The book ***"Allometric Tree Biomass and Volume Models in Tanzania"*** documents biomass and volume models and various processes involved in their development for different vegetation types and some tree species in Tanzania. This book is organized into 14 chapters:

- Chapter 1 is an introductory part which covers forests and forest types in Tanzania and the importance of forest biomass and volume models in Tanzania;
- Chapter 2 gives background information on development of biomass and volume models;
- Chapter 3 is on biomass and volume models for the vast miombo woodlands in Tanzania;
- Chapter 4 provides models for predicting biomass of individual trees in lowland and humid montane forests *(AGB, BGB, twigs and leaves, branches and stem);*
- Chapter 5 presents general and species-specific models for AGB and BGB for three main mangrove species *(Avicennia marina, Rhizophora mucronata and Sonneratia alba);*
- Chapter 6 focuses on AGB and BGB biomass models and total volume models for Itigi thickets of central Tanzania dominated by *Pseudoprosopi fischeri and Combretum celastroides;*
- Chapter 7 is on *Acacia-Commiphora* woodlands biomass and volume models. Site-specific *(AGB and BGB)* and general *(AGB, BGB and stem)* biomass models are presented;
- Chapter 8 is about general and site-specific allometric models for estimating biomass of *Pinus patula;*
- Chapter 9 describes models for predicting biomass and volume of *Tectona grandis.*
- Chapter 10 deals with biomass and volume allometric models for coconut trees *(Cocos nucifera);*
- Chapter 11 presents cashewnut trees *(Anacardium occidentale)* biomass and volume allometric models;
- Chapter 12 is on biomass and volume models of baobab *(Adansonia digitata)*. AGB and total volume allometric models are presented;
- Chapter 13 compares biomass and volume estimates for different vegetation types and forests obtained by applying models presented in this book with corresponding previously published estimates; and
- Chapter 14 expresses concluding remarks.

The book covers useful knowledge for scholars who wish to engage in tree allometric modelling, and expert practicing forestry for the determination of forest stocking levels needed for forest planning and other processes such as forest carbon trading. It is a book of great interest not only for forest experts but also for forestry students undertaking forest resources assessment at different levels.

ISBN: 985 9987 735 74 7

E&D Vision Publishing Limited

Allometric Tree Biomass and Volume Models in Tanzania

E&D Vision Publishing Limited

Allometric Tree Biomass and Volume Models in Tanzania

Edited by Malimbwi R.E., Eid T., and Chamshama S.A.O.

E&D Vision Publishing

College of Forestry, Wildlife and Tourism
Sokoine University of Agriculture
P.O. Box 3013, Morogoro, Tanzania
e-mail: dfram@sua.ac.tz

ISBN: 985 9987 735 74 7

Edited by:
Malimbwi R.E., Eid T. and Chamshama S.A.O
Allometric Tree Biomass and Volume Models in Tanzania
Second Edition, 2018

Cover photo: ©Josiah Zephania Katani

Published on behalf of Department of Forest Resources Assessment and Management by E&D Vision Publishing Ltd
E-mail:info@edvisionpublishing.co.tz
Website: www.edvisionpublishing.co.tz

Designed by: Maliti Design

9

Allometric Biomass and Volume Models for *Tectona Grandis* Plantations

Zahabu, E., Mugasha, W.A., Katani, J.Z., Malimbwi, R.E., Mwangi, J.R. and Chamshama, S.A.O.

9.1 Background

Large scale establishment of forest plantations in Tanzania started in the 1950s after a series of species and provenance trials. The gross area of forest plantations in year 2015 was estimated to be 554,500 hectares (ha). Out of this, the total area of industrial plantations (private and government) is 135,000 ha while that of woodlots is 419,500 ha (MNRT, 2015). The main planted species in government plantations include *Pinus patula, P. elliottii* and *P. caribaea*), cypress (mainly *Cupressus lusitanica*), *Eucalyptus* (several species), and teak (*Tectona grandis*). The Government owns two teak plantations, i.e. Mtibwa (1,410 ha) and Longuza (2,450 ha) (Ngaga, 2011).

The objectives of establishing forest plantations in Tanzania were to ensure sustainable supply of forest products and services. Teak has excellent properties with wide range of uses, including flooring, decking, framing, cladding and barge boards. In the decorative line, it can be used for lining, panelling, carving, furniture (both indoor and outdoor) and parquetry (Cacho et al., 2003). As such it is an excellent alternative to the dwindling fine hardwood species such as *Pterocarpus angolensis* and *Milicia excelsa.*

Forest plantations play a significant role to sequester atmospheric carbon dioxide (Kongsager et al., 2013). However, estimation of forest carbon requires allometric biomass models. In addition, tree volume models are required for general forest management purposes including timber licensing and pricing. Previous efforts in plantation forests were geared to quantifying tree growth and volume towards obtaining merchantable volume (Malimbwi, 1987; Malimbwi et al., 1998). For teak, data for quantifying tree growth and volume was obtained from government plantations. Furthermore, a biomass model for teak in the Mtibwa plantation forest has been developed (Okting'ati et al., 1998). There are no biomass models developed for Longuza teak plantation.

The aim of this chapter is to describe recently developed biomass and volume models for the teak plantation in Longuza, Tanzania. The models developed in this study are for predicting biomass and volume of different tree components. Although there are existing volume models for Longuza (Malimbwi et al., 1998), the data collected for biomass in this study were used to develop new volume models for comparison with the existing models.

9.2 Site description

Data for development of biomass and volume models were collected from Longuza forest plantation (4°55'- 5°10'S and 38°40'- 39°00' E), Muheza district, Tanga region. The altitude ranges from 160 to 560 m. The mean annual rainfall is 1,500 mm with annual temperature range of 27 to 32 °C. The soils are loamy sandy.

9.3 Data collection and analysis

Selection of sample trees

In order to obtain representative data for tree sizes and ages, six strata were established based on age. These strata were 1-5 years, 6-10 years, 11-15 years, 16 -20 years, 21-25 years and greater than 25 years. Circular plots of 8.92 m radius (area of 0.025 ha) were laid out along transects. Distance between plots and between transects ranged from 60 m to 140 m, depending on the area of the stratum. In each plot, all trees were measured for diameter at breast height (dbh) and three trees (large, medium and small) were sampled for measurement of total tree height (ht). This information was necessary for selection of trees for destructive sampling.

Eight dbh classes from 1-10 cm to 60.1-70 cm and > 70 cm were established from the forest inventory data. Selection of trees for destructive sampling was determined based on the distribution of tree numbers within each diameter class, while for dbh > 70 cm, at least four to five trees were selected. Summary statistics of sample trees are presented in Table 9.1.

Component	n	dbh (cm)			ht (m)		
		Mean	Min.	Max.	Mean	Min.	Max.
AGB, BGB and volume	44	42.5	6.0	84.4	28.6	6.5	37.5
BGB	44	42.5	6.0	84.4	28.6	6.5	37.5
Volume	44	42.5	6.0	84.4	28.6	6.5	37.5

Table 9.1: Summary statistics of sample trees used for developing biomass and volume models

Destructive sampling and biomass and volume determination

The trees were first divided into above- and belowground components. The aboveground component comprised of all biomass above a stump height of 15 cm except leaves. The aboveground component was further divided into three components, namely stem, branches and twigs. The following definitions apply to above- and belowground components when the biomass models were developed:

- Stem - tree trunk that can produce timber.
- Branches - branches (including cone) with diameter ≥ 2.5 cm.
- Twigs - small branches with diameter < 2.5 cm. Leaves were excluded from twigs and thus not included in the modelling.
- The belowground component comprised of all biomass of stump, root crown and roots down to a diameter of 1 cm.

Total volume included stem and branches up to 2.5 cm minimum diameter while merchantable volume included stem up to the minimum diameter of 10 cm. Merchantable stem was divided into billets (1.5 m length) and measured for length and mid diameter. AGB, BGB and volume were determined as described in Chapter 3. Scatter plots of AGB, BGB, and total volume versus dbh are presented in Figure 9.1. Figure 9.2 shows a scatter plot of ht versus age of teak trees. The scatter plot shows that teak seems to attain maximum ht at an early age.

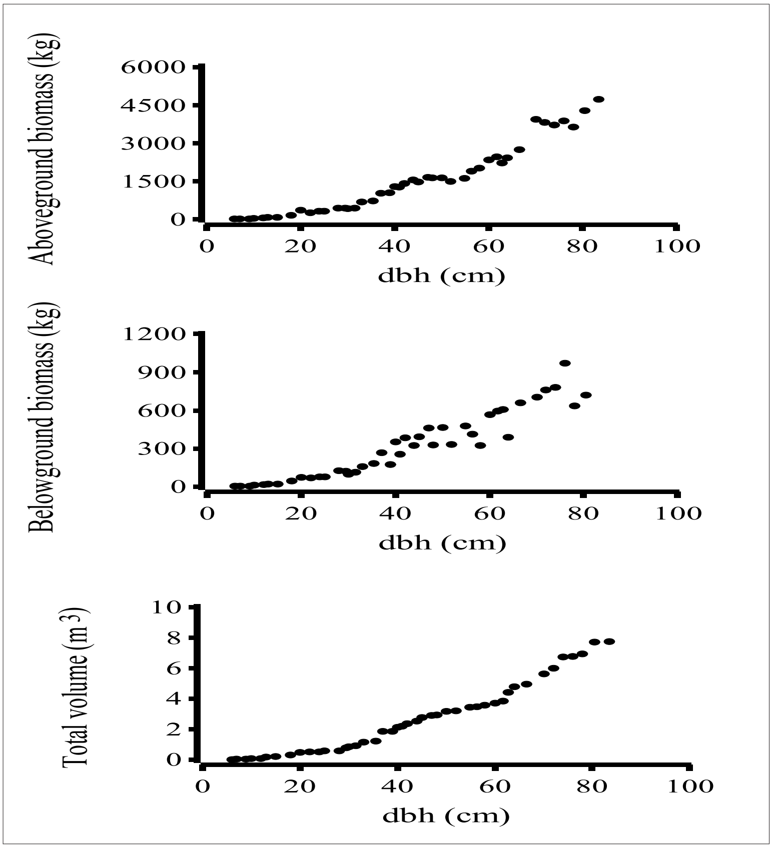

Figure 9.1: Scatter plots of AGB, BGB and total volume versus dbh

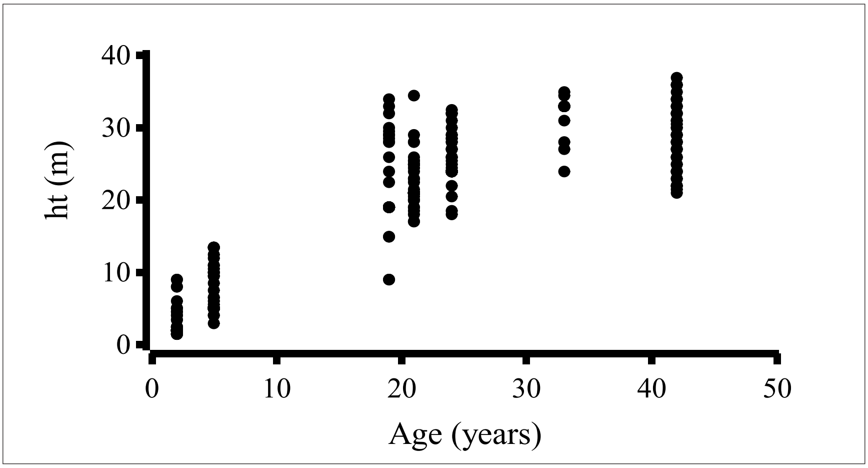

Figure 9.2: Scatter plot of ht versus age

Working conditions and resources required

Longuza plantation is situated at the foot of the Eastern Arc Mountains located at the north-eastern coast of Tanzania. Most of the forest plantation area is flat dominated by loamy sandy soils. This nature of soils made the excavation exercise easy. However, the major challenge was the close spacing between trees (above 700 trees per ha) which affected processing of both above- and belowground components. For example, tree hang ups were very common which protracted working time and reduced the number of trees processed per day. The high wood basic density of the tree heartwood led to frequent replacement of chainsaw chains and consequently affected the costs. Due to high stand density, tree roots were intertwined consequently making it difficult to collect below ground components of the sample trees.

Cost incurred included local labourers and researcher allowances; hiring chainsaw machine and vehicle; fuel for chainsaw; equipment such as bush knives (3), spades (3), mattocks (2), chainsaw chains (15), machetes (2), ropes (3), umbrellas (2), electronic balance (1), spring balances (2), iron brushes (3) and field sample bags (400). The total cost of all these equipment was TZS 440,000.

One crew with five members was involved to process above- and belowground components and they were paid on piecework basis. The cost for processing one tree into above- and belowground components ranged between TZS 30,000 and 80,000 with an average of TZS 50,000. On average, two trees were processed per day. Chainsaw and vehicle were hired at TZS 30,000 and TZS 50,000 per day respectively. The cost for food was TZS 20,000 per day. The cost estimates for destructive sampling are presented in Table 9.2. It should be noted that allowances for researcher and research assistant; and cost for other equipment such as callipers, Suunto hypsometer and tapes are not included.

Item	**Units**	**Unit Cost (TZS)**	**Total cost (TZS)**
Crew (two trees per day)	2	50,000	100,000
Chainsaw machine hiring cost	1	30,000	30,000
Cost for hiring vehicle	1	50,000	50,000
Equipment	Lump sum	440,000	440,000
Food	Lump sum	20,000	20,000

Table 9.2: Cost estimates for destructive sampling

Model fitting and evaluation

Four model forms were fitted to biomass and volume. Two model forms included dbh only and the other two included dbh and ht as follows:

$$Y = \beta_o + \beta_1 \times dbh^2 \qquad (1)$$
$$Y = \beta_o \times dbh^{\beta_1} \qquad (2)$$
$$Y = \beta_0 \times dbh^{\beta_1} \times ht^{\beta_2} \qquad (3)$$
$$Y = \beta_0 \times (dbh^2 \times ht)^{\beta_1} \qquad (4)$$

where Y is biomass (kg) or volume (m^3), β_0, β_1 and β_2 are model parameters to be estimated.

The NLP procedure (Non Linear Programming) in SAS software (SAS® Institute Inc., 2004) was applied when fitting models. The procedure fits both model parameters and variance parameters (variance = $a^2 dbh^{2b}$, where a and b are parameters) simultaneously.

The selection of final models was based on the Akaike Information Criterion (AIC). AIC takes into account the number of parameters in the model and penalises them accordingly. However, if a model had insignificant parameter estimates, it was not considered further. The coefficient of determination (R^2) and Root Mean Squared Error (RMSE) were reported for all models. In addition, relative mean prediction error was reported as:

$$MPE\ (\%) = \frac{100}{MB} \times \sum \left(\frac{e}{n}\right)$$

where e is model residuals (difference between observed and predicted biomass or volume), and MB is mean observed biomass or volume.

9.4 Biomass and volume models

Models for predicting AGB, BGB and stem were of two options which included either dbh only or both dbh and ht as independent variables. The model for predicting branches and twigs biomass used dbh only (Table 9.3). Models for predicting total and stem volume were of two options: with dbh only and with both dbh and ht as independent variables (Table 9.4).

Component	Model ID	Model	n	RMSE (kg)	R^2	MPE (%)
AGB	TE_S1S1_AGB_1	$B = 0.3356 \times dbh^{2.1651}$	44	208.1	0.97	0.3
	TE_S1S1_AGB_2	$B = 0.1711 \times dbh^{2.0047} ht^{0.3767}$	44	224.8	0.97	8.5
BGB	TE_S1S1_BGB_1	$B = 0.0636 \times dbh^{2.2182}$	44	91.6	0.91	5.7
	TE_S1S1_BGB_2	$B = 0.0279 \times dbh^{1.7430} ht^{0.7689}$	44	90.9	0.91	6.7
Merchantable stem	TE_S1S1_MSB_1	$B = 0.4179 \times dbh^{2.0455}$	41	209.3	0.96	6.7
	TE_S1S1_MSB_2	$B = 0.05196 \times (ht \times dbh^2)^{0.8943}$	41	218.3	0.95	5.0
Branches	TE_S1S1_BB_2	$B = 0.0170 \times dbh^{3.0573}$	41	140.7	0.87	25.1
Twigs	TE_S1S1_TB_1	$B = 0.1745 \times dbh^{1.5093}$	44	28.3	0.63	10.2

Note: B = biomass (kg), dbh = diameter at breast height (cm), ht = total tree height (m)
Table 9.3: Biomass models for Tectona grandis plantations

Component	Model ID	Model	n	RMSE (m^3)	R^2	MPE (%)
Total	TE_S1S1_TV_1	$V = 0.0012 \times dbh^{1.9912}$	44	0.05	0.99	2.2
	TE_S1S1_TV_2	$V = 0.00014 \times (ht \times dbh^2)^{0.8793}$	44	0.05	0.98	0.1
Merchantable stem	TE_S1S1_MSV_1	$V = 0.00058 \times dbh^{2.1219}$	41	0.36	0.96	3.7
	TE_S1S1_MSV_2	$V = 0.0001 \times dbh^{1.7240} \times ht^{0.9060}$	41	0.41	0.95	7.4

Note: V = volume (m^3), dbh = diameter at breast height (cm), ht = total tree height (m)
Table 9.4: Volume models for Tectona grandis plantations

9.5 Application recommendations

Models presented in this chapter were developed with data covering wide ranges of ages and tree sizes (dbh 6.0 to 84.4 cm). The developed models can be used for predicting AGB, BGB, total and stem volume in the study area. All the models can be applied with a reasonable certainty, provided that appropriate information on ht is available from the inventory. As observed in Tables 9.3 and 9.4, including ht does not improve the model fit. This is because teak seems to attain maximum ht at an early age in the study site (see Figure 9.2). Therefore, it is generally recommended to apply the models with dbh only. However, it is also recommended to use models with both dbh and ht in predictions for very large trees (dbh > 100 cm) because ht moderates the effect of dbh on biomass and volume predictions as compared to if only dbh is applied.

The recommendations given above also generally apply to the tree component biomass (twigs, branches and stem).The definitions of each component described in Chapter 9.3 should be carefully considered when applying these models.

References

Kongsager, R., Napier, J. and Mertz, O. (2013). The carbon sequestration potential of tree crop plantations. Mitigation and Adaptation Strategies for Global Change 18: 1197-1213.

Malimbwi, R.E. (1987). A growth and yield model for *Pinus patula* at Sao Hill. A thesis submitted for PhD at Aberdeen University. 145pp.

Malimbwi, R.E., Mugasha, A.G. and Zahabu, E. (1998). Yield tables for *Pinus patula* at Sao Hill Forest Plantations, Southern Tanzania. Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture. 41pp.

MNRT (2015). National Forest Resources Monitoring and Assessment (NAFORMA) main results. Tanzania Forest Services, Ministry of Natural Resources and Tourism, Dar es Salaam, Tanzania. 106pp.

Ngaga, Y.M. (2011). Forest plantations and woodlots in Tanzania. African Forest Forum Working Paper Series 1:16. 30pp.

O'Ktinga'ati, A., Monela, G. and Dale, T. (1998). The potential of *Tectona grandis* at Mtibwa to act as a carbon sink. Faculty of Forestry Record No. 67. Special issue for the First Annual Forestry Workshop in Tanzania, held at Olmotonyi, Arusha, 24 - 26 March 1997. pp 156 – 167.

Cacho, O.J., Marshall, G.R. and Milne, M. (2003). Smallholder agroforestry projects: potential for carbon sequestration and poverty alleviation. Rome, Italy: The Food and Agriculture Organisation of the United Nations (FAO). 81pp.

SAS® Institute Inc. 2008. SAS/ETS user's guide, version 9.2. Cary, NC: SAS Institute Inc. 218pp.