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Development of Biomass Equations for Estimation of the Contribution of Five Dominant Shrub Species to Carbon Storage of Ngitilis in Pandagichiza Village, Shinyanga Rural District, Tanzania

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1. Abstract

This study was carried out to develop aboveground biomass estimation equations for five dominant shrub species of Combretum longispicatum, Anisotes dumosus, Abrus schimperi, Opilia amantacea, and Harrissonia abyssinica and estimating their contribution to the total carbon storage of four selected private ngitilis in Pandagichiza Village, Shinyanga Rural District. A destructive sampling approach was adopted whereby 40 individual shrubs for each species were harvested for the purpose of developing aboveground biomass models. Regression analysis was used to examine the relationships between the biomass and three field measurements of equivalent diameter at root collar (edrc), crown diameter (D) and top height (H) for both species-specific models and for a general shrubs biomass model. Results show that shrub aboveground biomass can be estimated using equivalent diameter at root collar (edrc) alone. The best fit models were found to have coefficient of determination (R2) of 0.90, 0.85, 0.92, 0.88, 0.94 and 0.84 for *C. longispicatum, O. amantacea, A. dumosus, A. schimperi, H. abyssinica* and general model respectively. The candidate models were validated using independent data and found to have acceptable bias of <10%, which is acceptable. They can therefore be used to estimate aboveground biomass of the studied shrubs in the studied area. On the other hand, this study observed that there is a significant contribution of shrub species to aboveground biomass ranging from 4 to 18%. It is therefore recommended to include the shrub species in biomass studies for the ngitilis. Further research however, needs to be conducted to develop more species-specific shrub biomass models in the ngitilis of Shinyanga Rural District as well as in other areas.

Keywords: *ngitili, shrubs, REDD+*

2. Introduction

The United Republic of Tanzania has 48.1 million hectares of forests covering approximately 55% of the total land area (FAO&UNEP, 2020). Forests play a crucial role in the global carbon budget, as they both emit greenhouse gases and act as carbon stores, pulling CO2 out of the atmosphere. In fact, they are explicitly mentioned in the Paris Agreement, under article 5. They are therefore critical to action against climate change. In its Nationally Determined Contribution (NDC) to address climate change, Tanzania has also recognized the importance of forests for both climate change adaptation and reaching its emissions reductions goal.

However, the rate of deforestation in Tanzania is estimated at 372,816 hectares per annum (MNRT, 2015). Moreover, tropical deforestation contributes to about 20% of the global greenhouse gases emissions (IPCC, 2000). This further indicates the importance of forests in climate change mitigation. It is from this perspective that negotiations towards a post-Kyoto agreement to include Reduced Emissions from Deforestation and forest Degradation (REDD) started in the context of the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 2008).

The Reduced Emissions from Deforestation and forest Degradation and the roles of conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks (REDD+) has created an incentive mechanism to those responsible for reducing deforestation and degradation in tropical countries. For example, the Green Climate Fund (GCF) has approved funding proposals to countries like Brazil, Chile, Colombia, Ecuador, Indonesia, Paraguay and Côte d'Ivoire (FAO**.** 2020). However, establishing a REDD+ mechanism generates the challenges related to information about changes in biomass and carbon stock of the forests at national and sub-national levels. This is particularly true for Tanzania because**;** the carbon benefits of any forest carbon project such as the REDD+ are estimated on the basis of changes of carbon stocks in different biomass pools (Zahabu, 2008, Angelsen et al., 2009). Such changes are determined through forest inventories combined with the use of models for biomass estimation i.e., allometric biomass equations which are currently missing especially for most of the [1]shrub species in Tanzania. This is because, many of the studies concerning forest biomass assessment that use allometric equations have focused solely on the estimation of tree biomass (Mugasha et al, 2012) as trees have definite stems which makes it easy to measure their diameter at breast height (DBH), a common parameter used in forest mensuration not available in shrub species. However, apart from trees, forest is also composed of understory vegetation such as grasses, saplings and shrubs. Beedlow et al., (2009) and Zeng et al., (2010) pointed out that although tree biomass is the principle sink of carbon sequestration in mature forests, shrub biomass is an important component of the total forest biomass, and that it is also necessary to account for shrub biomass as these woody plants play an active role in forest ecosystem productivity. Nonetheless, studies that have been conducted to estimate the biomass of shrubs in Tanzania are scarce while quantification of biomass for this kind of vegetation type is increasingly becoming of great importance especially in carbon markets such as the REDD+ program.

In light of the shortage of shrub biomass models in Tanzania, five shrub species-specific biomass models for *Combretum longispicatum, Anisotes dumosus, Abrus schimperi, Opilia amantacea,* and *Harrissonia abyssinica* and one generic shrub models were developed in this study. They were then used to estimate the contribution of shrub species to the total carbon storage of four selected private *ngitilis*[2] in Pandagichiza Village, Shinyanga Rural District. These *ngitilis* are either privately owned or owned by the whole village and they normally experience a long dry season annually. The district is dominated by several different shrub species present in these *ngitilis* whose dominating shrub species are important sinks for atmospheric carbon

[1] A shrub is a small- to medium-sized **perennial woody plant** with multiple **stems** usually less than 6 m tall.
[2] an indigenous language in the study area which means reserved forests

dioxide, yet they still lack their biomass estimation equations. The five selected shrub species are the most dominant among the existing shrub species in the studied area.

3. Methodology and data collection

3.1 Shrub biomass equation development

A total of 40 individuals of each of the five shrub species were harvested of which at least 10 were set aside for model validation. The use of at least 30 trees for the development of the tree biomass equation is recommended (McDicken, 1997). For each species, individuals were selected to cover the entire range of size variation within populations in such a way that an equal or near-equal number of trees in each of the four size classes was selected. Before each shrub was harvested, measurements for shrub crown diameters (i.e., the maximum crown diameter (D_1) and its perpendicular crown diameter (D_2) were taken and recorded. The crown mean diameter (D) was calculated as follows;

$$D = \frac{D1 + D2}{2}$$

Where;

D_1 is the maximum crown diameter (width) of the shrub, and

D_2 is the crown diameter perpendicular to D_1

Shrub height (H) which is the height from the ground to the tip of the longest stem was also measured using a measuring tape. Shrub stems' diameter (d) of each stem at the root collar region but just above any abnormal swell was measured using a caliper (Figure 1). Equivalent diameter at the root collar region (edrc) was then calculated from the measured individual stems of a shrub. The formula as recommended by

Chojnacky and Milton, (2008) was used as follows;

$$edrc = \sqrt{\sum_{i=1}^{n} drc_i^2}$$

Where; n is the number of stems measured for shrub stem diameter at root collar (drc) in individual shrub plant.

After measurements were taken, a shrub was cut down at ground level using a cross-cut saw. The harvested materials were then separated into individual biomass components (stems and leaves) then separately measured for total green weight in the field. Thereafter, sub-samples representing each biomass component were randomly selected and weighed fresh, and placed in labeled paper bags ready for laboratory analysis of biomass. The sub-samples were approximately 10% of each biomass component. In the laboratory, the sub-samples for each shrub were dried at 105°C to constant weight and weighed to the nearest gram. Biomass for each of the components was obtained as a product of dry to green weight ratios of the sub-samples times the total green weight of the shrub component that was measured in the field. The total above-ground biomass of a shrub was then obtained as a sum of its biomass components.

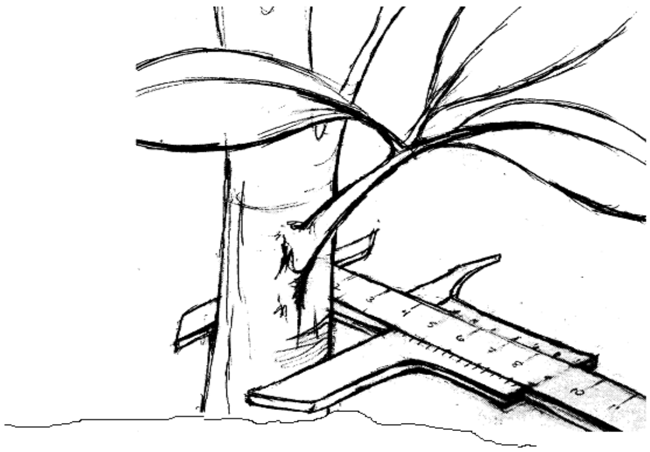

Figure 1: Shrub diameter measurement at root collar region **(**Source: (Chojnacky and Milton, 2008)

3.2 Biomass assessment for the selected *ngitilis*

The aim of assessing the biomass stock of the whole *ngitilis* was to gauge the contribution of shrub species to the carbon storage of the *ngitilis* could be compared. To achieve this, a forest inventory was carried out in four selected private *ngitilis* (i.e., *ngitili* I, *ngitili* II, *ngitili* III, and *ngitili* IV) in Pandagichiza Village. The forests were divided into ecotypes as different ecotypes may have different carbon stocks (Banskota et al., 2007). In each forest ecotype a pilot survey to estimate the variance in tree stocking was carried out. A total of 15 sample plots were randomly distributed all over each forest to estimate the needed number of sample plots (sample size). After obtaining the variance, the total number of plots (n) for each *ngitili* (Table 1) was calculated as follows:

$$n = CV^2t^2/E^2$$

Where;

n = Number of plots to be laid out in each forest

CV = The coefficient of variation is the measure of the variability of tree cross-sectional diameter at breast height (for trees, not the shrubs).

t = Expression of confidence (95%) that true average is within the estimated range. For the 15 plots, this is always 1.761

E = Allowable error

Concentric plots using the specified diameters of 2, 5,10 and 15meters radius representing size class 1,2,3 and 4 respectively (Figure 2) as used by Zahabu et al*.,* (2012) were adopted. Tree measurements for DBH in each of the concentric plots explained above included:

- ***Plots with a radius of 2* metres**

  All trees and shrubs with stems below 1 cm DBH were counted, trees and shrubs with stems equal to or above 1cm DBH were measured for DBH.

- ***Plots with a radius of 5 metres***

  Measure all trees equal to or above 5 cm DBH.

- ***Plots with a radius of 10 metres***

  Measure all trees equal to or above 10 cm DBH.

- ***Plots with a radius of 15 metres***

  Measure all trees equal to or above 20 cm DBH.

Moreover, root collar diameters were measured for the studied shrubs in each concentric plot to measure the biomass using the developed models. Plots were distributed systematically (with a random start) along the transects on a geo-referenced base map of the respective *ngitili*. Each plot was given an identification code and a description of the main characteristics and landmarks was also recorded Tree calipers and diameter tapes (for large trees) were both used to measure tree dbh while total tree heights of 3 sample trees (i.e. shortest, medium, and tallest) were measured using Suunto hypsometer. In each quadrat, samples of herbs and grasses, litter, and soil were collected. The only vegetation that originates within the quadrat, but includes branches that originate within the quadrat hangover to the outside. The vegetation was clipped down to ground level, placed in a sample weighing bag, weighed, and fresh weight record.

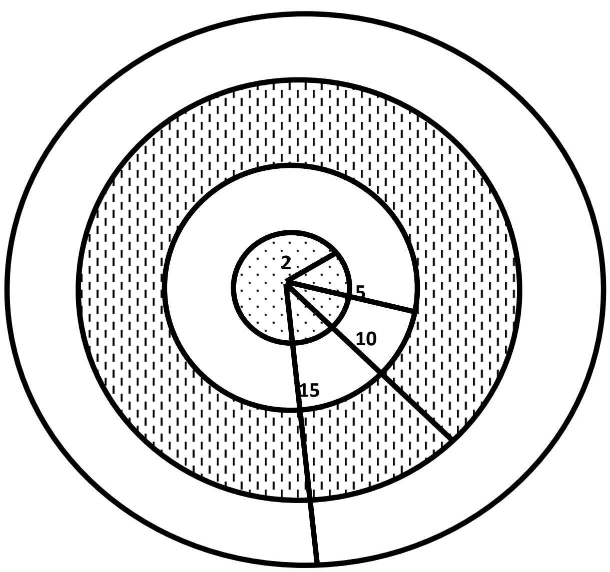

Figure 2: Layout of the plot using the specified diameters, 2, 5, 10, and 15 metres radius **(**Source: Zahabu et al., (2012)

Table 1: Distribution of sample plots in each of the studied *ngitilis* in Pandagichiza Village, Shinyanga Rural District.

Ngitili ID	Approx. area (ha)	Number of plots
ngitili I	86.0	25
ngitili II	30.4	15
ngitili III	11.3	13
ngitili IV	41.8	5

3.3 Data analysis

Different biomass models were fitted to the collected data. Regression analysis was used to analyze the relation between shrub aboveground biomass and the independent variables during biomass model construction. The criteria used to select the best candidate models for estimating shrub aboveground biomass were: high coefficient of determination (R^2), lower standard error of estimate (SE), and significance of the model based on the F-ratio. Model validation involved the detection of bias (%) in each model constructed whereby a model with a bias less than 10% in absolute term was regarded as unbiased. Bias (%) was estimated according to Malimbwi, (1997) as follows:

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$$Bias(\%) = \frac{\sum Bm - \sum Be}{Bm} * 100$$

Where;

Bm- measured biomass,

Be-estimated biomass using the best fit model.

Table 2 shows the general forms of the biomass equations that were tested in this study:

Table 2: Selected biomass model forms

Model	Expression
1	Biomass $= Ln(Y) = b_o + b_1 Ln(X)$
2	Biomass $= Ln(Y) = b_o + b_1 Ln(X_1) + b_2 Ln(X_2)$
3	Biomass $= Y = b_o + b_1 X^2$
4	Biomass $= Y = b_o + b_1 X_1^2 + b_2 X_2$

Where: Y stands for the dependent variable (biomass (tonnes/shrub); X stands for the independent variable (i.e., diameter at root collar (d) (cm), crown diameter (D) (m) and shrub total height (H) (m); b_0, b_1 and b_2 are regression coefficients

On the other hand, the following tree stand parameters i.e., the number of stems per ha (N), basal area per ha (Dominance) (G), volume per ha (V), and dry biomass/carbon (tones per ha) were calculated for the four selected *ngitilis*. Moreover, shrubs biomass for each *ngitili* was estimated using the models developed in this study.

Generally, the number of stems (N/ha) and basal area (G/ha) were computed using standard formulae while volume (V) for individual trees was computed using the equation V=0.5gH; where g is tree basal area in m^2 while a form factor of 0.5, was applied for each *ngitili.* Since height (H) was not measured for every individual, height-diameter equations in the form of Ln H = a+bLn (DBH) were developed to estimate height for the trees that were not measured for from the sample trees in each *ngitili*. The biomass of the trees was calculated by multiplying tree estimated volume by the basic density of 0.5 (Zahabu, 2008) while shrub biomass was calculated using the shrub models developed in this study.

4. Results and Discussion

This study had two objectives of developing aboveground biomass estimation equations for five dominant shrub species, and estimating their contribution to the total carbon storage of four selected private *ngitilis* in Pandagichiza Village, Shinyanga Rural District. The results obtained for each objective are presented and discussed in this chapter.

4.1 Shrub Biomass Model Development

This section presents the results for shrub aboveground biomass model development for each of the five studied species of *Combretum longispicatum, Opilia amantacea, Anisotes dumosus, Abrus schimperi,* and *Harrissonia abyssinica.* A general model for all the studied shrub species in Pandagichiza Village, Shinyanga Rural District was also developed.

The regression coefficients and other statistics of the fitted biomass equations using equivalent diameter at root collar (edrc) and crown diameter (D) for all the shrub species studied are shown in Table 3.

Table 3: Coefficient of allometric equations for estimating aboveground biomass using either edrc or D with H as independent variables for dominant shrubs of Shinyanga Rural District, Tanzania.

Species	Dependent variable	Equation	Regression coefficients b_o	b_1	b_2	R^2	Pr>F-ratio	SE	Remarks[1]
Combretumlongispicatum	edrc	1	-7.57421	1.415248		0.82	*	0.408492	Biased
		2	-7.573	1.419269	-0.01139	0.82	*	0.421832	Biased
		3	0.000868	0.000155		0.90	*	0.002648	**[2]Unbiased**
		4	0.000733	0.000155	5.4E-05	0.90	*	0.002729	[2]Unbiased
	D	1	-7.32688	1.935468		0.40	*	0.742759	Biased
		2	-7.48836	1.857895	0.369421	0.46	*	0.728972	Biased
		3	-0.00329	0.001197		0.62	*	0.005286	Unbiased
		4	-0.0041	0.001212	0.000272	0.63	*	0.005393	Unbiased
Opilia amantacea	edrc	1	-7.09674	1.657649		0.74	*	0.759191	Biased
		2	-7.31151	1.137956	1.256297	0.81	*	0.675529	[2]Unbiased
		3	0.003622	0.00023		0.85	*	0.004067	**[2]Unbiased**
		4	-0.0025	0.000201	0.003502	0.89	*	0.003522	[2]Unbiased
	D	1	-7.84963	2.401972		0.59	*	0.951127	Unbiased
		2	-7.52511	1.069011	1.731975	0.67	*	0.873953	Biased
		3	0.000103	0.000831		0.44	*	0.007879	Biased
		4	-0.00529	0.000537	0.004369	0.47	*	0.007883	Biased
Anisotes dumosus	edrc	1	-8.60418	1.866339		0.91	*	0.305059	[2]Unbiased
		2	-8.47897	1.696323	0.338226	0.91	*	0.31473	[2]Biased
		3	0.000173	0.000141		0.92	*	0.001835	**[2]Unbiased**
		4	-0.00228	0.000124	0.001881	0.93	*	0.001846	[2]Unbiased
	D	1	-6.96621	2.889407		0.75	*	0.507964	Biased
		2	-7.06013	1.621844	1.588735	0.82	*	0.449571	Biased

		3	-0.00275	0.002748		0.68	*	0.003663	Unbiased
		4	-0.00986	0.001442	0.006826	0.77	*	0.003262	Biased
	edrc	1	-7.47804	1.467592		0.72	*	0.519324	Unbiased
		2	-7.92879	1.565463	0.377588	0.78	*	0.474314	[2]Unbiased
Abrus		3	0.000379	0.000265		0.88	*	0.001095	**[2]Unbiased**
schimperi		4	0.000173	0.000269	4.61E-05	0.88	*	0.001107	Unbiased
	D	1	-7.06446	1.959429		0.76	*	0.479386	Biased
		2	-7.64204	2.172227	0.49421	0.86	*	0.380926	Biased
		3	-0.00021	0.000952		0.79	*	0.001461	Unbiased
		4	-0.00063	0.000987	8.33E-05	0.80	*	0.001462	Biased
	edrc	1	-8.64147	2.254968		0.94	*	0.339921	[2]Unbiased
		2	-8.6522	1.773605	0.863834	0.95	*	0.30838	[2]Unbiased
Harissonia		3	0.000886	0.000218		0.94	*	0.001601	**[2]Unbiased**
abyssinica		4	-0.00122	0.000194	0.001215	0.95	*	0.001518	[2]Unbiased
	D	1	-7.69	2.509056		0.73	*	0.717811	Biased
		2	-8.16114	1.010523	2.233794	0.85	*	0.555472	Unbiased
		3	-0.00203	0.001286		0.85	*	0.002489	Unbiased
		4	-0.00235	0.001254	0.000233	0.85	*	0.002568	Unbiased

[1]Remarks were based on residual and line of fit plots

[2]Indicates that the model was chosen for validation

[*]Indicates significance at P<0.05

The selected equation is bolded on the remark column

From Table 3, the models with the highest R^2 and lowest values of standard error for each shrub species were selected as the candidate models and therefore subjected to validation. During model validation, a model with a bias of <+10 % is considered worthy of adopting but above this value, the model becomes unsuitable for its application (Mugasha et al*.,* 2012).

For *C. longispicatum*, models 3 and 4 with edrc as an independent variable was selected as candidate models and therefore validated. Plots of predicted versus measured aboveground biomass by using the candidate models for *C. longispicatum* were therefore made (Figure 3). From the plots, both model 3 and 4 showed similar scatter trends. However, model 3 was selected as the best model because it utilizes a single independent variable (i.e., edrc alone) as compared with model 4 which utilizes both edrc and H as independent variables. Moreover, the bias for model 3 was 8.4% while that of model 4 was 9.5%. From these bias percent figures, model 3 is still in favor of adoption because it has a smaller value of bias than model 4. Model 3 with edrc as the independent variable can therefore be used to predict aboveground biomass for *C. longispicatum* in the *ngitilis* of Shinyanga Rural District. Below is the selected model that can be used to estimate aboveground biomass for *C. longispicatum* in the *ngitilis* of Shinyanga Rural District.

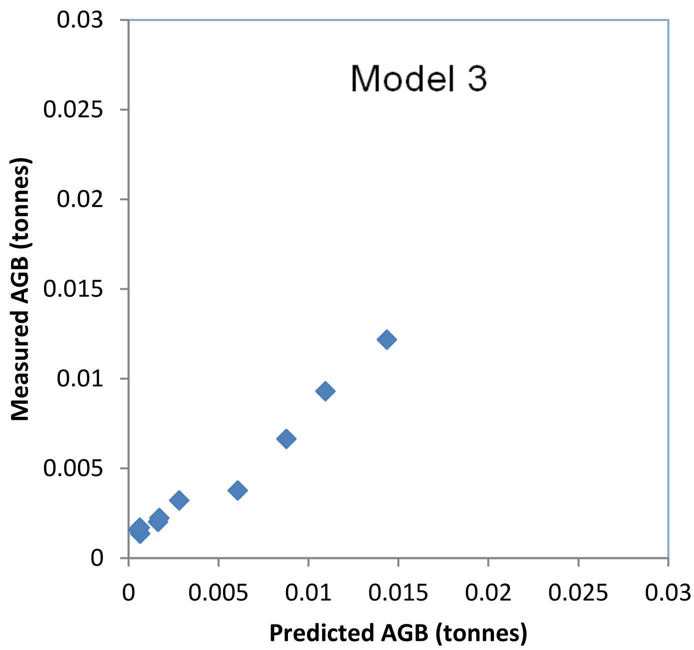
$$B = 0.000868 + 0.000155(\text{edrc})^2 \quad \ldots\ldots (1)$$

Where;

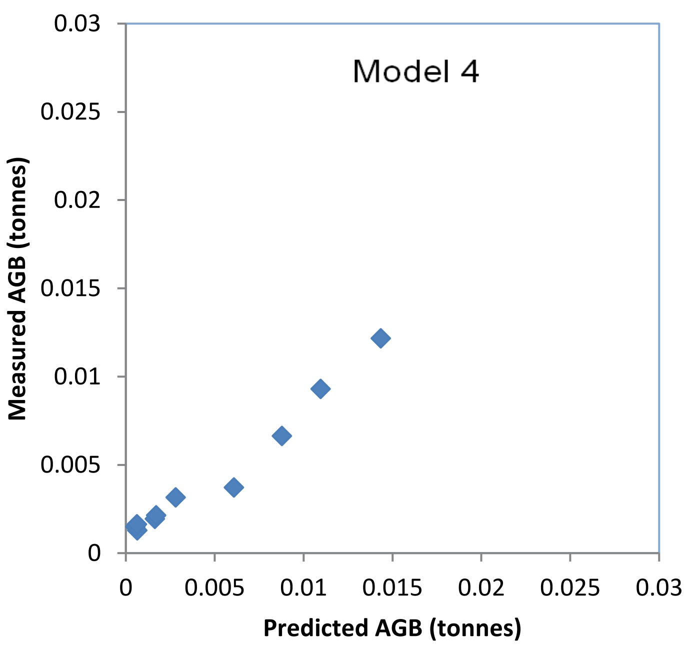
B stands for biomass (tonnes/shrub), and

edrc stands for equivalent diameter at root collar (cm).

For *O. amantacea* shrub species, model 2, 3 and 4 which utilizes edrc as the independent variable was selected as candidate models and therefore validated using the candidate models. Plots of predicted versus measured aboveground biomass were made (Figure 4). From the resulting plots, all models showed less bias with models 2, 3, and 4 having a bias of 7.0%, 2.8%, and 10% respectively. Due to its smallest bias in predicting aboveground biomass in comparison with models 2 and 4, model 3 was selected as the best model. Moreover, model 3 had only one independent variable than models 2 and 4 which employ more than one independent variable to predict aboveground biomass.

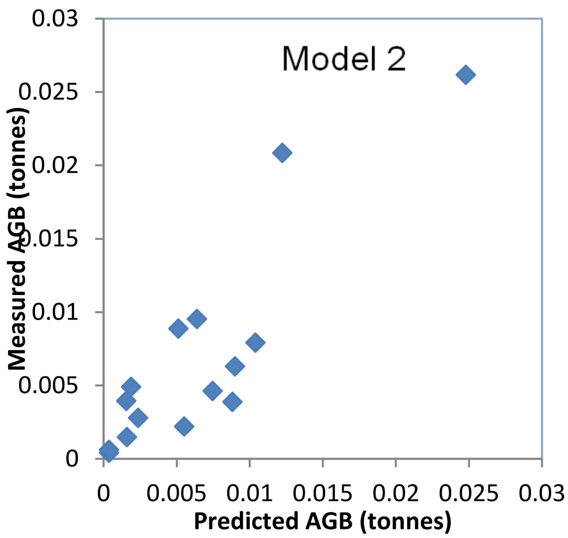


Bias 8.4%

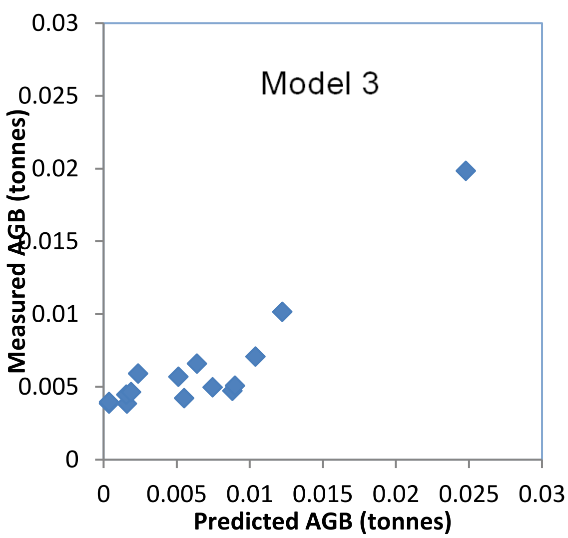


Bias 9.5%

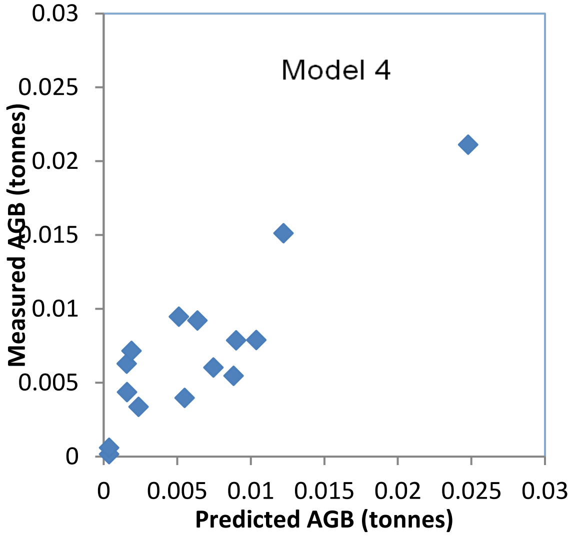
Figure 3: A plot of measured vs. predicted aboveground biomass using models 3 and 4 for *C. longispicatum* with edrc as the independent variable.



Bias 7.0%



Bias 2.8%



Bias 10%

Figure 4: A plot of measured vs predicted aboveground biomass using model 2, 3, and 4 *for O. amantacea* when edrc was used as the independent variable

Equation (2) indicates the selected model that can be used to estimate aboveground biomass for *O. Amantacea* in the *ngitilis* of Shinyanga Rural District.

$$B = 0.003622 + 0.00023(\mathrm{edrc})^2 \quad \ldots\ldots (2)$$

Where;

B stands for biomass (tonnes/shrub), and

edrc stands for equivalent diameter at root collar (cm).

For the case of *A. dumosus* shrub, models 1, 2, 3, and 4 with edrc as the independent variable were selected as the candidate models and therefore subjected to validation.

During models' validation, plots of predicted versus measured aboveground biomass for the candidate models were made (Figure 5). From the resulting plots, all models showed a similar scatter pattern. Model 1, 2, 3 and 4 scored a bias of 8.5%, 11.1%, 6.4% and 8.0% respectively. Due to its smallest bias in predicting aboveground biomass compared with models 1 and 4, model 3 was selected as the best model. Moreover, this model had the smallest standard error than the rest and had the advantage of using only one independent variable as compared to model 4 which employs more than one independent variable to predict aboveground biomass.

Equation (3) below indicates the selected model that can be used to estimate aboveground biomass for *A. dumosus* in the *ngitilis* of Shinyanga Rural District.

$$B = 0.000173 + 0.000141\,(\text{edrc})^2 \quad (3)$$

Where;

B stands for biomass (tonnes/shrub), and

edrc stands for equivalent diameter at root collar (cm).

Models 3 and 4 with edrc as the independent variable was selected as the candidate models for *A. schimperi*. During the validation, plots of predicted versus measured aboveground biomass using the candidate models were made (Figure 6). From the resulting plots, all models showed a similar scatter of residuals with a bias of 6.5% and 4.1% respectively for models 3 and 4. Since both models had the same value of R^2 again model 3 was selected as the best model because it has a lower value of standard error compared to model 4.

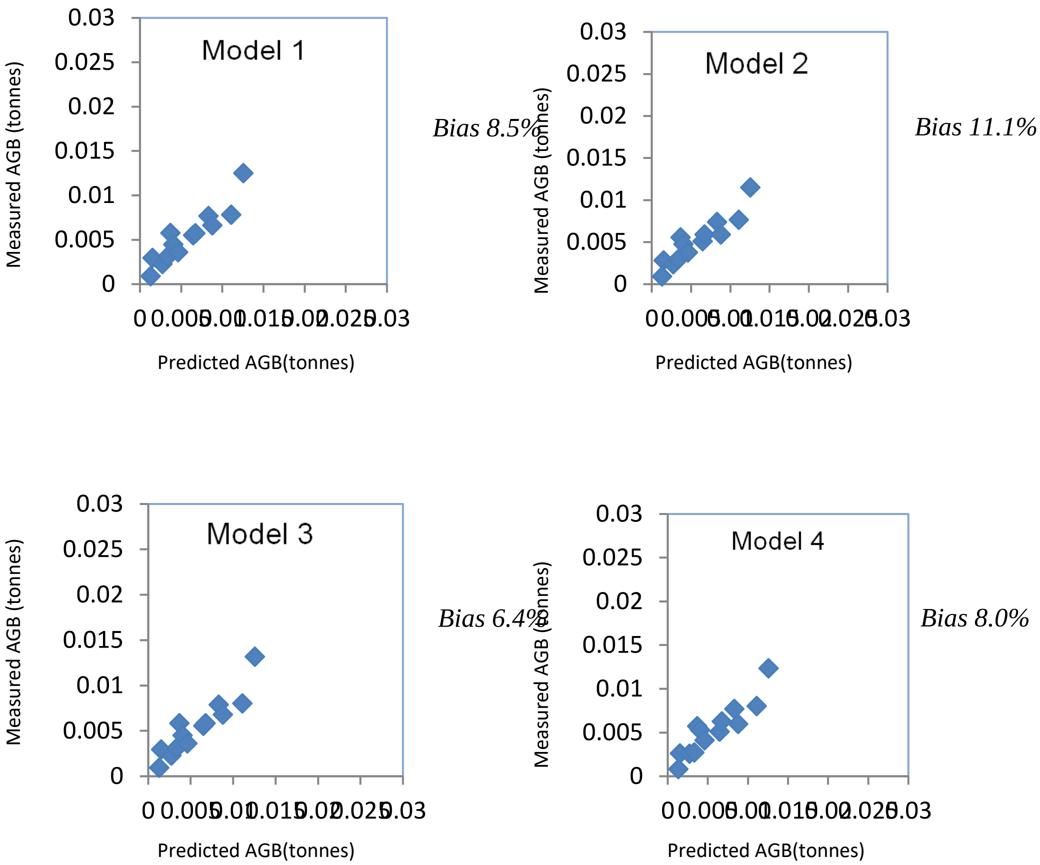
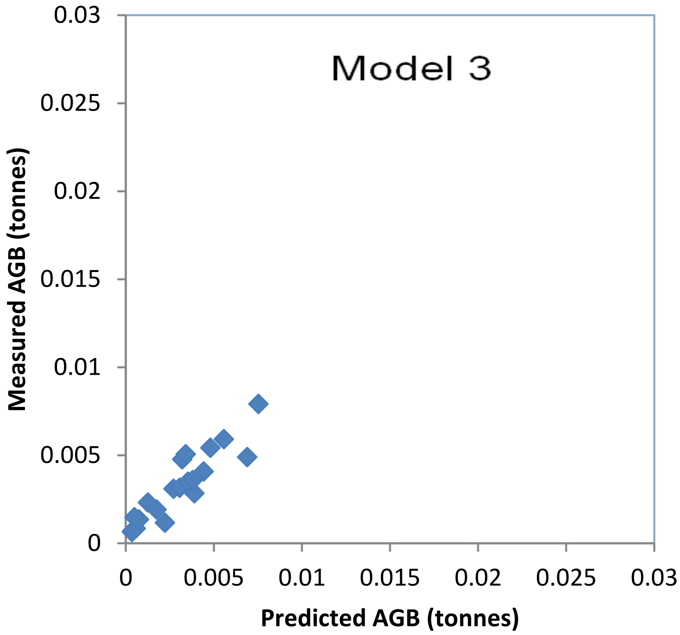
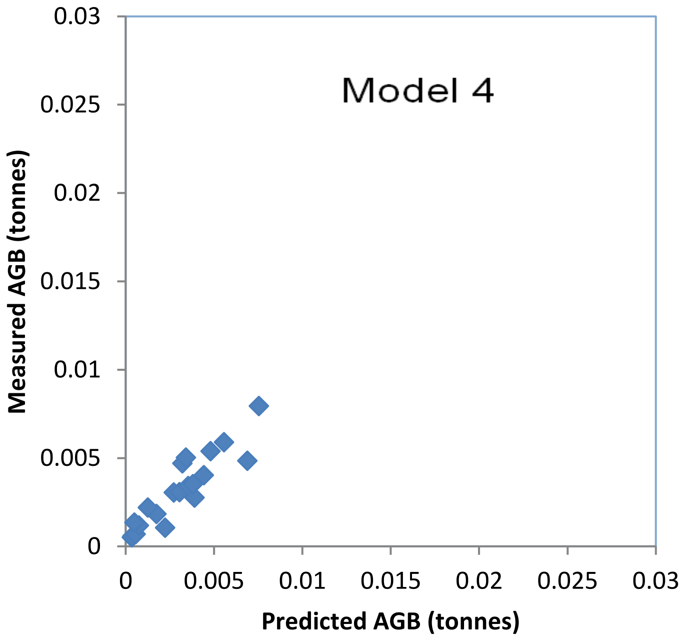


Figure 5: A plot of measured versus predicted biomass using models 1, 2,3, and 4 for *A. dumosus* using edrc and H as the independent variables.



Bias 6.5%



Bias 4.1

Figure 6: A plot of measured versus predicted biomass using models 3 and 4 for *A. schimperi* using edrc as the independent variables.

Equation (4) below indicates the selected model that can be used to estimate aboveground biomass for *A. schimperi* in the *ngitilis* of Shinyanga Rural District.

$B = 0.000379 + 0.000265(\text{edrc})^2$ …………………………………………………… (4)

Where;

B stands for biomass (tonnes/shrub), and

edrc stands for equivalent diameter at root collar (cm).

For *H. abyssinica* shrub, models 1, 2, 3, and 4 with edrc as the independent variable were selected as the candidate models and validated. The residual and line of fit plots for the tested equations are presented in Appendix 10 and 11.

Scatter plots of predicted versus measured aboveground biomass (Figure 7) by using the candidate models were made during the models' validation. All models showed less bias. The bias percent were 0.4%, 2.8%, 5.6% and 6.1% for model 1, 2, 3 and 4 respectively. However, models 1 and 2 had relatively higher values of standard error than models 3 and 4 and therefore were disqualified. Out of the remained candidate models, model 3 was selected as the best model due to its lower bias in predicting aboveground biomass than model 4.

Since model 3 was selected as the best model for the studied shrub species, it was considered wise to develop a general model for these shrub species taking into account this similarity. All data from the studied shrub species were therefore merged and similar procedures were used to develop and select the best model for each species followed. For this general model, the regression coefficients and other statistics of the fitted biomass equations using equivalent diameter at root collar (edrc) and crown diameter (D) are shown in Table 4. Models 3 and 4 with edrc as the independent variable was selected as the candidate models and therefore validated. Plots of predicted versus measured aboveground biomass using the candidate models were made (Figure 8). Model 3 had a bias of 7.4% while model 4 had a bias of 14.0%. Model 3 was selected as the best model due to lower bias as well as having an advantage of using only one independent variable (edrc) in predicting the aboveground biomass than model 4.

Equation (5) below indicates the selected model that can be used to estimate aboveground biomass for *H. Abyssinica* in the *ngitilis* of Shinyanga Rural District.

$$B = 0.000886 + 0.000218(\text{edrc})^2 \quad \ldots\ldots(5)$$

Where;

B stands for biomass (tonnes/shrub), and

edrc stands for equivalent diameter at root collar (cm).

Table 4: Coefficient of allometric equations for estimating aboveground biomass using either edrc or D with H as independent variables for the general shrub aboveground model of Shinyanga Rural District, Tanzania.

Species	Dependent variable	Equation	Regression coefficients b_o	b_1	b_2	R^2	Pr>F-ratio	SE	Remarks[1]
		1	-7.75972	1.648272		0.78	*	0.564512	Biased
	edrc	2	-7.94287	1.478611	0.651681	0.80	*	0.533115	Unbiased
General model		3	0.001867	0.000163		0.84	*	0.002638	[2]**Unbiased**
		4	-0.00123	0.000151	0.001729	0.86	*	0.002445	[2]Biased
	D	1	-7.25321	2.41223		0.74	*	0.610856	Unbiased

	2	-7.48073	2.147901	0.6574	0.76	*	0.582623	Unbiased
	3	-4.4E-05	0.001173		0.75	*	0.003267	Unbiased
	4	-0.00108	0.001127	0.000649	0.75	*	0.003269	Biased

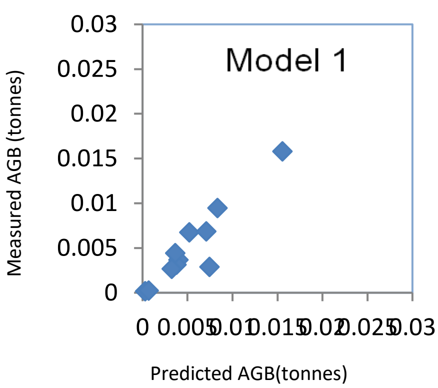
[1]***Remarks were based on residual and line of fit plots***

[2]***Indicates that the model was chosen for validation***

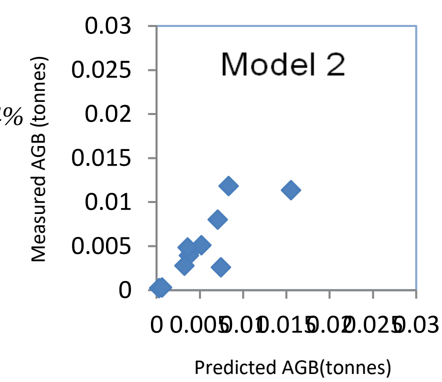
[*]***Indicates significance at P<0.05***

The selected equation is bolded on the remark's column

However, this general model has a low R^2 of 0.84 compared to the species-specific models. This indicates that the general model is less precise in estimating biomass. Where possible, therefore, the species-specific model should be used.



Bias 0.4%



Bias 2.8%

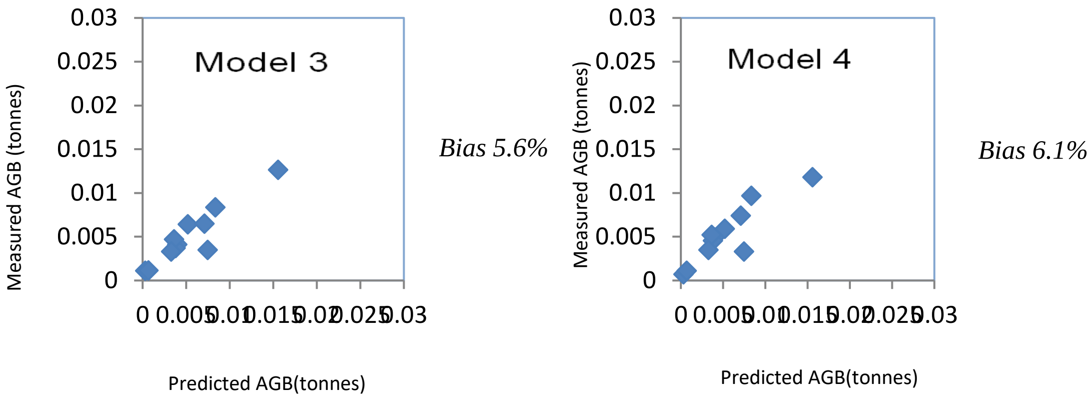
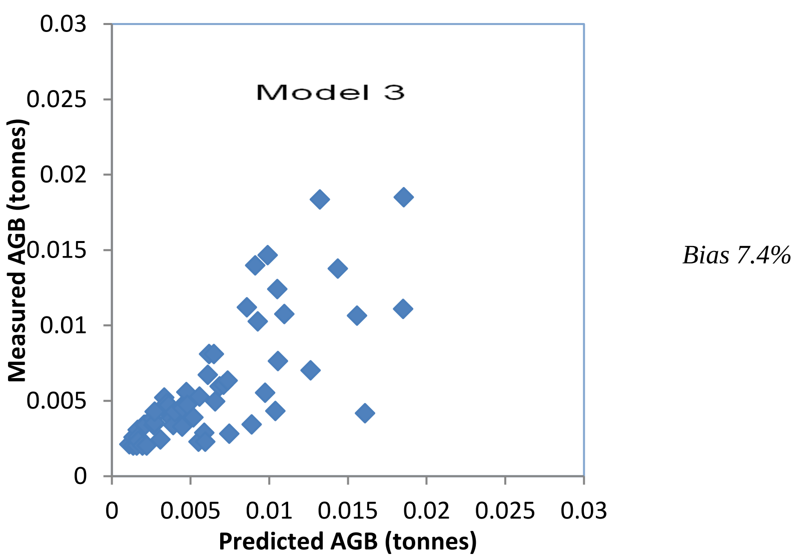
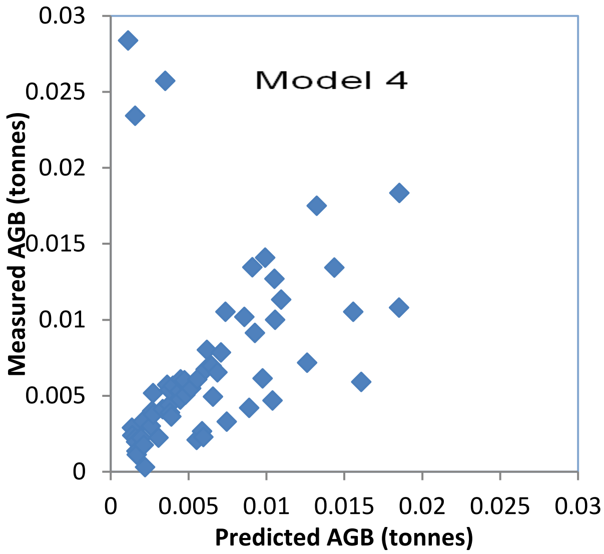


Figure 7: A plot of measured versus predicted aboveground biomass using model 1, 2, 3, and 4 for *H. abyssinica* using edrc as the independent variable





Bias 14%

Figure 8: A graph of measured versus predicted above-ground biomass for the general shrub model using model 3 and 4 with edrc and H as the independent variables

Equation (6) below indicates the selected general model that can be used to estimate aboveground biomass for the shrub species in the *ngitilis* of Shinyanga Rural District.

$$B = 0.001867 + 0.000163(edrc)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where;

B stands for biomass (tonnes/shrub), and edrc stands for equivalent diameter at root collar (cm).

4.2 Biomass stocking and the contribution of shrubs to total carbon storage of the ngitilis

In this section, the forest stand parameters i.e., the number of stems per ha (N), basal area per hectare (G), volume per ha (V), and aboveground biomass (t/ha) are presented for the four studied *ngitilis* (Table 5). The contribution of the shrub species to the total stand parameters was thereafter determined.

The number of stems per hectare varied considerably among the four studied *ngitilis* ranging from 682+695 stems/ha for *ngitili* II to 3571+1243_ stems/ha for *ngitili* I. However, these values are within the range reported by Monela et al., (2005) for the ngitilis in Shinyanga Rural District. On the other hand, the values for basal area and volume ranged from 0.87+0.55 m2/ha to 2.41+1.1 m2/ha and 1.53+2.073/ha to 5.11+2.27 m3/ha respectively. These volume/ha values of the ngitilis, however, are generally lower compared to other mature miombo forests with 36-79m3/ha (Malimbwi et al., 1994; Chamshama et al., (2004). The distribution of basal area and Volume per DBH classes is also presented (Figure 9). Irregular patterns of basal area and volume distribution are observed in all studied *ngitilis*. This is attributed to the intensive level of degradation in the *ngitilis* possibly due to overgrazing as well as harvesting for firewood and for construction of houses as well as shelters for the cattle which is a popular practice in the Shinyanga Rural District. Dependence on wood fuel as a major source of energy is believed to be a source for the intensive level of degradation in the *ngitilis* (Monela et al*.,* 2005). On the other hand, the characteristic reversed J-shaped trend of these forests seems to be changing. Increases in large-sized shrubs are an indication that the conservation ethic of *ngitilis* is gradually becoming effective. This seems to suggest that given time and sound management, the structure and possibly composition of *ngitilis* might change.

Table 5: Summary of the stocking parameters for each *ngitili* studied

Ngitili ID	Area (ha)	Stems /ha	Basal area/ha	Volume (m^3/ha)	AGB (t/ha)	Total trees AGB	AGB shrubs /ha	Total shrubs AGB[1]	Shrub's (%)

I	86.0	3571	2.11	3.49	1.75	150.19	0.06	5.58	4
II	30.4	682	0.87	1.67	0.83	25.33	0.13	4.01	16
III	11.3	1755	2.41	5.11	2.55	28.84	0.46	5.19	18
IV	41.8	2892	1.43	1.53	0.77	32.03	0.09	3.88	12

[1]*This is the biomass for the studied shrub species only*

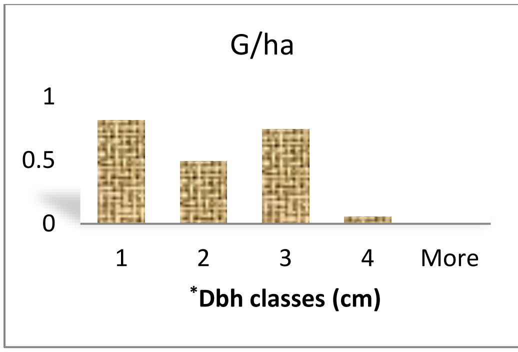
From Table 5 above, among the four studied *ngitilis*, *ngitili* I had the largest size of 86 ha. This *ngitili* had also the highest level of total aboveground biomass than the rest. Only *H. abyssinica* shrub was found in this *ngitili* and its contribution to the total aboveground biomass of the whole *ngitilis* was 4%.

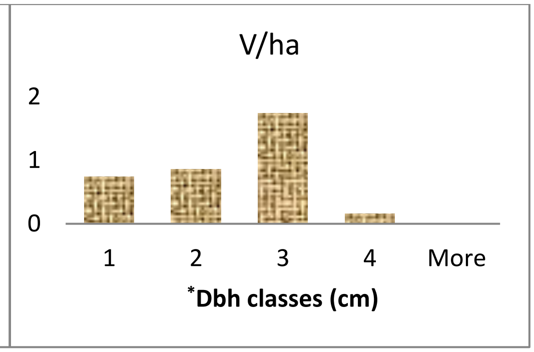
Ngitili II had an area of 30.4ha with the lowest value of stems per hectare and basal area. This suggests that this *ngitili* is the most degraded of all studied *ngitilis*. The contribution of shrub species to the carbon values of this *ngitili* was 16% and was contributed by *C. longispicatum* shrub species (Figure 10).

Ngitili III was the smallest in terms of area among the four studied *ngitilis* with an area of 11.3ha. This *ngitili* had relatively the highest value of aboveground biomass per ha. This suggests that this *ngitili* is the least degraded. The contribution of shrub species to the total biomass of this *ngitili* was 18%. This high value is contributed by the presence of both *A. schimperi* and *C. longispicatum* shrubs.

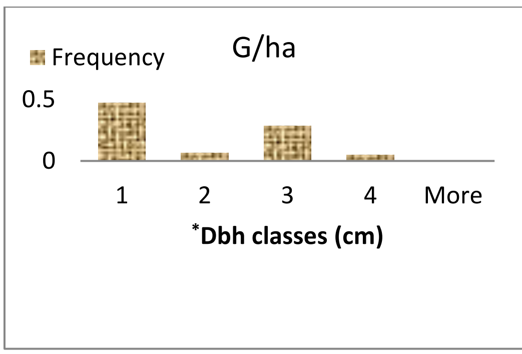
For the *ngitili* IV with 41.8ha, the percentage contribution of shrubs to the total aboveground biomass was 12% (Figure 11). This was contributed by *A. dumosus* shrub species only.

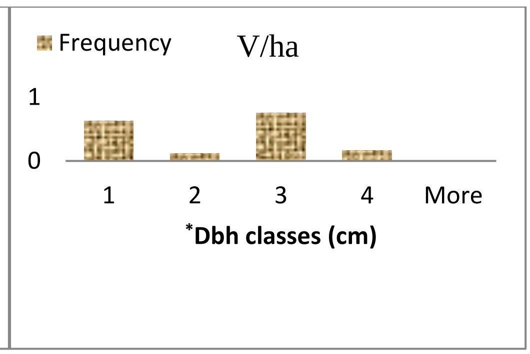
ngitili I



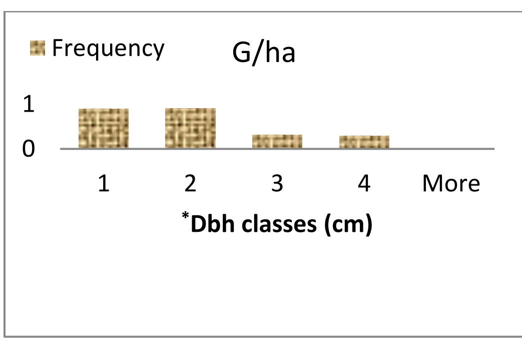


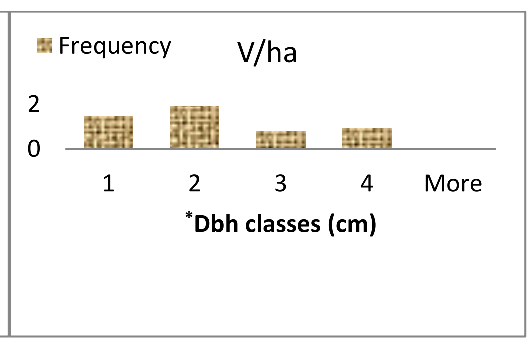
ngitili II





ngitili III





ngitili IV

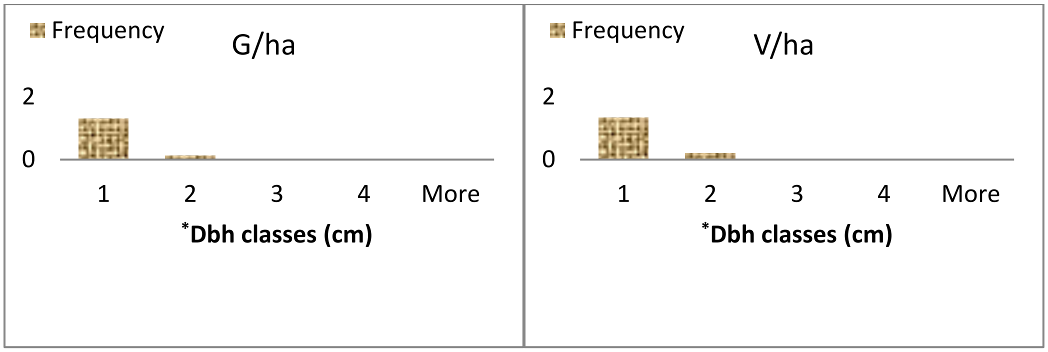


Figure 9: Distribution of basal area (G/ha) and volume (V/ha) for the studied *ngitilis*
**The dbh classes are Class 1,2,3 and 4 representing dbh at <5cm, <10cm, <20 and >20 respectively.*

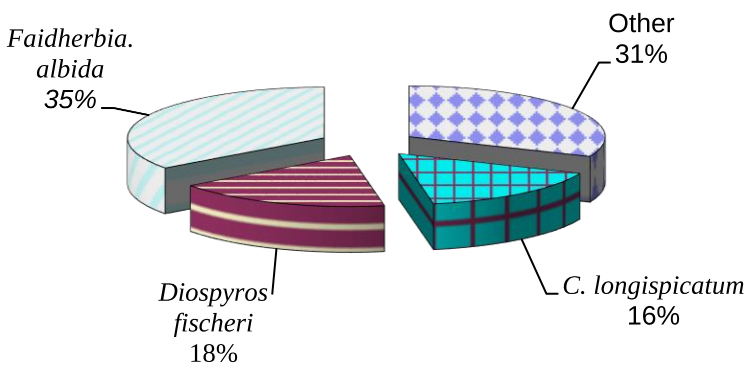


Figure 10: Contribution of species to the total biomass of *ngitili* II (30.4ha)

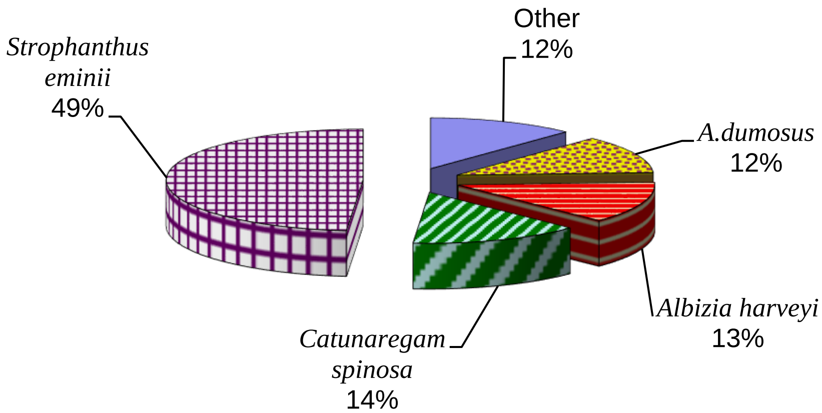


Figure 11: Contribution of species to the total biomass of *ngitili* IV (41.8ha)

From the results obtained by this study, there is a significant contribution of shrub species to the total biomass stored in the ngitilis ranging from 4 to 18%. However, the five studied shrub species occur either singly or two of them in a particular forest. This probably has something to do with microsite variation, the degradation level that had been reached before the start of conservation efforts, and the current plant succession level of this ngitilis.

5. Conclusion and future research

This study developed species-specific biomass estimation models for five shrub species of *Combretum longispicatum, Opilia amantacea, Anisotes dumosus, Abrus schimperi,* and *Harissonia abyssinica* as well as a general model for the shrubs in the *ngitilis.* The selected best models have R^2 ranging from 0.84 to 0.94. These models were validated using independent data and found to have an acceptable bias of <10%. They are therefore recommended for use in Shinyanga Rural District. Moreover, since shrubs lack definite stems which makes it difficult to measure their proper DBH and total height as compared to trees, measurement of equivalent diameter at root collar (edrc) in conjunction with the use of the models developed in this study, therefore, offers a solution to this problem.

This study also observed that there is a significant contribution of shrub species to aboveground biomass ranging from 4 to 18%. It is therefore recommended to include the shrub species in biomass studies for the *ngitilis* to improve the accuracy of estimates of carbon sequestered in the *ngitilis*. Accurate reporting of carbon sequestered in the *ngitilis* will also help to ensure that Tanzania reports its REDD+ commitments achievements in line with the established Enhanced Transparent Framework (ETF) under article 13 of the Paris Agreement.

It is however recommended that further research should be done to develop more species-specific shrub biomass models in the *ngitilis* of Shinyanga Rural District as well as in other areas of Tanzania so that to include more shrub species to refine the biomass models developed in this study.

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