Modeling of Aboveground Tree Stand-Level Biomass in Erukot Forest of Oban Division, Cross River National Park, Nigeria

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Abstract

This research estimated aboveground tree stand level Biomass in Erukot Forest of Oban Division, Cross River National. A total of 872 individual trees were identified and measured for diameter at breast height and total height (dbh ≥ 5cm). The 872 individual trees spread across 51 species belonging to 25 different tree families. Simple random sampling was used with sampling intensity of 0.3% to lay 15 nested plots (7m x 7m, 25m x 25m and 35m x 35m). Diameter at breast height, total height and specific density of each wood species were used to determine aboveground biomass for each tree. Conversion factors were applied to estimate stand level green and dry biomass, sequestered carbon and carbon dioxide (CO_2) emission in the study area. Simple linear regression models were fitted into the stand level growth data for the forest (basal area and volume). The mean diameter at breast height and mean total height were 38.5cm and 18.5m respectively. Mean basal area of 39.8 m^2 ha^{-1} was obtained with a mean volume of 177.3 m^3 ha^{-1}. Average green biomass, dry biomass, carbon stock and carbon-dioxide emission of 521.8113 ton ha^{-1}, 341.5880 ton ha^{-1}, 183.196 ton ha^{-1} and 694.2067 ton ha^{-1} respectively were obtained in the study area. Stand level biomass model developed for the forest showed that common logarithm of volume per hectare is significantly related to common logarithm of stand biomass (R^2 = 58%). The actual and predicted biomasses were not significantly different (Paired T-test at $p < 0.05$). The actual and predicted biomass values were not significantly different (Paired T-test at $p < 0.05$). Estimated bias of 0.10% for the stand biomass model means that the developed model can be used to predict the aboveground biomass of the study area without any adjustment. The research has provided easy to use regression model for determining aboveground biomass at stand level. This is very useful for carbon trade and assessment of carbon-dioxide emissions through deforestation in the study area. The model is also a tool for assessing the wood productivity of the study area and for better management of the park.

Keyword: Sequestered carbon, aboveground biomass, dry biomass, conversion factor and predicted biomass.

Introduction:

FAO (2005) has defined biomass as the organic material both above and below the ground, and both living and dead, e.g., trees, grasses, tree liters, roots etc. Aboveground biomass, belowground biomass, dead wood, liter, and soil organic matter are the main carbon pools in any forest ecosystem (FAO, 2003; IPCC, 2005; IPCC, 2006). Above-ground biomass (AGB) includes all living biomass above the soil, while below-ground biomass (BGB) includes all biomass of live roots excluding fine roots (<2mm diameter). Forest biomass is measured either in terms of fresh weight or dry weight. For the purpose of carbon estimation, dry weight is preferred as dry biomass roughly contains 50% carbon (Brown, 1997; IPCC, 2003). Majority of biomass assessment are done for aboveground of trees because these generally account for the greatest fraction of total living biomass in a forest and do not pose too many logistical problems in the field measurement (Brown, 1997).

Biomass assessment is important for national development planning as well as for scientific studies of ecosystem productivity, carbon budgets, etc. (Parresol 1999; Zheng *et al.,* 2004; Pandey *et al.,* 2010). Biomass analysis is an important element in the carbon cycle especially, carbon sequestration. Recently, biomass is increasingly used to help quantify pools and fluxes of greenhouse gases (GHG) from terrestrial biosphere associated with land use and land cover changes (Cairns *et al.,* 2003). The importance of terrestrial vegetation and soil as significant sinks of atmospheric CO_2 and its other derivatives is highlighted under Kyoto Protocol (Wani *et al*. 2010). Vegetation especially, forest ecosystems store carbon in the biomass through photosynthetic process, thereby sequestering carbon dioxide that would otherwise be present in the atmosphere. Undisturbed forest ecosystems are generally highly productive and accumulate more biomass and carbon per unit area compared to other land use systems like agriculture. A recent estimate indicates that tropical forests account for 247metric tons vegetation carbon, of which 193 billion tons is stored above ground (Saatchi *et al*. 2011).

For estimating tree biomass, the tree analysis is conducted by measuring weights of different components of tree and by taking biomass samples of the components (Repola, 2009). The general principle in biomass estimation is the relationship between fresh biomass of the tree components measured in the field, fresh biomass of the sample and oven-dried biomass of the sample. Because different parts of the tree have different density and moisture content, the tree is divided into the following compartments: the stem (trunk), the wood distinguished from the bark and saw logs to determine the wood density and moisture content in sections of different diameters; branches usually sampled by size classes; foliage, leaves and needles including buds, flowers and fruits; stump and lastly roots by diameter classes. Furthermore, explicit estimates of biomass and other forest structures are required to understand how forest will respond to climate change. Estimating aboveground biomass is therefore a critical step in quantifying and monitoring the change in tropical forests. At a time when the issue of reducing GHG emissions is seriously growing, the carbon sequestration potentials of the Erukot division is still unknown. Again, forest biomass assessment is important for national development planning as well as for scientific studies for ecosystem productivity, carbon budget (Hall *et al.,* 2006); therefore, this research was keyed to fit a linear regression model that can be used for the estimation aboveground tree biomass in the Erukot tropical high forest

Methodology

Study Area

The study was carried out in Oban East, Erukot forest of Oban Division of the Cross River National Park (CRNP). The Cross River National Park (CRNP) lies between latitudes 5^0 05'and 6^0 29'N and longitudes 8^0 15' and 9^0 30'E in Cross River State, Southeastern Nigeria. The Cross River National Park was created by a Federal decree in 1991, consolidating the existing Oban and Boshi-Okwangwo Forest Reserves which are some of the richest areas of tropical rainforest in West Africa. The annual rainfall ranges between 2000 m to 3000m; relative humidity in and around the park is well over 30%. The temperature rarely falls below 19°C with an annual mean of 27°C.The moist green vegetation cover makes the forest an excellent place to view birds and butterflies (Eniang, 2001).

Sampling Technique and Data Collection

At first, the geo-position of the forest was determined using GPS (Global Positioning System). Simple random sampling was used with sampling intensity of 0.3% to lay 15 nested plots (7mx7m, 25m x 25m and 35m x 35m). The estimate of mean and the variance of a population or subdivision within a stratum are independent of the number of sampling units that was used. Therefore, both parameters were estimated from relatively few sampling units measured in a pilot survey (Avery and Burhart, 2002). Ratio of confidence interval to the mean was used to determine sampling intensity:

$$n \quad = \quad \left(t\, X\, \frac{cv}{E}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .1$$

$$CV = \frac{s}{\bar{X}} \times \frac{100}{1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2$$

$$n = t^2 \times \frac{s^2}{E^2\,\bar{x}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

where n= number of sample plots required

CV = coefficient of variation, t= t-value (n-1) degree of freedom

E = allowable margin of error (ratio of confidence interval to the mean =10%)

S = standard deviation $\bar{X}$ = mean

Primarily, the land use of each intercession was identified. In the fixed lines, tree stems were counted, diameter tape and Sunto clinometer were used for diameter at breast height and height respectively, Diameter at breast height (1.3cm above ground) and height were measured for all trees of the plot while density of each of the tree measured was determined from the default values of the Pan tropical table (Chudoff, 1984) and wood density for tropical tree species (Gisel *et al*, 1992). The obtained values were used to estimate the biomass of each tree within the sample plots in the tropical high forest (Ajayi and Adie, 2018).

Large plot =35mx35m

Trees >50cm DBH

Intermediate plot =25mx25m

Trees =30cm-49cm DBH

Small plot=7mx7m

Trees- 10cm-29cm DBH

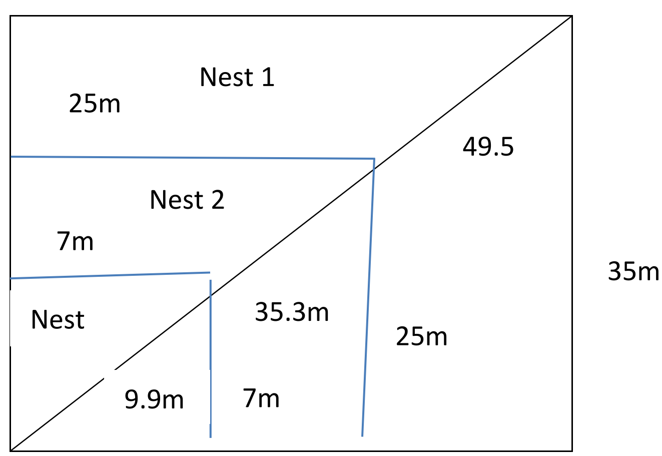

Figure 1: Schematic Diagram of Three-nest 35mx35m Square Sampling Plots

Data Analysis

Basal Area Estimation

The diameter at breast height was used to calculate the basal area.

Basal Area $(BA) = \frac{\pi D^2}{4}$……………………………………4

Where; D = diameter at breast height (cm) $\pi = 3.142$ BA = Basal Area.

Volume Estimation

Individual tree volume was estimated using the regression model below:

$LnV = -8.2525 + 2.209LnD$ (Ajayi and Obi, 2016)…………………..……5

Where, V= Tree volume (m^3)

D= Diameter at breast height (cm)

Ln = natural log

Aboveground Biomass Estimation for Single Live/Dead Tree

$$AGB = 0.0673 \times (P \times D^2 \times H) \times 0.976 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.6$$

where AGB= aboveground biomass (kg)

P = species specific wood density (g/cm^3),

D= diameter at breast height (cm), H= tree height (m)

Aboveground Live Green Biomass Estimation per Hectare

The summation of the biomass calculated for all trees in a sample produced the total plot biomass (AGBplot). This per plot estimate of aboveground (in kg) was divided by 1000 to express it in metric tons. This was then converted to per hectare estimate (AGBha) by using the equation

$$AGBper\ ha = \left(\frac{Ah}{Ap}\right) \times AGBplot \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..7$$

where: AGBha= aboveground biomass (metric tons per hectare)

Ah= area of one hectar in m^2

Ap= area of the plot (m^2)

Aboveground Dry Biomass Estimation

Aboveground dry biomass estimation was calculated from:

$$W = \frac{AGBh \times 0.725}{1000} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 8$$

where W= aboveground dry biomass (metric tones)

AGB_h = aboveground green biomass (kg ha^{-1})

However, average tree is 72.5% dry matter and 27.5% moisture (Chaven and Rasal., (2010) and 1000kg is equal to 1 metric ton).

Estimation of Carbon-dioxide equivalent from Carbon Stock

The content of carbon in woody biomass of any forest is generally 50% of the tree total volume. Hence, to compute the weight of carbon stock in a tree was obtained by multiplying the dry weight of the tree by 50% (Eneji *et al.,* 2014). Therefore the equation for the measurement of carbon sequestered per hectare is given as:

$$Sc = W \times 0.5 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. \ldots \ldots 9$$

where, Sc = sequestered carbon W = aboveground dry biomass (t^{-}ha)

Model Formulation

In this study, the simple regression models advanced for screening were of the form:

i. $Y = bo\ + b_1BA \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots.10$

ii. $Logy = bo\ + b_1logBA \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots.11$

iii. $Y = bo\ + b_1logV \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots.\ldots.12$

iv. $Logy = bo\ + b_1logV \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots 13$

v. $Y = bo\ + b_1logV^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots..14$

vi. $Logy = bo\ + b_1logBA \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots..\ldots..15$

vii. $Logy = bo\ + b_1BA \ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots.\ldots.\ldots.16$

viii. $Y = bo\ + b_1BA^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots.\ldots\ldots.\ldots.\ldots.17$

ix. $Logy = bo\ + b_1BA^{-1} \ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots.\ldots..\ldots.18$

where, y = Biomass (kg/Ha^{-1})

BA= Basal area per hectare (m^2/Ha)

V = volume per hectare (m^3/Ha)

Criteria for Model Selection

The selection of the best biomass models were based on:

i. Significant variance ratio (F) at 5% probability level
ii. A goodness of fit with highest coefficient of determination (R^2)
iii. Least Root Mean Square (RMSE)
iv. High Durbin Watson value.

Validation of Selected Models

Paired T-test and test of bias were carried out on the errors associated with the final prediction. Ten independent sample plots were used to validate the selected stand model.

Null (H0) = paired observations are not different

Alternative (H1) = paired observations are different

$$t = \frac{\overline{D}}{SD/\sqrt{n}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..19$$

where: T= t-statistics

$\overline{D}$= mean of the difference between pairs (ton)

SD= standard deviation of the difference between pairs (ton)

n= number of paired observation (degree of freedom is n-1)

$$Bias = \frac{\sum residual}{\sum Actual\ observation} \times \frac{100}{1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 20$$

Data generated were analyzed using SPSS version 20 on windows 10.

RESULTS

Results in table 1 below show that a total of 872 individual tree species spread across 51 species belonging to 25 different tree families were measured for DBH and height. The mean diameter at breast height and total height of 38.5cm and 12.5m were obtained. Mean basal area of 39.8 m^2 ha^{-1} was obtained with a mean volume of 177.3 m^3 ha^{-1}. Average green biomass, dry biomass, carbon stock and carbon-dioxide emission of 521.8113 ton ha^{-1}, 341.5880 ton ha^{-1}, 183.196 ton ha^{-1} and 694.2067 ton ha^{-1} respectively were obtained in the study area.

Table 1: Parameters of Aboveground Tree Biomass in Erukot Forest of Oban Division, Cross River National Park, Cross River State, Nigeria

S/N	Parameters	Summary	Min.	Max.	Std. Error	Std. Deviation	Skewness	Kurtosis
1	No. of sample plots measured	15	-	-	-	-	-	-
2	No of trees measured	872	-	-	-	-	-	-
3	Average DBH (cm)	38.47	1.00	250.00	0.7883	23.277	4.475	30.33
4	Average height	12.52	0.40	105.20	0.2368	6.699	8.172	90.34
5	Mean basal area ha^{-1}	39.8000	22.95	49.20	1.916	7.42	-.789	.201
6	Mean volume ha^{-1}	77.2647	0.00	225.10	18.99	73.56	-2.203	3.720
7	Sampling intensity	0.3%	-	-	-	-	-	-

Average Green Biomass, Dry Biomass, Carbon Stock, Carbon Emission per Stand in Erukot Forest, Cross River National Park, Cross River State, Nigeria

The result in table 2, shows that the mean aboveground green biomass, dry biomass, carbon stock and carbon emission were 521.8113tons ha^{-1}, 341.58803ton ha^{-1}, 183.19673ton ha^{-1} and 694.20673ton ha^{-1}, respectively.

Table 2: Average Biomass, Carbon Stock, Carbon Emission in Erukot Forest, Cross River National Park, Cross River State, Nigeria

S/N	Parameter	Mean	Confidence Interval (95%)	Range
1	Green biomass (ton ha^{-1})	521.8113	436.9836±606.9391	332.31-759.83
2	Dry biomass (ton ha^{-1})	341.5880	261.2876±417.8884	250.28-545.99
3	Carbon stock (ton ha^{-1})	183.1967	151.6088±214.7846	120.47-275.44
4	Carbon-dioxide emission (ton ha^{-1})	694.2067	515.2468±801.0679	442.11-1010. 89

General Models Developed for Stand Biomass Estimation

The result in Table 3 below shows a linear regression analysis used in developing allometric models for estimating forest stand biomass in the study area using stand basal area per hectare, volume per hectare and their logarithmic transformations as predictor variables. The table also shows the regression constants and coefficients, R^2, Root Mean Square Error (RMSE) F-ratio and Durbin Watson for logarithmic, non-logarithmic and inverse of logarithm expressions of the dependable variables in the study area. Model 4 was judged and selected because it has the highest F-ratio value (20.431), lowest RMSE (0.26) and highest Durbin Watson value (2.428) with R^2 value of 58%. Ranked very closely was model 3 with R^2 value of 59% and F-ratio value of 18.299.

Table 5: General Models Developed for Stand Biomass Prediction in Erukot Forest, Cross River National Park, Cross River State, Nigeria

Mode	Dep. Vari.	Reg. Constant	Reg. Coefficient	R^2 %	F-ratio	RMSE	Durbin Watson	Remark

i.	Y	715.589	-4.869BA	6	0.766	154.48	2.17	unsuitable
Ii	Y	1085.715	354.255LogBA	4	0.59	119.37	2. 85	unsuitable
iii.	Y	-6859.931	3192.795LogV	59	18.299	102.45	2.362	Suitable
iv.	Logy	-3.804	2. 813LogV	58	20.431	0.26	2.428	Selected
v.	Y	-7030.342	-3265.030LogV^{-1}	54	17.411	103.93	2.406	Suitable
vi.	Logy	3.246	-0.344LogBA	56	0.756	0.134	2.179	Suitable
vii.	Logy	2. 884	-0.005BA	7	0.956	0.4123	2.160	unsuitable
viii.	Y	407.211	4381.266BA^{-1}	44	0.410	149.99	2.190	unsuitable
Xiv	Logy	2.586	4.349BA^{-1}	33	0.549	0.424	2.189	unsuitable

Logy -3.804 + 2. 813LogV

Validation of Stand Green Biomass Model in Erokut Forest, Cross River National Park, Cross River State, Nigeria

Result in Table 4 shows the residual analysis for ten sample plots independently sampled for stand model validation. Paired T-test was used to validate the model by comparing the actual green biomass (biomass obtained conversion factors) and predicted biomass (biomass obtained using the developed model) as presented in Table 5 above. The equation selected recorded non-significant difference (P>0.05) with the actual biomass computed from the field. Again, with an estimated bias of 0.10%, the selected model can be used to predict stand biomass in Erukot forest; the study area. However, logarithmic transformation is a necessary requirement for fitting an appropriate allometric equation in the study area.

Table 7: Validation of Stand Green Biomass Model

S/N	Volume (M^3ha^{-1})	Actual Biomass (ton ha^{-1})	Predicted Biomass (ton ha^{-1})	Residuals (ton ha^{-1})
1	179.27	576.4	342.86	233.54
2	191.92	420.43	415.353	5.077
3	185.04	312.86	374.816	-61.956
4	200.68	541.95	470.917	71.033
5	180.49	489.74	349.464	140.276
6	168.49	220.63	287.974	-67.344
7	194.86	233.96	433.501	-199.541
8	205.59	320.86	504.052	-183.192
9	193.47	542.91	424.858	118.052
10	170.29	281.51	296.712	-15.202
	Total	3941.25	3900.507	40.743

Logy -3.804 2. 813LogV

n=10

T-calculated = 0.092

T-tabulated = 1. 833

Residual mean=4.0743 ton ha^{-1}

Bias = 4.0743/3941.25 x100 therefore, Bias= 0.10%

Discussion

The Erukot Forest of the Cross River National Park shows high species abundance with a mean volume per hectare of $177.2647m^3h^{-1}$. This volume is slightly below that reported by Ajayi and Adie, (2018) ($212.588m^3h^{-1}$), which is greatly below the volume of $250m^3h^{a-1}$ recommended by Dianyuan Han (2012) for a normal tropical high forest. This therefore reflects high encroachment level in the park. Thus, efforts should be made to control and reduce encroachment level through good management approach such as integrated management system and anti-poaching patrol. Mean basal area was $38.8000m^{2/}h^{-1}$, this agrees with findings made by Ajayi, and Adie (2018) ($38.5\ m^2h^{-1}$) in Okpon Forest Reserve, Cross River State, while mean dbh and height were determined to be 38.47cm and 12.52m, respectively. The selected stand aboveground biomass model recorded a non-significant difference ($P>0.05$) with the actual biomass computed from the field, hence, the model is adequate for estimating stand aboveground biomass in the study area as stated by (Ajayi and Adie, (2018). By implication therefore, volume can be judged to be a good predictor variable for aboveground biomass estimation but in its logarithmic form. The percentage bias for the selected stand model of 0.10% ag-rees with the findings of Adekunle (2002) who reported that the percentage bias as low as 30% is an indication of good fit model. Bi *et al.*, 2004 and Zhao *et al.*,2015 also found that inclusion of tree height improved the accuracy of predicting the stem biomass but not the crown (needles and branches) biomass components. This type of model and the models requiring both diameter and height are undoubtedly more accurate and precise, and have larger scope than the models with diameter alone, as the former model would be a more generalized one.

Conclusion

Aboveground biomass assessment is critical to understanding the influential role of forest in global carbon stock cycle and climate change. Precise models, specific to local conditions and good quality ground data are accurate for aboveground biomass assessment. This study explored the feasibility of using models to estimate aboveground biomass in a tropical rainforest of Erukot, Oban Division of the Cross River National Park. The biomass regression stand model developed shows that the logarithmic volume per hectare is significantly related to the common logarithm of stand level green biomass with R^2 value of 58%. The developed stand model is given as:

$$\text{LogY} = -3.804 + 2.\ 813\text{LogV}$$

Where; y = Green biomass ($tonha^{-1}$)   V = volume (m^3h^{-1})

Estimated bias of 0.10% was observed which implies that the model derived can be used to predict stand level green biomass in the study area without any adjustment.

Recommendations

Based on the findings of this research, the following recommendations are therefore made:

1. Efforts should be geared towards reducing the high encroachment level in the park, and integrated sound management approach should be put in place to promote tree lateral growth and sustainability.

2. Permanent sample plots should be established in the study area to enhance and promote accurate data collection, and the development of models for informed management decisions.

3. The fitted models should be used by the Cross River National Park (CRNP) for effective monitoring and better management practices in Erukot tropical forest.

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