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Allometric Model Development for Crude Oil Spilled Southern Nigerian Mangrove Vegetation

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***Abstract*— Estimation of the above ground biomass in the forest ecosystems by non-destructive means requires the development of allometric models, to allow prediction of above ground biomass from readily measurable variables such as Diameter at breast height, DBH and Height of tree. The equations developed consider the effect of spilled crude oil on the biomass components. In the present study, tree biomass components – branches, foliage and stems- measurements for 20 samples of Rhizophora were taken with the aim of developing appropriate allometric equations and thus characterized. The measurements were modified by a factor of 5. Twelve models of total and aboveground biomass were developed from destructive sampling data. The models, in some instances performed well, explaining R2 ≥ 50% of the variation in aboveground and total biomass. We developed twelve allometric models from the analysis. Some models were chosen that best fitted each tree species with high R2 ≥0.9.The total biomass estimated with DBH as the sole regressor was 1580.658kg. The total biomass estimated with H as the sole regressor was 1875.36kg. Foliage biomass as predicted by the height of tree showed a 43% increase as compared to the biomass as predicted by DBH. Branch biomass as predicted by the height of tree showed a 32% increase as compared to the branch biomass as predicted by DBH. For foliage and branch biomass, the Height of the tree seem to be a better predictor of biomass. On the contrary, the stem biomass as predicted by the DBH and Height of tree were equal.**

***Index Terms*—Biomass, Mangrove, Rhizophora.**

I. INTRODUCTION

With the advent of the industrial revolution, and the consequent ripple effects caused by man's advances in energy demand, exploitation, exploration, production and utilization; these activities have led to the production of greenhouse gases, consequently, to global warming and climate change.

The carbon-oxygen dynamics is created (figure 1) between forest soils and vegetation and every sources of carbon and its oxides. Interestingly, these forest soils and vegetation comprise an important part of regional and global carbon pools. Changes in the size of these pools due to forest succession, disturbance and management practices may result in significant change in the sinks for carbon or atmospheric levels of carbon dioxide. The advent of the United Nations Framework Convention on Climate Change (UNFCC) and its Kyoto Protocol has increased the need for accurate inventories of forest carbon storage and sequestration[1].

As is known, forest houses trees, which in turn house quite a huge volume of carbon. This carbon plays a significant role in the carbon-oxygen dynamics (figure 1.0).The forest, or rather the trees, specifically, absorbs carbon in form of CO2 and 'exhale' oxygen; while, man exhale CO2 and inhale O2.From the analysis of the carbon-oxygen dynamics, man is the O2 sink while trees are the carbon sink.

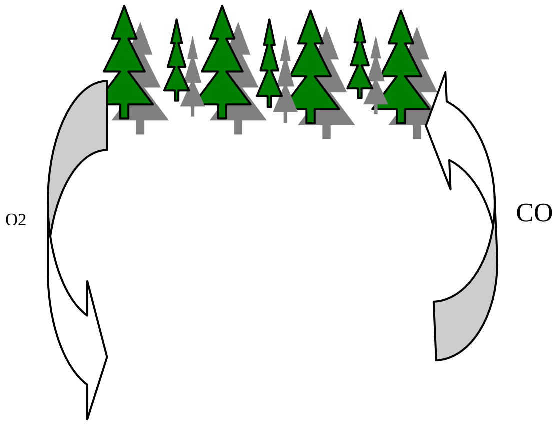

Figure 1: Schematics of the carbon-oxygen dynamics

To estimate the amount of this carbon stock in the forest, a study of biomass estimation is carried out. One of the very first studies was by [2]. As expected, numerous work have been done in this regards, which has led to interesting allometric models. As succinctly put by [3] : '…but its (allometric models) frequency of evaluation has increased recently due to its importance for evaluating energy usage, productivity and ecosystem services.' [4] developed allometric models for Southern Nigerian Mangrove vegetation; however, the stem biomass was not considered in the allometric model development, neither was that of spilled crude oil considered.

Importance of biomass estimation are, amongst others: 1. Compiling carbon inventories in forest.2. Studying biogeochemical cycles and understanding variations in structural and functional attribution of forest ecosystems across a wide range of environmental conditions and silvicultural practices. [5].

The objectives of the present study are to develop and evaluate allometric models for the prediction of above ground biomass of Rhizophora plant species in Uvwie forest, in Southern Nigerian Mangrove Vegetation. The present study also seeks to evaluate the diameter at breast height and height of tree as a predictor of tree biomass component. It also seeks to quantify the combustible fuels/ or biomass.

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II. MATERIALS AND METHODS

A. *Study Area*

The study area is located in Uvwie Local Government Area of Delta State. Coordinates 5.300N to 6.000E, Tidal height (1m to 4m), and the climate is of warm temperature in both arid and wet regions. The annual rainfall totals vary from 2400 to over 4000 mm. The forest is characterized by three species of Rhizophora's, which are Rhizophora Harrizona, Rhizophora Mangal and Rhizophora Racemosa.

B. *site description*

In the prepared fuel bed (25m X 25m), surface and crown fuel loadings were measured.[6] obtained weight of 20 samples of Rhizophora trees. The effect of the crude oil spill on the mangrove vegetation was studied, by including the contribution of the moisture content of the stem and, a factor of 5 g/g was used to account for/ approximation to the crude oil sorption capacity of mangrove fiibers [7].

C. *Methods*

A subset of an existing data set of harvested trees, originally analyzed in Nwigbo et al.[4], was used to develop allometric models for predicting Rhizophora foliage, wood, and total aboveground biomass from DBH and Tree height. Although, [4] developed allometric models for above ground biomass, yet these models only used diameter at breast height, but not height of tree as a predictor of tree biomass component.

And, again, the biomass contribution of the crude oil was not accounted for. The DBH range of trees comprising the data set was 4.8–8.4 cm . Details on harvest methods are available in [4].

The best fit was obtained from a power curve of

$$y = \alpha X^{\beta} \qquad 1a$$

And, subsequent transformation of equation

$$Iny = \beta InX + In\alpha \qquad 1b$$

III. RESULTS AND DISCUSSIONS

Scatter plots of data obtained from [4] were modified to account for the mass contribution of crude oil to the biomass. The allometric plots (figures 2 to figure12) shows the relationship between various biomass components and biomass components predictors-DBH and H.

$$F_B = 0.789DBH + 5.649 \qquad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$F_B = 2.392DBH^{-2.93746} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$F_B = 1.089H + 9.316 \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

($R^2 = 0.62$)

$$F_B = 3.34H^{-2.32} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

From the scatter plot of Foliage Biomass versus DBH (figure 2, as is for all plots), the plots show a clear linear relationship.

Though the linear relationship between equations 1 and 2 is mathematically equivalent, [7] admonishes that they are not identical in a statistical sense and that this log-transformed model introduces a systematic bias that is generally corrected using a correction factor estimated from the standard error; but it has become conventional practice in allometric model development.

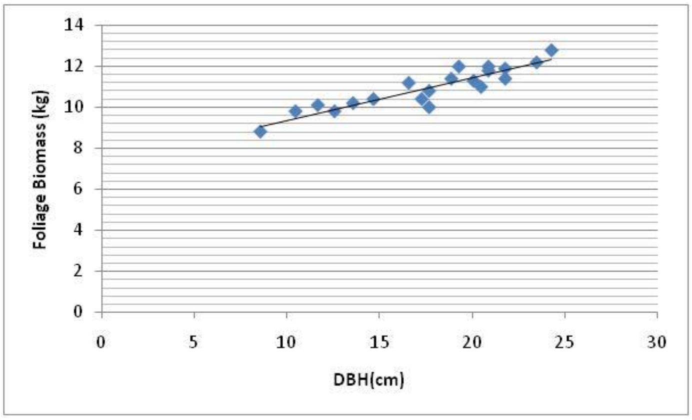

Figure 2: Relationship between foliage biomass versus DBH

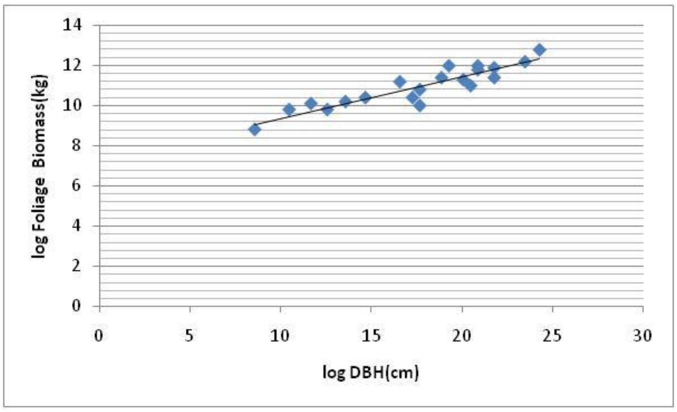

Figure 3: Relationship between logarithm-transformed Foliage Biomass versus DBH

The relationship between foliage biomass and height (figure 4), represented by allometric equation 3, has coefficient of determination R2 =0.532; while for the logarithm transformed allometric model, represented by equation 4, the coefficient of determination is R2=0.640.The logarithm transformed model had a percentage improvement of 20%.

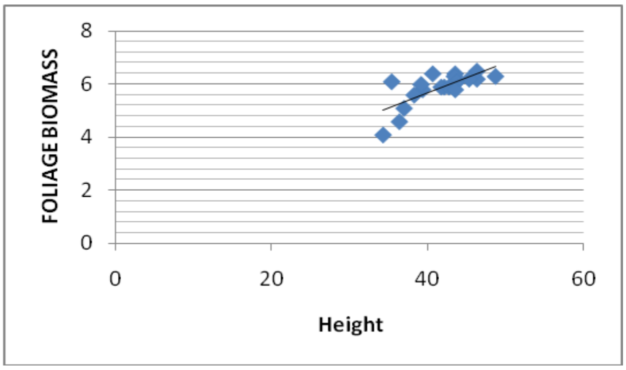

Figure 4: Relationship between foliage biomass versus Height

The relationship between branch Biomass and DBH (figure 5) shows a linear relationship with coefficient of determination R2=0.85; while the logarithm transformed biomass and DBH (figure 6) has R2=0.90.

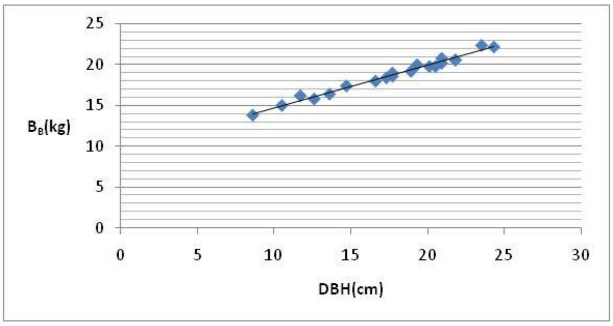

Figure 5: Relationship between logarithm-transformed Foliage Biomass versus Height

$BB = 2.951DBH + 11.66$ ………...5

$BB = 0.442DBH^{0.83768}$ …………6

$BB = 4.711H + 13.90$ …...............7

$BB = 0.615H^{0.8368}$ ……………8

For figure 6, represented by allometric equation 5, the coefficient of determination is R2 =0.9; while for the logarithm transformed allometric model, represented by equation 6, the coefficient of determination is R2=0.745.

For the relationship between Branch biomass versus height of tree (figure 7), the allometric equation (equation 7) has coefficient of determination of R2 = 0.532.For the allometric relationship between the logarithm-transformed biomass versus height of tree (figure 8), the allometric equation (equation 8) has a coefficient of determination of R2 = 0.540.

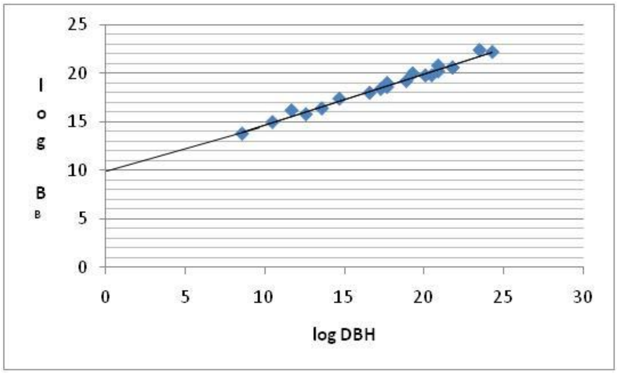

Figure 6: Relationship between Branch biomass versus DBH

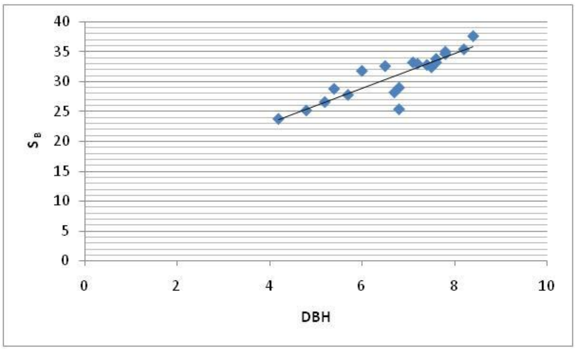

Figure 7: Relationship between logarithm-transformed models of Stem biomass versus DBH

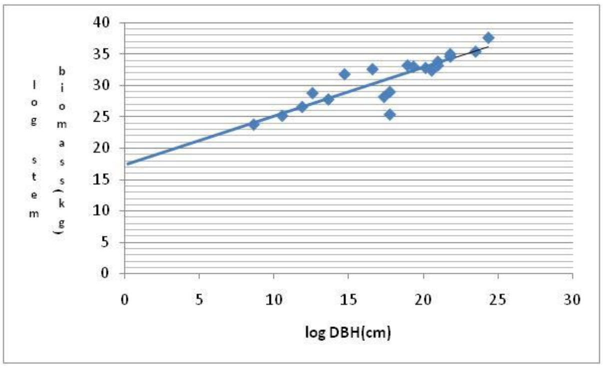

Figure 8: Relationship between log-stem biomass versus log DBH

$B_B = 4.711H + 13.90$ ……………..9

The coefficient of determination for the allometric model (equation 9) is R² = 0.532

$B_B = 0.615H^{2.637}$ ……………..10

The coefficient of determination of the allometric model (equation 10) is R² = 0.540

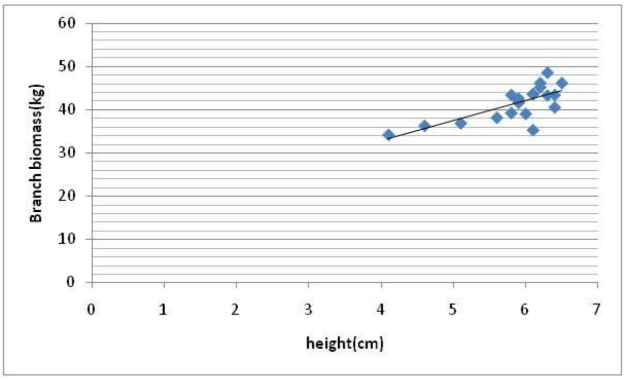

Figure 9: Relationship between Branch Biomass versus Height

Several linear models (figures 2 to 11) were fitted to logarithm transformed data because these functions tend to stabilize the variance and linearize the relationships. However, this did not completely remove the curvature underlying the model (figure 12).

With the logarithm transformation of equation 11 to equation 12, we have the best fit to data to be R2 = 0.9.

A. Stem biomass:

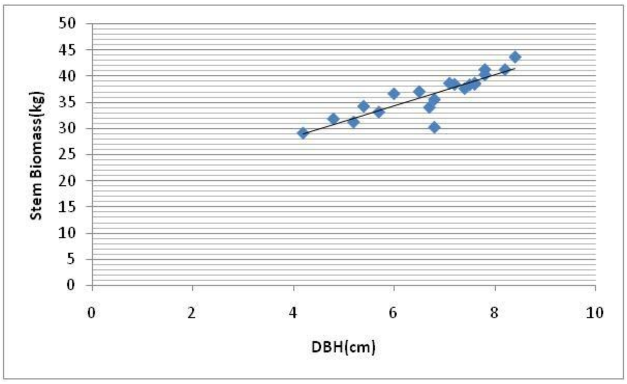

Figure 10: Relationship between Stem Biomass versus DBH

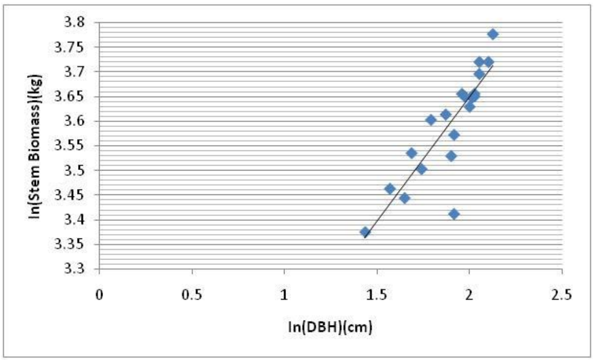

Figure 11: Relationship between logarithm-transformed models of Stem biomass versus DBH

The allometric models (equation 11 & 12) representing figures 11 and 12 have as coefficient of determination R² = 0.532 and R2=0.73, respectively. Taking the logarithm-transformed models of equations 11 there is a percentage increase of 37.2%.

$$S_B = 4.711H + 8.905 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 11$$

$$S_B = 0.703H^{2.351} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

Relationship between Stem Biomass versus DBH (Figure 3.8) represented by equation 13 has R2 = 0.762.

$$S_B = 2.951DBH + 16.66 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

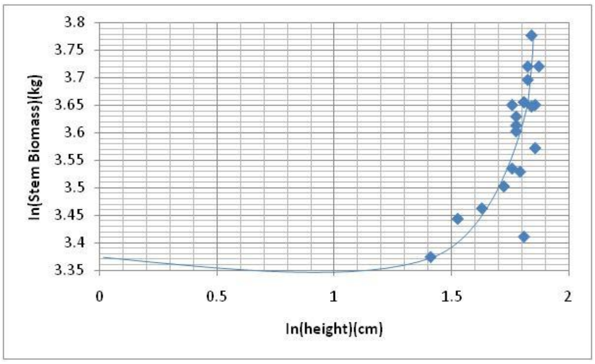

Figure 12: Relationship between logarithm-transformed models of Stem biomass versus Height

Considering field data as leaf length, fresh weight, dry, water content it was possible to develop predictive mathematical models . These models may contribute to better understand of Rhizophora species population dynamics showed possibly helps understanding different development stages.

With just the exception of figure 12, a linear function best fit the data for all regression analysis. These allometric equations are used to predict above ground biomass.

The total biomass estimated was 3456.018kg.Foliage biomass as predicted by the height of tree showed a 43% increase as compared to the biomass as predicted by DBH. Branch biomass as predicted by the height of tree showed a 32% increase as compared to the branch biomass as predicted by DBH. For foliage and branch biomass, the Height of the tree seems to be a better predictor of biomass. On the contrary, the stem biomass as predicted by the DBH and Height of tree were equal.

IV. CONCLUSION

From the various allometric equations developed, the spilled crude oil scarcely has effect on the relationship between various biomass components as against the Diameter at Breast Height, DBH and Height. The relationships between the various biomasses versus the DBH are linearly dependent on each other.

The total biomass estimated was 3456.018kg.Foliage biomass as predicted by the height of tree showed a 43% increase as compared to the biomass as predicted by DBH. Branch biomass as predicted by the height of tree showed a 32% increase as compared to the branch biomass as predicted by DBH. For foliage and branch biomass, the Height of the tree seems to be a better predictor of biomass. On the contrary, the stem biomass as predicted by the DBH and Height of tree were equal.

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Table 1.1: data and computation table

sample	height(ft)	DBH	$DBH^{1.5}$	Dry weight foliage (kg)	Dry weight foliage with crude oil(kg)	wet weight foliage(kg)	wet weight foliage with crude oil	µ	FB(DBH)	FB(H)	BB(DBH)	BB(H)	SB(DBH)	SB(H)	
1	5.8	5.4	12.6	4.8	9.8	8.6	13.6	0.720588	9.9096	15.6322	27.5954	41.2238	32.5954	36.2288	
2	6.1	7.1	18.9	6.4	11.4	10.3	15.3	0.745098	11.2509	15.9589	32.6121	42.6371	37.6121	37.6421	
3	5.6	5.7	13.6	5.2	10.2	10.1	15.1	0.675497	10.1463	15.4144	28.4807	40.2816	33.4807	35.2866	
4	6	6.7	17.3	5.4	10.4	9.8	14.8	0.702703	10.9353	15.85	31.4317	42.166	36.4317	37.171	
5	6.4	7.6	20.9	7	12	10.5	15.5	0.774194	11.6454	16.2856	34.0876	44.0504	39.0876	39.0554	
6	5.9	6.5	16.6	6.2	11.2	11.6	16.6	0.674699	10.7775	15.7411	30.8415	41.6949	35.8415	36.6999	
7	5.9	6	14.7	5.4	10.4	10.6	15.6	0.666667	10.383	15.7411	29.366	41.6949	34.366	36.6999	
8	6.3	7.5	20.5	6	11	10.9	15.9	0.691824	11.5665	16.1767	33.7925	43.5793	38.7925	38.5843	
9	6.4	6.8	17.7	5.8	10.8	10.7	15.7	0.687898	11.0142	16.2856	31.7268	44.0504	36.7268	39.0554	
10	6.2	7.8	21.8	6.9	11.9	12.2	17.2	0.69186	11.8032	16.0678	34.6778	43.1082	39.6778	38.1132	
11	5.1	4.8	10.5	4.8	9.8	9.8	14.8	0.662162	9.4362	14.8699	25.8248	37.9261	30.8248	32.9311	
12	6.1	7.6	20.9	6.8	11.8	10.2	15.2	0.776316	11.6454	15.9589	34.0876	42.6371	39.0876	37.6421	
13	5.9	7.4	20.1	6.3	11.3	10.8	15.8	0.71519	11.4876	15.7411	33.4974	41.6949	38.4974	36.6999	
14	4.6	5.2	11.7	5.1	10.1	10.7	15.7	0.643312	9.7518	14.3254	27.0052	35.5706	32.0052	30.5756	
15	5.8	7.2	19.3	7	12	12.2	17.2	0.697674	11.3298	15.6322	32.9072	41.2238	37.9072	36.2288	
16	6.5	8.2	23.5	7.2	12.2	12.7	17.7	0.689266	12.1188	16.3945	35.8582	44.5215	40.8582	39.5265	
17	4.1	4.2	8.6	3.8	8.8	8.2	13.2	0.666667	8.9628	13.7809	24.0542	33.2151	29.0542	28.2201	
18	6.1	6.8	17.7	5	10	9.6	14.6	0.684932	11.0142	15.9589	31.7268	42.6371	36.7268	37.6421	
19	6.3	8.4	24.3	7.8	12.8	12.9	17.9	0.715084	12.2766	16.1767	36.4484	43.5793	41.4484	38.5843	
20	6.2	7.8	21.8	6.4	11.4	11.7	16.7	0.682635	11.8032	16.0678	34.6778	43.1082	39.6778	38.1132	
sum	117.3	134.7	353	119.3	219.3	214.1	314.1	13.96426	219.2583	314.0597	630.6997	830.6003	730.6997	730.7003	3456.018
									0.432373		0.316951		8.21131E-07		

Nomenclature:
FB = Foliage Biomass
DBH = Diameter at Breast Height
R2 = Coefficient of Determination
BB= branch biomass
Height = height of Tree
SB= Stem biomass
µ = moisture content