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MODELLING ABOVEGROUND FOREST BIOMASS OF OMO BIOSPHERE RESERVE USING DOMINANT TREE SPECIES

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Abstract

Forest ecosystems have been considered to be valuable environmental sustainability and climate change amelioration agent. Forest biomass assessment is vital to determine the carbon contents of trees. The objective of this study is to model species-specific tree biomass for dominant species in Omo Biosphere Reserve with the aim of establishing allometric equation for most abundant tree species. Ten (10) sample plots were randomly selected within the biosphere reserve for data collection. Trees =10 cm Diameter at Breast Height (Dbh) within the sample plots was identified and their Dbh measured. For biomass assessment two mean trees per species group were selected. Biomass models were developed for dominant/most abundant species. These important hardwood tree species include; *Celtis wightii*, *Diospyros iturensis* and *Strombosia postulata*. In the quest to predict above-ground tree biomass using both Dbh and/or tree total height, three forms of transformations were used for the variables for model construction to obtain the best fit model. Six models were selected preliminarily for each species based on higher adjusted coefficient of determination (AdjR^2) values for further analysis. Amongst the pre-selected models, the final selection was done using the Furnival index value and standard residual distribution. The result showed that two log-transformed models and one polynomial model gave the best fit for the study having the smallest Furnival index value, and better randomly distributed residuals:

Celtis wightii $LnB = 4.303 + 0.211D$

Diospyros iturensis $LnB = -1.933 + 2.493LnD$

Strombosia postulate $B = 918.980 - 96.274D + 2.948D^2$

Keywords: Forest, Model, Climate, Biomass, Carbon and species

Introduction

Forest ecosystems had a leading role in the global carbon budget because they dominate the dynamics of the terrestrial carbon cycle (Zhao and Zhou, 2005). Tan *et al.*, (2007) reported that forest biomass constitutes the largest terrestrial carbon sink and accounts for approximately 90% of all living terrestrial biomass. Also, according to Dixon *et al*., (1994) almost 60% of the global forest carbon pools reside in low latitude forests (between 0° and 25° latitudes). In accordance with this report, it is justified that tropical forests play a major role in the global carbon cycle.

Tropical rainforests of Nigeria are rich with indigenous hardwood tree species with high biomass/carbon accumulation and their capacity to trap carbon as well as mitigate the climate change effect. *Ebanaceae*, *Ulmaceae Olacaceae*, *Meliaceae* and *Moraceae* important families are dominated by tropical rainforest ecosystems of southwest Nigeria (Onyekwelu *et al.,* 2008; Adekunle *et al.*, 2010). These important hardwood tree species include; *Celtis wightii*, *Diospyros iturensis* and *Strombosia postulata* among other. *Celtis* species are generally medium-sized trees, reaching 10–25 m (33–82 ft) tall, rarely up to 40 m (130 ft) tall. The leaves are alternate, simple, 3–15 cm (1.2–5.9 in) long, ovate-acuminate, and evenly serrated margins. Diagnostically, *Celtis* belong to family of Umalceae. *Celtis wightii* is also referred to as *Celtis philippensis* in some literatures. While the genus *Diospyros*, on the other hand belongs to an extensive family of Ebenaceae consisting of 7 genera. There are over 400 species forming the genus *Diospyros* and substantial numbers of these species are of economically important (Yonemori *et al.,* 2000). Also, *Strombosia* is a genus that comprises of about 10 species, 7 out of which are found in tropical Africa (e.g. *Strombosia pustulata*) and the remaining 3 are found in tropical Asia (Breteler, 2007). It has been classified in the family *Olacaceae*.

Modelling the distributions of biomass/carbon for these species is a prerequisite in determining the biomass/carbon pool of tropical forests in the regional and global carbon cycle (Lu, 2006). According to Zhao and Zhou (2005) selection of appropriate biomass estimation method and use of reliable forest inventory data are two prime factors for this practice. The main objective of this study is to model species-specific tree biomass for dominant species in Omo Biosphere Reserve with the aim of establishing allometric equation for most abundant tree species.

Methodology

Study Area

This study was conducted in Omo Biosphere Reserve (OBR), which is locally called *Igbo-iyalode* by the rural dwellers in Omo forest reserve in Ogun state. Geographically, Omo Biosphere Reserve lies approximately between latitude 6° 55" 12.0' to 7 ° 10" 12.0' N and longitude 4 º 13" 12.0' to 4 º 24" 0.0' E within the high forest zone in southwest, Nigeria. OBR, with its core area and buffer zone of 460 ha and 14,200 ha respectively, was constituted a Strict Nature Reserve in 1949 and Biosphere Reserve in 1977 (Onyekwelu *et al*., 2008). The climate of the study area is humid tropical. The reserve exhibit two seasons: rainy and dry seasons as obtained in the rainforest ecological zone of Nigeria.

The wet (rainy) season starts from March and ends in November while dry season lasts from December to February. Annual rainfall ranges from 1700 to 2200 mm while annual temperature and average daily relative humidity are 26°C and 80%, respectively. Rainfall distribution is bi-modal with a marked decline in August and at the peaks in July and September. Average elevation is about 123 meter (Onyekwelu *et al*., 2008). Geologically, the reserve rest on crystalline rocks of the undifferentiated basement complex which in the southern parts is overlain by Eocene deposits of sand, clay and gravel as reported by Augustine, (1995). Thus, the soils are predominantly ferruginous tropical, typical of the variety found in intensively weathered areas of basement complex formations in the rainforest zone of south-western Nigeria (Nwachokor and Uzu, 2008). The soils are well drained, mature, red, stony and gravely in upper parts of the sequence (Onyekwelu *et al*., 2008).

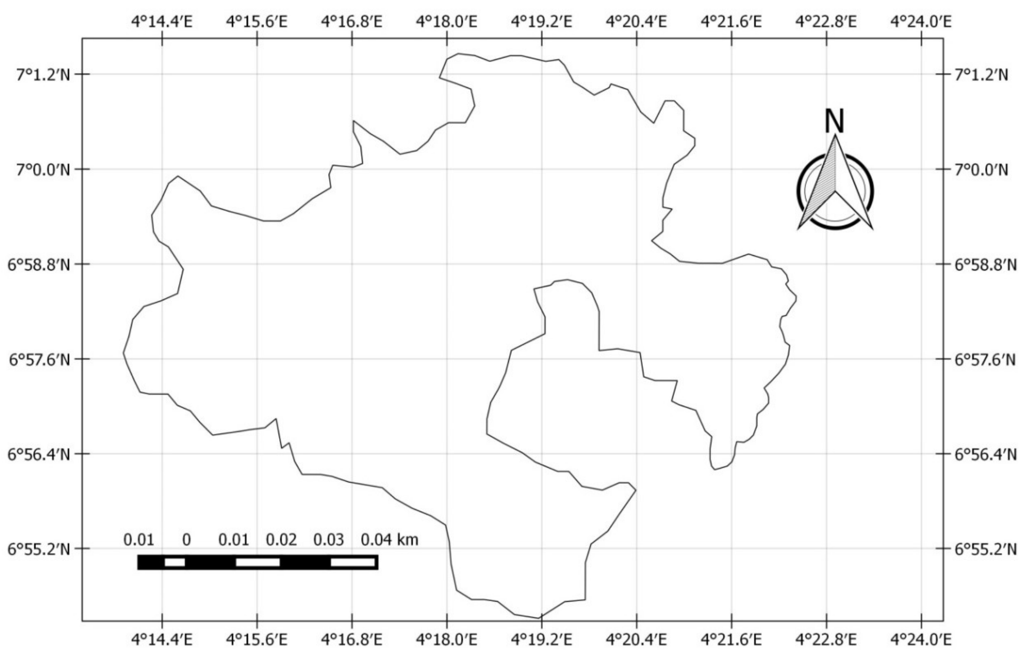

Fig. 1: Map showing the study area (Omo Biosphere Reserve)

Sampling Design

The map of the core area of Omo Biosphere Reserve (i.e. undisturbed natural forest) was gridded into plots of 30m by 30m as obtained in the Landsat image of the geographically referenced map of the study area. Ten (10) sample plots of 0.09 ha were randomly selected from the map and located on the field with the use of Global Positioning System (GPS) during the data collection stage of the research.

Data Collection and Measurements

All standing trees (10 cm Dbh minimum) within each sample plot were identified by forest taxonomist and their Dbh measured using a diameter tape. The trees in each sample plot were grouped into species groups. Afterwards two mean trees per species, whose Dbh were closest to the corresponding mean Dbh of the species group, were selected for biomass assessments. The total heights, diameters at the base, middle and top of all the mean trees were measured using Spiegel Relaskop and used for the volume estimation. Newton's formula (Equation 1) was used to estimate the standing volume of each mean tree as adopted by Subasinghe (1998)

$$V_{total} = \frac{\pi h}{24}\{D_b^2 + 4D_m^2 + D_t^2\} \quad \text{.......... Equation (1)}$$

Where:

V_{total} = Volume of the stem
h = Total Height
D_b = Diameter at the base
D_m = Diameter at the middle
D_t = Diameter at the top
$\prod$ = 3.142

Estimation of Above Ground Biomass

A non-destructive (indirect) sampling method was used in this study to estimate the above-ground tree biomass. The two mean trees per species group selected were used for biomass determination. A core sample of each of the two mean trees of each species group was extracted with an increment borer at the breast height point (i.e. 1.3 meter above the ground). The length of the stem core extracted using the increment borer was measured in centimetres. Core diameter was also measured for the selected sample trees and the average was taken since only one increment borer with one extraction tube was used for the entire study. The core samples were oven-dried at 75^0C to a constant weight and the mass measured for computation of Above-ground Biomass of each sample tree.

Estimation of Stem Core Volume

Shape of the stem core sample is cylindrical and therefore the equation (2) was employed to estimate the volume of each core sample.

$V_s = \frac{\pi d_s^2}{4} l$ ………………………………………………………….. Equation (2)

Where;
d_s = diameter of the core sample, (cm)
l = length of the core sample, (cm)
v_s = volume of the core sample, (m)

Conversion of Stem Volume and Core Volume to Above Ground Biomass

The stem core samples were oven-dried at 75^0C to a constant weight and the mass measured. Dry weight of the core sample was measured in grams using an electronic weighing balance. Stem biomass i.e., the dry weight of the stem was calculated by using the equation (3) below (Subasinghe and Harpriya, 2014). The stem biomass was estimated by converting the weight of the known volume of core samples through the stem volume.

$W_{total} = \frac{w_d \times V_{total}}{v_s}$ ………………………..…………………………………… Equation (3)

Where:
V_{total} = total stem volume (m^3)
w_d = oven dry weight of the core sample (kg)
W_{total} = total biomass of the stem, kg

Construction of relationships between biomass and other variables

Regression analysis was employed to develop the relationship between above-ground tree biomass and the selected explanatory variables, i.e., Dbh and its different form of transformations such as logarithmic, square and reciprocal. These data was used to obtain models with the minimal bias and the highest efficiency. Thereby all possible combinations of variables were tested to obtain the best model to predict the above-ground tree biomass. Coefficient of determination (R^2) was initially used to identify the possible candidate models. Apart from the accuracy of model fitting, the biological plausibility of the model was tested by employing the theory from Subasinghe, (1998). If the height of the tree moves to zero (h → 0), Dbh should be zero (Dbh = 0). In this case, biomass of the stem should also be zero (Biomass = 0). Therefore, the intercept of the selected model should be zero or at least it should not be significantly different from zero. The preliminary model selection was based on higher Adjusted R^2 values and insignificant intercepts. Then they were further tested using standard residual distribution. In order to correct the bias in biomass estimation due to the logarithmic transformation, a Correction Factor (CF) for each regression equation was computed using the procedure adopted by Onyekwelu (2004) equation (4).

$$CF = exp\left(\frac{RMSE^2}{2}\right) \quad \text{.......... Equation (4)}$$

Where: CF = correction factor and RMSE = Root Mean Square Error

Result

Tree Species Variable Means

Table 1 shows the total number of species encountered in all the plots with their frequencies of occurrence. The Table also shows the mean tree Dbh and height, as well as biomass and carbon of each tree species. A total number of 35 tree species was encountered in all the sample plots. *Diospyros iturensis* has the highest number of occurrence with 80 stems ha^{-1}, followed by *Strombosia pustulata* with 73 stems ha^{-1}. Some tree species were encountered only once in all the sample plots. Though *Ceiba pentandra* occurred only once, it had the highest mean Dbh and mean total height of 90.0 cm and 34.5 m, respectively. Also, *Musanga cecropioides* had the lowest mean Dbh and total tree height of 10.7 cm and 11.0 m, respectively, with also one frequency of occurrence. Also, *Diospyros iturensis* had the highest biomass and carbon of 305,560.56 kg ha^{-1} and 152,780.28 kg ha^{-1} respectively. While the lowest biomass and carbon of 335.22 kg ha^{-1} and 167.61 kg ha^{-1} was recorded from *Musanga cecropioides* respectively. Therefore, biomass model(s) are developed for the three species with highest number of occurrence i.e *Diospyros iturensis, Diospyros iturensis* and *Celtis wightii* see table 1 below.

Table 1: Summary of Tree Species Variables and their Growth Parameters

Species	No of Stems ha^{-1}	Mean Dbh (cm)	Mean Height (m^3)	Mean Biomass (10^3)	Biomass kg ha^{-1} (10^3)	Carbon kg ha^{-1} (10^3)
Musanga cecropioides	1	10.7	11.0	0.03	0.34	0.17
Dialium guineense	1	10.8	13.5	0.04	0.43	0.21
Cleistopholis patens	1	18.0	21.0	0.12	1.28	0.64
Lannea acida	1	16.0	18.2	0.14	1.50	0.75
Kigelia africana	1	14.4	16.5	0.20	2.17	1.08
Alstonia boonei	1	26.1	20.5	0.38	4.18	2.09
Treculia africana	1	40.0	24.2	0.43	4.79	2.40
Cola gigantea	3	18.1	18.4	0.48	5.38	2.69
Macaranga barteri	2	21.9	16.9	0.51	5.64	2.82

Uapaca staudtii	7	19.5	18.0	0.59	6.53	3.27
Nauclea diderrichii	1	38.3	19.9	0.60	6.63	3.32
Irvingia grandifolia	3	20.4	17.7	0.85	9.40	4.70
Pterygota macrocarpa	1	35.0	31.5	0.92	10.22	5.11
Parinari excelsa	6	21.4	20.6	1.62	18.05	9.03
Celtis integrifolia	29	14.8	16.1	1.75	19.44	9.72
Croton longiacemosus	3	50.4	23.8	1.85	20.54	10.27
Uapaca guineensis	10	20.2	15.9	1.90	21.13	10.57
Xylopia aethiopica	4	30.6	25.6	2.26	25.08	12.54
Mitragyna ciliata	2	33.5	22.7	2.33	25.86	12.93
Entandrophragma angolense	3	40.0	22.5	2.70	29.95	14.97
Milicia excelsa	2	43.2	32.0	2.90	32.25	16.13
Ceiba pentandra	1	90.0	34.5	3.76	41.79	20.89
Ficus exasperata	21	17.1	17.8	4.12	45.77	22.89
Diogoa zenkeri	10	23.3	24.2	4.15	46.13	23.06
Funtumia elastica	10	25.9	24.2	4.23	47.04	23.52
Piptadeniastrum africanum	13	24.3	20.8	4.38	48.71	24.36
Nesogordonia papaverifera	2	69.6	30.5	4.84	53.79	26.89
Celtis wightii	46	14.5	17.4	5.21	57.89	28.94
Khaya ivorensis	16	26.2	20.1	7.28	80.84	40.42
Cordia millenii	2	50.3	28.8	8.84	98.16	49.08
Sterculia rhinopetala	17	29.9	21.7	9.52	105.79	52.89
Pycnanthus angolensis	11	37.4	25.3	9.55	106.09	53.05
Terminalia superba	6	37.5	26.3	12.56	139.51	69.75
Strombosia pustulata	73	21.2	21.6	15.54	172.61	86.31
Diospyros iturensis	80	21.3	19.5	27.50	305.56	152.78
Total	**393**			**144.06**	**1600.46**	**800.23**
Mean				**4.12**	**45.73**	**22.86**

Construction of biomass prediction equations

Relationships between above-ground tree biomass and measurable tree growth variables were developed using regression analysis. As mentioned earlier, in addition to the untransformed variables, various transformations were tried on the data. The selected models are given in Table 2. For all the selected models, Dbh alone and/or in combination with its transformation fitted well to the biomass data (Table 2).

The initial observation was that all models listed on Table 2 meet the criteria for appropriateness selection, high Adjusted R^2, low furnival index, and significant regression.

Substantive numbers among the selected models exhibit logarithmically transformed variable(s). However, apart from model number 10, 12 and 28, which appeared to have normally and randomly distributed residuals, all other models fitted for this study have non-homogenous standard residual distributions. Models 10 and 12 had logarithmic transformed response variable i.e., biomass while model 18 was polynomial fitted. Based on the fact that the models (i.e. model 10, 12 and 18) met the criteria for appropriateness, with homogenous residual, it was selected as most appropriate for estimating the aboveground biomass of *Celtis wightii*, *Diospros iturensis and Strombosia postulata* in Omo Biosphere Reserve respectively.

Table 2: Species Specific Selected models for Omo Biosphere Reserve

(A) Biomass model fitted for *Celtis wightii*

Model No	Model	AdjR^2	RMSE	FI	CF
5	B= -162.532 + 18.651D	0.930	14.931	0.13917	0.000
6	B= -576.219 + 257.643LnD	0.901	17.732	0.16602	0.000
7	B= -45.216 + 1.809D + 0.582D^2	0.930	14.943	0.13915	0.000
8	B= -3.478 + 3.013LnD	0.897	0.212	0.00198	1.112
9	LnB= 7.473 + 41.175(1/D)	0.918	0.189	0.00176	1.099
10	LnB= 4.303 + 0.211D	0.859	0.248	0.00013	1.132
(B) Biomass model fitted for *Diospyros iturensis*					
11	LnB= -8.300 - 52.22(1/D)	0.926	0.258	0.00071	1.138
12	LnB= -1.933 + 2.493LnD	0.916	0.275	0.00075	1.147
13	LnB= 24.019 + 0.111D	0.890	0.315	0.00084	1.171
14	LnB= 3.179 + 0.111D	0.890	0.315	0.66157	1.171
15	LnB= 24.019 + 1.117D	0.890	0.315	0.71240	1.171
16	Ln(1/B)= 0.042 + 0.895D	0.890	0.315	0.29722	1.171
(C) Biomass model fitted for *Strombosa postulate*					
17	B= 250.455 - 1.536D^2 + 0.068D^3	0.923	47.727	0.17711	0.000
18	B= 918.980 - 96.274D + 2.948D^2	0.920	48.551	0.02199	0.000
19	LnB= 21.799 + 1.117D	0.861	0.218	0.44045	1.115
20	LnB= 0.321 + 2.276LnD	0.824	0.245	0.00095	1.130
21	LnB= 3.082 + 0.111D	0.861	0.218	0.00083	1.115
22	LnB= -3.082 + 1.111D	0.861	0.218	0.39566	1.115

B = dependent variable (Biomass); D = independent variable (Dbh); Ln = natural logarithm; FI = Furnival index; CF = correction factor.

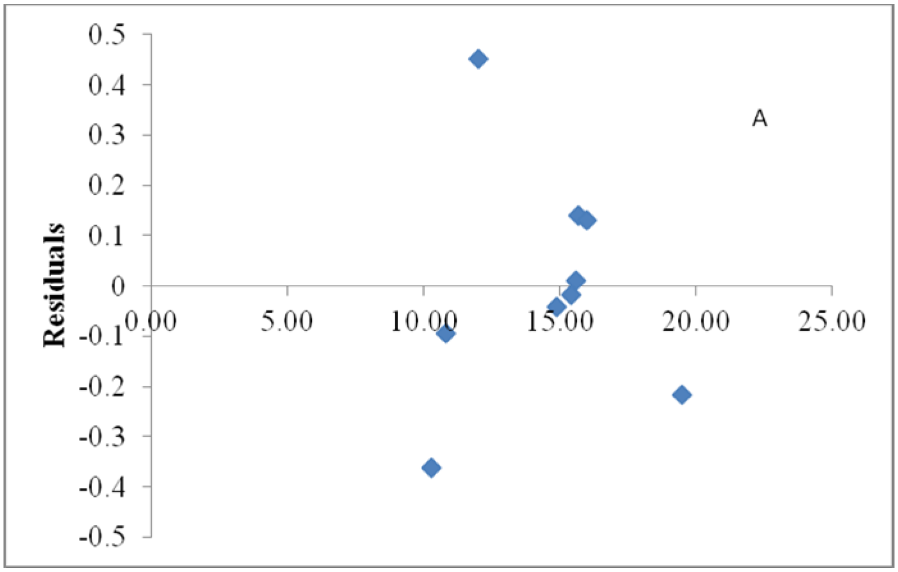

Fig. 1: Standard residuals for model 10 selected for *Celtis wightii*

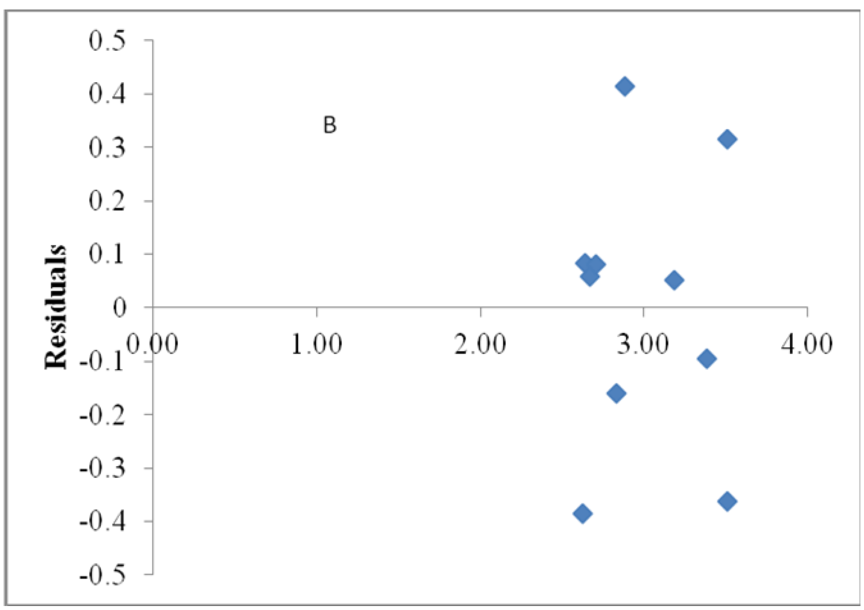

Fig. 2: Standard residuals for model 12 selected for *Diospyros iturensis*

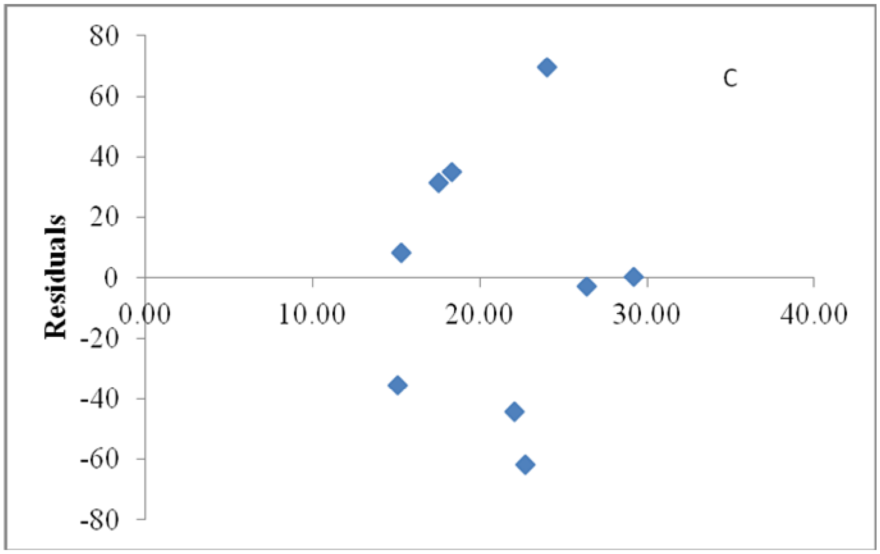

Fig. 3: Standard residuals for model 18 selected for *Strombosia postulata*

Discussions

Model Construction to Predict Stem Biomass from Other Variables

Forests play important functions in the carbon balance both source and sink. Therefore, sustainable forests management can contribute to global carbon cycle and climate change mitigation. According Brown *et al*., (1992), about 50% of the biomass of trees are carbon. The greatest potential for biomass/carbon storage in forest ecosystems is usually found within the tree above-ground biomass components (such as stem, branches, and foliage) (Subasinghe and Harpriya, 2014).

Most forest biomass studies conducted in the past used destructive method to estimate biomass and/or carbon values of different tree components (Williams and Gresham, 2006). Though, the use of destructive method of forest biomass was not possible for the present study because of the strict protection and conservation nature as biosphere reserve. Consequently, the use of a core sample analysis to estimate the biomass of the main stem in this study. The biomass allometry method involves relationships between tree above-ground biomass and tree measurable characteristics like stem diameter and/or height or their derivatives was also adopted as done by some researchers (e.g Onyekwelu, 2004; Spelcht and West, 2006).

The results from this study indicated that Dbh and its derivative can predict above-ground tree biomass effectively since all the selected models are significant with high adjusted R^2, and low Furnival index. However, some data transformations were used to correct the non-homogeneity of variance of the biomass and the growth characteristics data before undertaking the regression analyses which consisted with Subasinghe and Harpriya, 2014 report on prediction of stem biomass of *Pinus caribaea*. Although there was little improvement in the performance of the model by including height data in the model but the improvement was marginal and thus, did not result to a significant variation to explain the biomass. Nevertheless, Onyekwelu (2004), had argued that the inclusion of height data in biomass models is of little significances considering the fact that the inclusion of height did not significantly improve the performance of the model considering the enormous time normally invested in obtaining height data in the field, accompanied with the height measurement error(s). The advantage of biomass models with only Dbh and/or its derivative(s) as independent variable(s) is that they are simple, practical and easy to use as well as provide a more rapid and cost effective biomass estimates which have low-data requirement (Onyekwelu, 2004).

In this study, three different transformation forms were tried on the data and found acceptable, and thus incorporated in the biomass prediction models. These transformation forms are as follows; logarithmic, square and reciprocal. The models selected for this study met the criteria for appropriateness as good fit, significant, having low Furnival index and very high adjusted R^2. This is an indication that the independent variable (Dbh) account for a very high proportion of the variation in the dependent variable (biomass). All the models form has comparable high adjusted R^2 and low Furnival index but their residual distributions varied, which formed the basis for model selection. Using the selected models generated in this study will lead to good prediction of above-ground tree biomass of the *Celtis wightii*, *Diospyros iturensis* and *Strombosia postulata* in Omo Biosphere Reserve. Therefore, two logarithmic transformed models and one square transformed model which is also called polynomial model were selected as the best for these selected species (*Celtis wightii*, *Diospyros iturensis* and *Strombosia postulata*) respectively. This finding is consistent with many authors who reported logarithmic allometric models for tree biomass (e.g. Claesson *et al*., 2001; Onyekwelu, 2004). Also the polynomial biomass model is in agreement with (Mabowe, 2006) in the study of aboveground woody biomass assessment in Serowe woodlands, Botswana.

The advantage of these models is that it can be derived by means of linear regression and can be extrapolated more easily than linear or weighted regression models (Onyekwelu, 2004). Therefore, the use of these models demands that before the data are transformed back to original units, the estimate be corrected for bias by a Correction Factor (CF) (Onyekwelu, 2004). Thus, to obtain an unbiased estimate of above-ground biomass of *Celtis wightii* and *Diospyros iturensis* trees species in Omo Biosphere Reserve, the predicted values should be multiplied by the CF value). This correction is necessary because regression fitting using logarithm estimates geometric mean rather than arithmetic mean as reported by Onyekwelu, (2004). But the model for *Strombosia postulata* does not require a correction factor as it uses only square transformed variable.

Conclusions and Recommendations

The *Diospyros iturensis, Strombosia* and *Celtis wightii postulata* species' form the highest number of tree species encountered in the study area. These three species in Omo Biosphere Reserve have the highest number of individual trees with the population of 80, 73 and 46 stem per hectare with high biomass accumulation capacity. Therefore, any development or declined on these species will affect the density of tree in the biosphere reserve as well as the carbon content. Thus developing biomass equation for these species or any other development will have significant effect on the biosphere reserve.

Logarithmic transformed models were selected for both *Celtis wightii* and *Diospyros iturensis* with lowest Furnival index and highest adjusted coefficient of determination respectively, while a polynomial (square transformed) model was developed for *Strombosia postulata*. Therefore, with these models significant amount of biomass accumulation can be determined with easy.

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