**Original Research Article**

**DEVELOPMENT OF LOCAL VOLUME TABLE FOR *Pinus caribbaea* var. *hondurensis* (Senecl) IN AREA J4, OMO FOREST RESERVE, NIGERIA**

# ABSTRACT

Volume estimation is a crucial part of every forest or plantation because it provides the quantity of timber or wood available at a given period and predicts future or expected growth of the forest. Unfortunately, local volume table are not readily available for some – economically important tree species in Nigeria. Hence, it is of paramount importance that local volume tables for economic tree species such as *Pinus caribbaea* in Area J4, Omo Forest reserve, Ogun state, Nigeria.

**Aim**: The aim of this study is to develop a local volume table for *Pinus caribbaea* in Area J4, Omo Forest Reserve, Ogun State, Nigeria.

**Study design**: Simple random sampling was used for this study. Ten Temporary Sample Plots (TSP) of equal size 25m x 25m were randomly located in the selected plantation (*P. caribbaea*: established in 1997). All the trees with diameter at breast height (dbh) ≥ 10cm in each TSP were enumerated.

**Place and duration of Study**: The study was carried out in the *Pinus caribbaea* plantation in Area J4, Omo forest reserve, Ogun State from November 9th to 20th, 2023.

**Methodology**: The total tree height, merchantable height, diameters at the top, middle, base, and dbh were measured and used to estimate stand volume. A volume table was developed using five selected models, and the best model was selected using least Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Root Mean Square Error (RMSE). Data were analyzed using descriptive statistics and regression at α0.05 with R statistical software.

**Results**: The results obtained in *P. caribbaea* plantation revealed that the dbh and height were 27.93±6.95 cm and 28.72±3.47 m, respectively, while individual tree volume was 0.83±0.57m3. The combined variable model ($V\_{i}=-9.857e-02+3.851e-05D\_{i}^{2}H\_{i}+ε\_{i})$ was selected as the best model to develop local volume table for *P. caribbaea* (AIC = -54.73, BIC = -45.49 and RMSE = 0.20).

**Conclusion:** The developed volume table for estimating the quantity of wood or timber available in the *Pinus Caribaea* plantation at a given time. The volume model and local volume table developed are to be applied only to the *Pinus caribaea* plantation in the study area.

***Keywords****: Volume table, Volume models, Non-destructive sampling, Pinus caribbaea , Omo Forest Reserve, Forest volume estimation.*

**1. INTRODUCTION**

Forest inventory is a crucial tool in forest management, providing essential data for planning, monitoring, evaluation, research, growth and yield predictions, and timber sales. The current level of the growing stock can be assessed through forest inventories and the future growth can be projected using growth and yield models [1]. Volume estimation plays a vital role in forestry as it quantifies the available timber or wood at a given time and predicts future growth. . Accurate wood volume estimates are central to forest management and the trade of forest resources. [2]. For inventory and management purposes, the forest managers or researchers must be able to determine the volume of standing trees quickly and efficiently, even after the trees have been harvested. A volume table is a tabular statement that shows the volume in relation to diameter of trees in a specific area. Globally, volume tables play a significant role in calculating the volume of standing trees. [3; 4].

*Pinus caribbaea* is a durable and easily workable softwood widely used for construction, engineering, and decorative purposes. In tropical countries, the demand for long-fiber wood in the building and paper industries has made *P. caribbaea* a suitable species for extensive reforestation reforestation programs that not only restore forest losses but also aims to increase forest cover and mitigate desertification. . This Caribbean pine has been suc­cessfully used in reforestation programs worldwide.. Research has shown that volume tables have been developed for *P. caribeae* in Bulolo-Wau Forest plantations New Guinea [5] and volume equations and tables have been developed for other species [e.g. 6; 7]. However, no volume table has been developed for *P. caribaea* in Area J4, Omo Forest reserve. The main objective of this study is to develop a local volume table for *Pinus caribbaea* in area J4, Omo Forest Reserve, Ogun State, Nigeria.

**2. MATERIALS AND METHOD**

**2.1 Study Area**

The study was conducted on the *Pinus carribaea* plantation at Area J4, Ijebu- Ode, Ogun State, Nigeria. The location spans latitudes 6°35' to 7°05' N and longitudes 4°19' to 4°40' E in the South-west of Nigeria (Fig 1) and covering an area of 130,500 hectares [8]. It is approximately 135 km North-East of Lagos, 120 km East of Abeokuta and 80 km East of Ijebu-Ode [9]. The reserve shares its northern boundary with the Ago Owu and Shasha Forest Reserve in Osun state and its Eastern boundary with Oluwa Forest Reserve in Ondo State [10]. The mean annual rainfall ranges from 1600 to 2000 mm with peaks in June and September, and the driest months being November and February. [11;12].

Figure 1Omo Forest Reserve showing the study area. Source: [13]

**2.2 Species Description**

*Pinus caribaea* var. *Hondurensis* (Senecl) Barr.et Golf. is widely grown in the African tropics and subtropics [14]. In its natural habitat in central America and the Caribbean Basin, *Pinus caribaea* thrives best at low altitudes (up to approximately 700 m above mean sea level) on fertile, well-drained soils with mean annual rainfall (MAR) of 1200 mm per year and mean annual temperatures ranging from 20°Cto 27°C [15]. In Africa, *Pinus caribaea* is known for its adaptability to a wide range of climates and elevations [16; 17]. The hard wood of *Pinus caribaea* is suitable for floors and various types of construction.

# 2.3 Sampling Procedure

Simple random sampling was employed in this study. *P. caribbea* plantation stand established in 1997 was purposively selected due to its availability and relatively low disturbance/ harvesting. Developing a volume table for this age series is crucial as the trees are mature enough to meet management objectives (timber production). Consequently, the management of the forest reserve will utilize the table for valuation purposes during allocation processes. Ten Temporary Sample Plots (TSP) each measuring 25 m x 25 m were randomly located in each of the plantation.

# 2.4 Method of Data Collection

All trees in each Temporary Sample Plot (TSP) were enumerated. The total tree height, merchantable height, diameter at the top (Dt), middle (Dm), base (Db), and diameter at breast height (dbh) over bark at 1.3 m above the ground of all trees in the sample plot were measured using a diameter tape and height was measured using a Spiegel relaskop.

# 2.5 Data Analysis

#### **2.5.1 Volume Estimation**

The volume of all trees in the sample plots was calculated using Newton’s formula.

$V=π\frac{H}{24}\left(D\_{b}^{2}+4D\_{m}^{2}+D\_{t}^{2}\right)$ …………………… Eq.1

Where,

V= volume (m3)

$D\_{b}$ = the diameter at the base (m2)

$D\_{m}$ = the diameter at the middle (m2)

$D\_{t}$ = the diameter at the top (m2)

H = total tree height (m)

**2.5.2 Development of Local Volume Tables**

For developing the local volume table, a non-destructive method was used. Five (5) volume equations, including the the constant form factor, combined variable, logarithmic, generalized combined variable and generalized logarithmic were used (Table 1).

Table 1 Selected Local Volume Equations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S/N** | **MODEL NAME** | **FORMULA** | **REFERENCE** |  |
| 1 | Combined variable | $V\_{i}=b\_{0}+b\_{1}D\_{i}^{2}H\_{i}+ε\_{i}$  | [18]  |  |
| 2 | Constant form factor | $V\_{i}=b\_{1}D\_{i}^{2}H\_{i}+ε\_{i}$  | [18] |  |
| 3 | Logarithmic  | $V\_{i}=e^{b1}D\_{i}^{b2}H\_{i}^{b3}e^{ε\_{i}}$  | [18] |  |
| 4 | Gen. combined variable | $V\_{i}=b\_{0}+b\_{1}D\_{i}^{2}+b\_{2}H\_{i}+b\_{3}D\_{i}^{2}H\_{i}+ε\_{i}$  | [18] |  |
| 5 | Generalized logarithmic | $V\_{i}=b\_{0}+b\_{1}D\_{i}^{b2}H\_{i}^{b3}e^{ε\_{i}}$  | [18] |  |

**Note:** $V\_{i}$- Individual tree stem volume, Di- Individual tree diameter at breast height, Hi- Individual tree total height, b0, b1, b2 and b3- Regression parameters, e- Exponential function, $ε\_{i}$- Error term. Gen-Generalized

# 2.5.3 Model Evaluation

The Akaike information criterion (AIC), Bayesian information criterion (BIC) and Root Mean Square Error (RMSE) were used as evaluation indices. Models with the least AIC, BIC and RMSE were selected as the best.

$AIC=ln\left(\frac{RSS}{n-k}\right)+\frac{2}{n}K$ ………………………………….. Eq. 2

$BIC=ln\left(\frac{RSS}{n-k}\right)+\frac{k}{n}ln\left(n\right)$ ……………………………….…. Eq. 3

$RMSE=\sqrt{\frac{\sum\_{}^{}(y\_{i}-\hat{y}\_{i})^{2}}{n}}$ …………………………………… Eq. 4

Where,

$ln$= Natural logarithm

$RSS=$ Residual sum of squares

$n =$Total number of observations

K= Number of independent variables

$y\_{i}$ = Observed values of y

$\hat{y}\_{i}$ = Predicted values of y

**3. RESULTS AND DISCUSSION**

Table 2 summarizes the descriptive statistics of the different tree growth variables obtained and calculated for *Pinus caribbaea* plantation in Area J4, Omo Forest reserve. According to the result, diameter at breast height (dbh, cm) has a mean of 27.93±6.95 cm, with minimum and maximum values of 16.2 and 52.0 cm, respectively. For total height (H, m), the mean value is 28.72±3.47 m, with minimum and maximum heights of 10.6 and 33.2 m, respectively. The Basal Area (BA, m2) has a mean of 0.065±0.033 m2, with minimum and maximum values of 0.021 and 0.212, respectively. The mean volume is 0.832±0.571 m3, with minimum and maximum volumes of 0.088 and 3.284 m3, respectively.

The relationship between dbh and stem height (Figure 2) shows a positive linear relationship, typical of tropical plantation forests [3]. Additionally, all the selected trees in this study exhibit similar tapering from bottom to the top, confirming the biological validity of the data set as indicated by [3].

Table 2 Descriptive statistics for Growth Variable of *Pinus caribaea* plantation in Area J4, Omo Forest Reserve

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Growth variable** | **Mean** | **Min**  | **Max**  | **Standard deviation** |
| **Dbh (cm)** | 27.93 | 16.2 | 52.0 | 6.95 |
| **H (m)** | 28.72 | 10.6 | 33.2 | 3.47 |
| **BA (m2)** | 0.065 | 0.021 | 0.212 | 0.033 |
| **V (m3)** | 0.832 | 0.088 | 3.284 | 0.571 |

Dbh=diameter at breast height, H=total tree height, BA=basal area, V= volume

Figure 2 Relationship between Total Tree Height and Diameter at Breast Height for Pinus caribaea.

 The Table 3 summarizes the five volume models used for *Pinus caribbaea* plantation in the study area. According to the results, the Combined variable model has the best fit with the least values for two of the fitting indices *i.e.,* AIC (-54.73395), BIC (-45.48974) and RMSE (0.2016). The next best fit is the Generalized Combined Variable (GCV) with AIC (-54.09115), BIC (-38.68413) and RMSE (0.2008), followed by the Logarithmic Model with AIC (-48.07534), BIC (-38.83112) and RMSE (0.2058). The Constant Form Factor model has the least favourable fit with AIC (-47.70249), BIC (-41.53968) and RMSE (0.2067). The Combined Variable Model was chosen as the best fit and used to construct the volume table for *Pinus caribbaea.* All the models used in this study were based on two variables ( dbh and total height). As noted by [6], models based on two variables (dbh and total tree height) generally have the least standard error (10.3) and the highest Adjusted $R^{2}$ (0.982) making them the best choice. .

Table 3 Summary of Volume Models for Pinus caribaea in Area J4, Omo Forest Reserve.

|  |  |  |  |
| --- | --- | --- | --- |
| **S/N** | **Models**  | **Regression parameters**  | **Fit indices** |
| 1 | Combined variable | $b\_{0}$= -9.857e-02$b\_{1}$= 3.851e-05 | AIC= -54.73395BIC= -45.48974RMSE= 0.2016 |
| 2 | Constant form factor | $b\_{1}$= 3.540e-05 | AIC= -47.70249BIC=-41.53968RMSE= 0.2067 |
| 3 | Logarithmic | $b\_{0}$= -11.8963$b\_{1}$= 1.4826 | AIC= -48.07534BIC= -38.83112RMSE= 0.2058 |
| 4 | Generalized combined variable | $b\_{0}$= 3.352e-01$b\_{1}$= -4.859e-04$b\_{2}$= -1.547e-02$b\_{3}$=5.542e-05 | AIC= -54.09115BIC= -38.68413RMSE= 0.2008 |
| 5 | Generalized logarithmic | $b\_{0}$= 3.352e-01$b\_{1}$= -4.859e-04$b\_{2}$= -1.547e-02$b\_{3}$= 5.542e-05 | AIC= -54.09115BIC= -38.68413RMSE= 0.2008 |

AIC= Akaike information criterion, BIC= Bayesian information criterion, RMSE= Root Mean square error, $b\_{0}, b\_{1}, b\_{2}, b\_{3}$ are regression parameters

**3.1 Volume Table**

After fitting the selected volume models on the *Pinus caribbaea* data set and subjecting them to the required selection indices such as Akaike information criterion (AIC), Bayesian information criterion (BIC) and Root Mean square error (RMSE), the Combined variable model, with the least AIC (-54.73395), BIC (-45.48974) and RMSE (0.2016) was selected as the best fit and used to construct the volume table. The measured and estimated volumes were compared using correlation graph (Figure 3).

The models used in this study were similar to the models used by [18] to estimate the volume of *Tectona grandis* stands in Nnamdi Azikiwe University, Awka, Nigeria. The result from this study differs from those of [5] who used the Logarithmic volume model to develop the volume table for *Pinus caribaea* in Bulolo Wau forest plantations of Papua New Guinea. The Logarithmic model was found suitable based on the data and has an Adjusted $R^{2}$ of 0.957 indicating that the volume estimation of *Pinus caribaea*using the derived volume equation will be 95.70% accurate . The disagreement might result from differences in site quality, stand age or other factors . To confirm the validity of using these equations, residual analysis was conducted as pointed out by [19], revealing a strong positive correlation (Figure 3) between the volumes obtained from Newton’s equation and the selected volume model. The developed volume table is presented in Table 4 using the selected model:

 $V\_{i}=-9.857e-02+3.851e-05D\_{i}^{2}H\_{i}+ε\_{i}$

Figure 3 Correlation between Measured and Estimated volume for *P. caribaea*

Table 4. Volume table for Pinus caribaea based on Combined Variable Model (Estimated 1997)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Dbh(cm)** | **H(m)** | **V (**$m^{3})$ | **Dbh(cm)** | **H(m)** | **V (**$m^{3}$**)** | **Dbh(cm)** | **H(m)** | **V (**$m^{3}$**)** |
| 18.4 | 29.5 | 0.286049 | 27.4 | 17.3 | 0.401604 | 39.8 | 30 | 1.731471 |
| 33.2 | 28.2 | 1.098443 | 20.3 | 12.3 | 0.096626 | 41.1 | 31.6 | 1.957057 |
| 24.3 | 27.9 | 0.53587 | 32.8 | 30 | 1.144348 | 32 | 31.5 | 1.143609 |
| 39.1 | 30.1 | 1.673552 | 28.4 | 28.2 | 0.77734 | 40.7 | 29 | 1.751381 |
| 22.5 | 29.7 | 0.480452 | 40.8 | 32.1 | 1.95921 | 32.1 | 30.5 | 1.111703 |
| 27.9 | 26.1 | 0.683818 | 29.3 | 29.4 | 0.873407 | 23.1 | 25 | 0.415163 |
| 23.5 | 26.9 | 0.473516 | 23.3 | 28.3 | 0.493089 | 32.7 | 30.5 | 1.15737 |
| 27.6 | 31.1 | 0.81376 | 25.7 | 29.9 | 0.661951 | 16.7 | 22.4 | 0.142007 |
| 25.6 | 30.2 | 0.663615 | 26.2 | 28.7 | 0.660109 | 27 | 23.6 | 0.563971 |
| 22 | 17.2 | 0.222018 | 25.5 | 28.9 | 0.625119 | 30.6 | 28.2 | 0.9183 |
| 31 | 29.5 | 0.993169 | 29.4 | 27.4 | 0.81348 | 25.5 | 25.8 | 0.547491 |
| 29.4 | 27.3 | 0.810152 | 25.5 | 27.2 | 0.582549 | 17.1 | 10.6 | 0.020794 |
| 17.2 | 17.5 | 0.100804 | 42.1 | 30.1 | 1.955921 | 40 | 30.6 | 1.78688 |
| 25.7 | 30 | 0.664494 | 23.9 | 20.6 | 0.354574 | 38.5 | 30.9 | 1.665247 |
| 40.3 | 32.2 | 1.915337 | 24.5 | 26.6 | 0.516306 | 25.9 | 30.7 | 0.6945 |
| 40.7 | 32.3 | 1.961893 | 44.5 | 31.9 | 2.334106 | 39.4 | 30.9 | 1.748675 |
| 22.9 | 28.2S | 0.47093 | 26.3 | 27.1 | 0.623292 | 32.3 | 30.6 | 1.130849 |
| 22.5 | 17.4 | 0.240655 | 18.2 | 20.1 | 0.157827 | 28.9 | 30.2 | 0.872781 |
| 26.2 | 29.9 | 0.691831 | 22.5 | 30.7 | 0.499948 | 25 | 32.6 | 0.686071 |
| 40.5 | 33.1 | 1.992226 | 27.2 | 28.8 | 0.721978 | 52 | 30.1 | 3.035774 |
| 25.4 | 27.9 | 0.594609 | 31.7 | 30.2 | 1.070119 | 35 | 28.5 | 1.24591 |
| 25.4 | 28.9 | 0.619454 | 24.8 | 30.6 | 0.626197 | 22 | 17.7 | 0.231337 |
| 19.4 | 17.1 | 0.149271 | 18.9 | 32.1 | 0.343003 | 34.4 | 30.7 | 1.300466 |
| 19 | 16.8 | 0.134985 | 24 | 28.9 | 0.542483 | 22.9 | 27.8 | 0.462852 |
| 36.3 | 30.7 | 1.459278 | 24.9 | 28.6 | 0.5843 | 24.5 | 30.1 | 0.59721 |
| 29.1 | 30.6 | 0.899316 | 29 | 28.9 | 0.837412 | 42.3 | 30 | 1.968597 |
| 20.4 | 29.8 | 0.379014 | 33.8 | 25 | 1.001314 | 42.3 | 30 | 1.968597 |
| 30.6 | 28.9 | 0.943542 | 36 | 25 | 1.149154 | 21.6 | 26.9 | 0.384748 |
| 35.3 | 32 | 1.437012 | 21.3 | 26.3 | 0.360933 | 22.6 | 26.9 | 0.430536 |
| 27.4 | 31.4 | 0.80926 | 26.7 | 26.7 | 0.634436 | 29.6 | 28.5 | 0.863046 |
| 21.6 | 28.9 | 0.420683 | 26.4 | 28.6 | 0.669052 | 39.8 | 30.1 | 1.737572 |
| 26.4 | 30.7 | 0.725416 | 29.6 | 30.1 | 0.917032 | 28.3 | 29.9 | 0.823614 |
| 29.3 | 30.6 | 0.91308 | 42.6 | 31.6 | 2.10984 | 39.3 | 30.5 | 1.715518 |
| 26.4 | 29.5 | 0.693208 | 21 | 31.1 | 0.429599 | 34.7 | 26.9 | 1.14877 |
| 27.5 | 30.1 | 0.778038 | 38.8 | 32.2 | 1.768209 | 25.5 | 26.7 | 0.570028 |
| 23.9 | 30.3 | 0.567948 | 29.9 | 31.9 | 0.999694 | 23.2 | 26.7 | 0.454858 |
| 26.6 | 28.9 | 0.688901 | 29.3 | 29.9 | 0.889937 | 22.6 | 27.9 | 0.450205 |
| 22.6 | 28.9 | 0.469875 | 29.9 | 30 | 0.93428 | 26.1 | 28.1 | 0.638588 |
| 22.6 | 30.1 | 0.493478 | 31.7 | 30.6 | 1.085598 | 23.9 | 30 | 0.561349 |
| 23.2 | 30.3 | 0.529477 | 23.1 | 31 | 0.538459 | 31.5 | 30.1 | 1.051598 |
| 31.5 | 30.5 | 1.066882 | 22 | 30.7 | 0.473642 | 27.7 | 29.9 | 0.784925 |
| 22.3 | 28.6 | 0.449138 | 22 | 30.7 | 0.473642 | 26.4 | 30.1 | 0.709312 |
| 29 | 28.8 | 0.834173 | 24.7 | 28.6 | 0.573375 | 37.6 | 31 | 1.589191 |
| 21 | 25.8 | 0.339589 | 31.6 | 30.5 | 1.074294 | 31.2 | 31 | 1.063532 |
| 39.1 | 32 | 1.785413 | 32 | 30.2 | 1.092344 | 29.3 | 30.1 | 0.89655 |
| 18.1 | 20.9 | 0.16511 | 31.6 | 30.3 | 1.066603 | 17.2 | 29.8 | 0.240935 |
| 24.8 | 30.5 | 0.623828 | 29.8 | 30.6 | 0.947902 | 33.4 | 31.2 | 1.241789 |
| 30.2 | 30.8 | 0.983208 | 22.9 | 29.9 | 0.505261 | 39.5 | 31.6 | 1.800123 |
| 33.7 | 30.6 | 1.239734 | 28.6 | 29.6 | 0.833819 | 39.5 | 31.6 | 1.800123 |
| 21 | 28.9 | 0.392236 | 32.5 | 30 | 1.121716 | 24.5 | 30.6 | 0.608768 |

**4. CONCLUSION** This developed volume table is a valuable tool for estimating the quantity of wood or timber available in the *Pinus caribaea* plantation at any given time. This tool is not only essential for forest managers aiming to monetize their plantations but also for making informed decisions regarding forest management and planning. The volume model and the local volume table are specifically designed for application within the *Pinus caribaea* plantation in the study area, ensuring accuracy and relevance to the local condition.

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