0.978*	-0.025	0.176*	0.106	1

** Correlation is significant at the 0.05 level (2-tailed). Dst= stump diameter, DBH= diameter at breast height, WSG= wood specific gravity, BA= basal area, TH= Total height and E= Elevation*

Influence of elevation on tree species composition and distribution

Figure 1 shows the relationship between the elevation and distribution of trees using class intervals that ranged from <75, 76 – 85, 86 – 95, and >95. The total number of trees used in this elevation class interval is 169. The highest number of trees (136 trees) distributed was observed in the elevation class interval of 76-85. This was followed by the elevation class interval of 86 – 95, which had a distributed number of 32 trees. The lowest number of trees occurred in the elevation class interval of <75, with one (1) tree found in the class interval.

The results of the relationship between the elevation and number of tree species found in class intervals (<75, 76 – 85, 86 – 95, and >95) are presented in Figure 2. The results revealed that the highest number of tree species (26) occurred in the elevation class interval of 76-85, followed by the elevation class interval of 86 – 95, which had a total number of 16 species. The lowest number of tree species (1) occurred in the elevation class interval of <75.

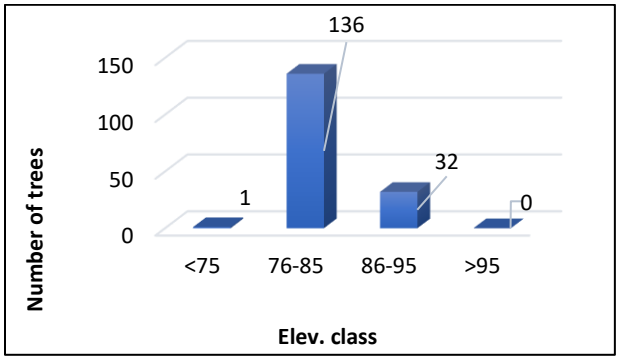


Figure 1: Relationship between Elevation and tree distributions

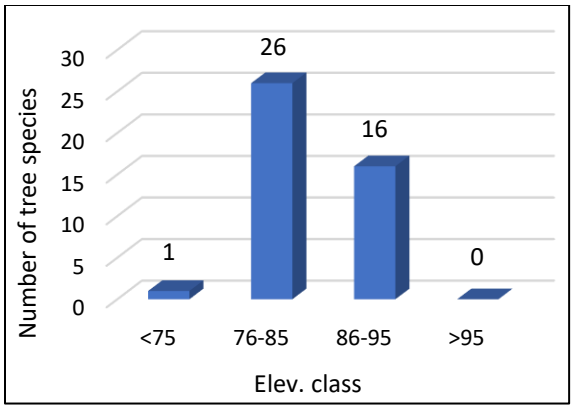


Figure 2: Relationship between Elevation and tree species distributions.

Evaluate the influence of elevation and wood specific gravity on individual tree basal area

In this study, six (6) basal area candidate (simple linear, multiple linear, and reciprocal) models were used to investigate the influence of elevation (Elev.) and wood specific gravity (WSG) on tree basal area (tree horizontal structure). These candidate models were fitted and examined using two fit statistics criteria. The results of selected basal area models fitted and evaluated are presented in Table 4. The results showed that models 2 and 3 had the highest and same Adj.R^2 value of 0.87 with the same SEE value of 0.08. This was followed by model 1 having an Adj.R^2 value of 0.80, with a high SEE value of 0.29. Models 5 and 6 had the same Adj.R^2 of 0.46 and different SEE values of 0.12 and 0.13, respectively, while model 4 had the lowest Adj.R^2 value of 0.44 and the highest value of SEE of 0.33. Therefore, models 2 and 3 were selected as the best models.

Table 4: Developed Basal area models.

M/No	Model	Parameter Estimate			Goodness of fit criteria	
		b_0	b_1	b_2	Adj. R^2	SEE
1	$BA = \beta_0 + \beta_1 Dst$	-0.185	0.007		0.80	0.29
2	$BA = \beta_0 + \beta_1 Dst + \beta_2 Elev$	-0.086	0.007	-0.001	0.87	0.08
3	$BA = \beta_0 + \beta_1 Dst + \beta_2 WSG$	-0.2	0.007	0.028	0.87	0.08
10	$BA = \beta_0 + \beta_1 \frac{1}{Dst}$	0.418	-11.29		0.44	0.13
11	$BA = \beta_0 + \beta_1 \frac{1}{Dst} + \beta_2 \frac{1}{Elev}$	0.454	-11.245	-2.991	0.46	0.12
12	$BA = \beta_0 + \beta_1 \frac{1}{Dst} + \beta_2 \frac{1}{WSG}$	0.450	-11.261	-0.14	0.46	0.12

BA = basal area, Dst = stump diameter, WSG= wood specific gravity, Elev= elevation, b_0, b_1, b_2, b_3 = parameters estimated.

Discussion

Tree growth characteristics refer to the physical or biological features that describe the development and size of a plant over time. The results of this study showed that the data followed a biological pattern, that is, as stump diameter (Dst) increases, diameter at breast height (DBH) also increases. These can be used to assess the health and productivity of trees and also monitor changes in forest ecosystems over time. Correlation analysis results revealed that elevation had a positive correlation with BA, which also has the lowest significant value at the 0.05 level. Basal area has a positive correlation with the other variables, excluding the tree height. The implication of this is that basal area is affected by wood specific gravity (WSG), elevation (Elev.), diameter at breast height (DBH), and stump diameter (Dst), while the tree height does not influence its increase. This conforms to the report of Wang *et al.* (2014), who found that the maximum tree height of *Abies georgei* decreased along elevational gradients. Elevation influences vegetation structures and dynamics (Sanders & Rahbek, 2012).

The results of this study revealed that elevation has effects on the number of trees distributed as well as the number of species found in the study area. The number of tree growth supported by elevation varies along the elevation classes. This is in support of the report of Wang *et al.* (2022) that environmental factors seen along elevation gradients differ (mainly based on temperature, humidity, and soil properties) markedly and determine or change the pattern of plant growth and distributions within their study area. The findings of this study are also in agreement with reports of Song *et al.* (2021) that variations in tree growth and distribution of trees exist along elevation gradients, which may be due to differences in climatic conditions. Bai *et al.* (2021) also established elevation to be the key driving factor of vascular plant distribution in a *Larix gmelinii* forest in northeast China. Yang *et al.* (2016) and Tang *et al.* (2014) also reported that species richness at the community level may vary with elevation.

These models (simple linear, multiple linear, and reciprocal) were used to investigate the influence of elevation and WSG on basal area, which accounts for horizontal tree structure. Based on estimated Adj.R^2 values, about 44 to 87 % of the total

variation in observed basal area values was explained by the candidate models. This implies that some of the candidate models had good and similar performance. The criteria adopted for selecting the best model in this study were through comparison of Adj.R^2 and SEE, which are standard ways of evaluating a model's predictive ability, as pointed out by Shamaki & Akindele (2013).

Based on the model's evaluation results, models 2 and 3 were selected out of the six candidate models as the models with the best predictive abilities. Models 2 and 3 had the same and highest value of Adj.R^2 and the lowest value of SEE in this study. The efficiency of this procedure was confirmed by Adesoye & Ezenwenyi (2014). The result of this study revealed that most models having either elevation or wood specific gravity added as independent variables performed better than those that used only stump diameter as the independent variable. This indicated that elevation and WSG influence basal area, which accounts for tree structure. This conforms to the report of Williamson & Wiemann (2010) that elevation and WSG influence tree growth and structure are considered useful for understanding species life history, strength, and physiological strategies.

CONCLUSION AND RECOMMENDATION

This study concluded that elevation can influence tree species composition as well as tree distribution. The study also concluded that elevation and wood specific gravity influence tree structure and can be added as independent variables in the basal area prediction of forest stands.

This study recommends further research using a larger forest area. Secondly, since this study was based on a small sample size, the results should not be assumed to hold in other regions.

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Authors' Contributions

JUE and ASE managed data collection. JUE did the interpretation of the data, writing of the manuscript, and material support. ELA and CLU reviewed the manuscript. ASE and ELA managed the literature searches. JUE & OC managed the development of methodology and data analysis. All Authors read and approved the final manuscript.

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