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

Allometric Biomass and Volume Models for Coconut Trees

10

Zahabu, E., Mugasha, A.W., Malimbwi, R.E. and Katani, J.Z.

10.1 Background

Coconut tree (*Cocos nucifera*) is one of the four major palm species of economic importance among nearly 2400 palm species in the world. The other three are *Elaeis oleifera, Borassus flabellifer* and *Phoenix dactylifera* (Arancon, 1997; Govaerts and Dransfield, 2005; Goodman et al., 2013). A lager majority of coconut trees are found in higher rainfall coastal areas characterised by saline soils (Kant, 2010). In Tanzania mainland, coconut trees are dominantly found in regions located in the eastern coast and quite a few in patches in non-coastal regions like Morogoro, Manyara and Tabora (Mwinjaka et al., 1999). In Zanzibar, coconut trees are the most dominant tree species (Revolutionary Government of Zanzibar, 2013). At the end of 1990s, the number of coconut trees in Tanzania was estimated to be about 22.6 million, growing on 240,000 hectares (ha) where about 95% of the coconut acreage was grown by smallholder farmers (Mwinjaka et al., 1999).

Coconut trees have high economic and environmental importance. Fruits, fronds and wood provide thousands of smallholders throughout the tropics with a cash income and many of the basic necessities of life such as food, drink, fuel and shelter. The coconut fruit is by far the most important nut in the world (DebMandal and Mandal, 2011). The mature trunk of a coconut tree may be used for timber and charcoal (Arancon, 1997; Durst et al., 2004).

Nevertheless, there is an unexploited opportunity in which smallholder farmers of coconut trees may benefit. This is their potential to sequester atmospheric carbon dioxide and therefore qualify for carbon (C) trading mechanisms such as Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of carbon stocks (REDD+). An added advantage of coconut trees to the farmers is that quite few other woody vegetation types grow in coastal saline lands. Therefore, coconut trees provide an outstanding opportunity to the community residing in these lands to benefit from C market projects. However in Tanzania, biomass models which are necessary tools for estimation of C stored in coconut trees are missing. Similarly, models for estimating timber volume from coconut trees are lacking. Much of the efforts in developing these tools were focused on dicotyledonous trees (e.g. Mugasha et al., 2013; Mauya et al., 2014). The aim of this chapter is therefore to describe recently developed biomass and volume models for coconut trees in Tanzania.

10.2 Site description

Data for development of biomass and volume models were collected from Mkuranga and Kisarawe districts, Pwani region. Mkuranga district is located 50 km south of Dar es Salaam city adjacent to the coastal shores of the Indian Ocean, whereas Kisarawe district is located about 78 km from the coastal shore. Study sites description is presented in Table 10.1.

District	Location	Dominant soil type	Altitude (m)	Mean annual rainfall (mm)	Mean annual temperature (^{0}C)
Mkuranga	39° 09" 16' E 07° 17" 23' S	Sandy soils (Arenosals)	< 400	1,090	28.0
Kisarawe	38° 44" 12' E 07° 15" 44' S	Sandy soils and fluvisols	< 400	1,090	26.1

Table 10.1: Study sites description

10.3 Data collection and analysis

Selection of sample trees

Mixed age farms of coconut trees were selected for data collection. Farms are often small and fragmented. This limits systematic layout of sample plots. Therefore, purposive sampling was carried out in a few farms to represent a wide range of coconut tree sizes. For each study site, a total of 23 coconut trees were selected for destructive sampling. Prior to destructive sampling, the coconut trees were measured for diameter at breast height (dbh) using calliper and total height (ht) excluding rachis using Suunto hypsometer. The ht was measured at the bottom of the oldest rachis. Summary statistics of sampled coconut trees are presented in Table 10.2. It was not possible to include young coconut trees whose trunks were still occupied by rachis below 1.3 m from the ground. Consequently, the minimum dbh encountered was 19.0 cm.

Component	Site	n	dbh (cm)			ht (m)		
			Mean	Min.	Max.	Mean	Min.	Max.
AGB and volume	Mkuranga	23	29.4	21.0	40.0	8.1	1.6	14.4
	Kisarawe	23	29.5	19.0	39.0	12.7	5.9	21.0
	All	46	29.5	19.0	40.0	9.9	1.6	21.0
BGB	Mkuranga	14	29.7	21.0	37.0	8.4	1.6	14.4
	Kisarawe	15	29.3	22.5	38.0	12.2	9.6	15.3
	All	29	29.5	21.0	38.0	9.5	1.6	15.3

Table 10.2: Summary statistics of sample trees used for developing biomass and volume models

Destructive sampling and determination of biomass and volume

The aboveground component consists of stem (other uses including charcoal and merchantable component), rachis and leaflets (Figure 10.1). Characterisation of the stem components was based on local knowledge as well as observable wood properties during crosscutting. Consequently, the merchantable component is the entire stem excluding the top part which is normally softer than the rest (Figure 10.1). The stem components were crosscut into billets with lengths of 1 m at most. Each billet was weighed, measured for length and mid diameter. Leaflets were removed from rachis, bundled and their fresh weight determined separately. Three samples from stem components of about 2.5 cm width from the bark to the pith were extracted and weighed using an electronic balance. Similarly, at least two samples from rachis and leaflets were collected and fresh weighed ready for laboratory analysis.

Due to the fibrous nature of coconut tree roots, BGB was determined by excavating an area of 1 m radius from the coconut tree to the depth of 1.5 m. This is because most of the coconut tree roots are within this radius and depth (Thampan, 1981). The coconut trees were excavated while still standing for them to fall on their own weight and thus uproot any roots beyond the prescribed excavation dimensions. Roots were removed from the root crown and then both root crown and roots were cleaned off soils and measured for fresh weight. For each of the two belowground components, at least three sub-samples were collected and fresh weighed for laboratory analysis. In the laboratory, the collected sub-samples were oven dried at 105 ± 2 °C for at least 72 hours to constant weight. Thereafter, average dry to fresh weight ratios (DF-ratio) were computed for each component.

Tree biomass was determined as a product of respective component fresh weight and DF-ratio. AGB and BGB were computed by summing the biomass of all above- and belowground components respectively (Figure 10.1). Billet volume was computed by using Huber's formula. Scatter plots of AGB, BGB and volume versus ht and dbh are shown in Figure 10.2.

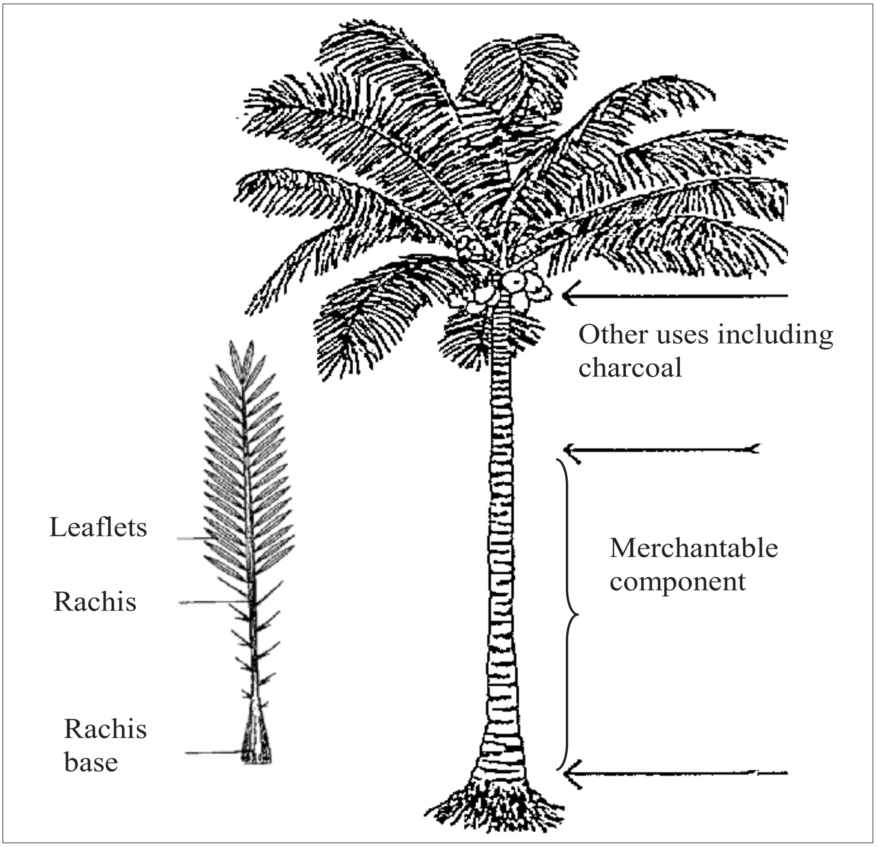

Figure 10.1: Components of a coconut tree

Working conditions and resources required

Working conditions in the coconut tree farms were conducive. Distance and terrain conditions from the road to the working sites had no impact on time consumption, since most of the farms are accessible by road. Terrain conditions were also favourable. The soils are sandy and therefore easily excavated.

In contrast to other vegetation types studied where sample trees were provided free of charge by relevant authorities, coconut trees for this study were purchased at an average price of TZS 50,000 per tree. During the fieldwork, the owners of the trees and neighbours were recruited as members of the crew to facilitate understanding with local communities and avoid conflicts.

On average it was possible to accomplish three trees of 40 cm dbh per day for both above- and belowground components with a crew of 10 people. Table 10.3 summarises the cost estimates used for the destructive sampling of coconut trees. Note that the estimates exclude the cost of researchers, transport and equipment.

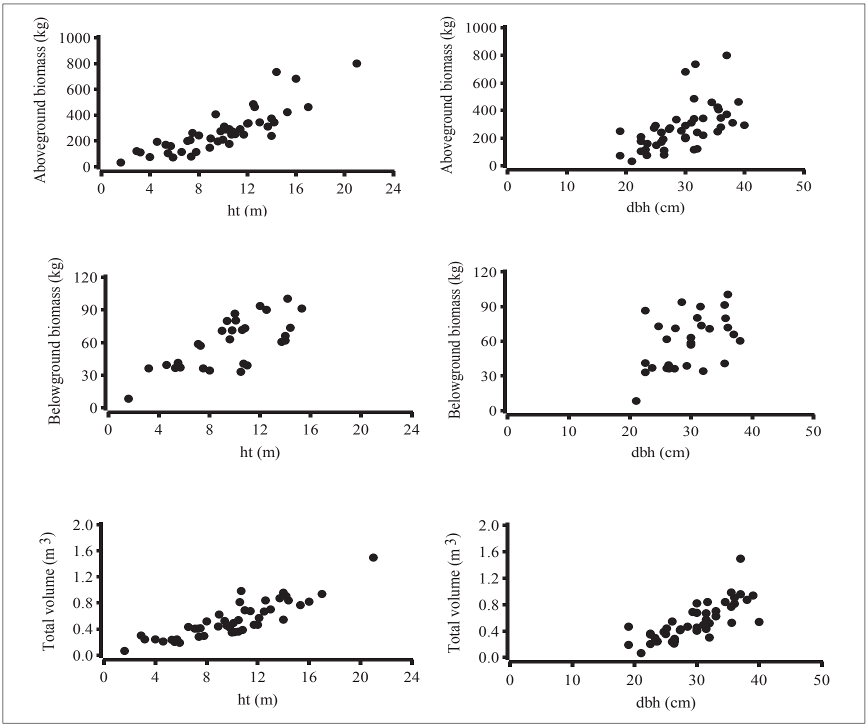

Figure 10.2: Scatter plots of AGB, BGB and volume versus ht and dbh

Equipment used during the sampling included diameter tape and calliper for dbh measurements. Suunto hypsometer was used for ht measurements. Tape measure was used for measuring the length of billets; machetes and axe for cutting off small branches; a chainsaw to fell trees and crosscut stems, large branches and roots. Hoes, spades and mattock were used for excavating and exposing roots, while iron brush was used to remove soils from roots. A spring balance was used to weigh logs and branches whereas an electronic balance was used to weigh sub-samples or small tree parts.

Item	**Number of units**	**Unit cost (TZS)**	**Total cost (TZS)**
Crew size (10 persons)	Labour cost per day, per person	20,000	200,000
Petrol	5 litres per day	2,000	10,000
Engine oil	0.5 litre per day	7,000	3,500
Chainsaw replaceable	1 pc per day	45,000	45,000
Research assistant	1 person	65,000	65,000
Total cost per day			**323,500**
Number of trees per day (3)	Average cost (one coconut tree)		**107,833**

Table 10.3: Cost estimates for destructive sampling

Model fitting and evaluation

Biomass and volume data were fitted to non-linear functions (1-4) which are common and widely documented in literature (e.g. Zianis et al., 2005; Chave et al., 2014). The mixed effect modelling approach was applied to accommodate the variation among sites using PROC NLMIXED, a procedure in SAS (SAS®, 2008). To account for random effects, parameter b varied with sites in such a way that $b = \beta + \varrho$, where ϱ is a random parameter varying with sites.

$$Y = a \times dbh^{b} \quad (1)$$
$$Y = a \times dbh^{2} + b \quad (2)$$
$$Y = a \times ht^{b} \quad (3)$$
$$Y = a \times ht^{b} \times dbh^{c} \quad (4)$$

where Y is a dependent variable i.e. biomass (kg) or volume (m^3), a, b and c are unknown parameters to be estimated. Total tree height (ht) and dbh are in m and cm respectively.

Selection of best performing models was based on low Akaike Information Criterion (AIC) and relative mean prediction error. Other model performance criteria such as Root Mean Square Error (RMSE) and coefficient of determination (R^2) were presented. Relative mean prediction error was computed as:

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

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

10.4 Biomass and volume models

This study developed allometric models for predicting total AGB, BGB and merchantable stem biomass for coconut trees. Total and merchantable volume models were also developed. For all models predicting biomass, i.e. AGB, BGB, merchantable stem, there is one option i.e. models with ht only as an independent variable (Table 10.4).

For all models predicting volume, i.e. total volume and merchantable volume, there are two options: 1) with ht only as an independent variable and 2) with both dbh and ht as independent variables (Table 10.5).

10.5 Application recommendations

Models presented in this chapter were developed with data collected from two sites located in Pwani region covering tree sizes ranging from dbh of 19.0 - 40 cm and ht of 1.6 - 21 m. These models can only be applied elsewhere after they are tested.

For coconut trees, ht explained a lot of variation in biomass and volume, which contrasts with most models developed for dicotyledonous tree species where dbh explained much of the variation. This implies that for accurate estimation of biomass and volume, ht should be measured with care, e.g. for leaning and curved coconut trees. In addition, ht should be measured from stump to the bottom of the oldest rachis.

Component	Model ID	Model	n	RMSE (kg)	R^2	MPE (%)
AGB	CO_S1M_AGB_8	$B = 3.7964 \times ht^{1.8130}$	46	77.9	0.78	-4.5
BGB	CO_S1M_BGB_8	$B = 13.5961 \times ht^{0.6635}$	29	16.2	0.53	9.9
Merchantable stem	CO_S1M_MSB_8	$B = 6.0344 \times ht^{1.4191}$	22	84.3	0.75	16.1

Note: B = biomass (kg), ht = total tree height (m)

Table 10.4: Biomass models for coconut trees

Component	Model ID	Model	n	RMSE (m^3)	R^2	MPE (%)
Total	CO_S1M_TV_8	$V = 0.03470 \times ht^{1.1873}$	46	0.12	0.80	4.9
	CO_S1M_TV_2	$V = 0.00134 \times ht^{0.7841} \times dbh^{1.2295}$	46	0.09	0.88	2.6
Merchantable stem	CO_S1M_MSV_8	$V = 0.0043 \times ht^{1.7780}$	22	0.11	0.75	8.1
	CO_S1M_MSV_2	$V = 0.0015 \times ht^{1.6400} \times dbh^{0.4138}$	22	0.11	0.77	9.2

Note: V = volume (m^3), dbh = diameter at breast height (cm), ht = total tree height (m)

Table 10.5: Volume models for coconut trees

References

Arancon, R.N. (1997). Asia Pacific forestry sector outlook: focus on coconut wood. Asia-Pacific Forestry Towards 2010. Asia-Pacific Forestry Sector Outlook Study Working Paper Series (FAO). 42pp.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., Duque, A., Eid, T., Fearnside, P.M., Goodman, R.C., Henry, M., Martínez-Yrízar, A., Mugasha, W.A., Muller-Landau, H.C., Mencuccini, M., Nelson, B.W., Ngomanda, A., Nogueira, E.M., Ortiz-Malavassi, E., Pélissier, R., Ploton, P., Ryan, C.M., Saldarriaga, J.G. and Vieilledent, G. (2014). Improved pantropical allometric models to estimate the aboveground biomass of tropical forests. Global Change Biology 20: 3177–3190.

DebMandal, M. and Mandal, S. (2011). Coconut (*Cocos nucifera* L.: Arecaceae): in health promotion and disease prevention. Asian Pacific Journal of Tropical Medicine 4: 241-247.

Durst, P.B., Killmann, W. and Brown, C. (2004). Asia's new woods. Journal of Forestry 102: 46-53.

Goodman, R.C., Phillips, O.L., del Castillo Torres, D., Freitas, L., Cortese, S.T., Monteagudo, A. and Baker, T.R. (2013). Amazon palm biomass and allometry. Forest Ecology and Management 310: 994-1004.

Govaerts, R. and Dransfield, J. (2005). World checklist of palms. Royal Botanic Gardens. 223pp.

Kant, P. (2010). Should bamboos and palms be included in CDM forestry projects? (IGREC Working Paper No. IGREC07:2010). New Delhi: Institute of Green Economy. Web Publication No.07/2010. 5pp.

Mauya, E.W., Mugasha W.A., Zahabu E., Bollandsås O.M. and Eid, T. (2014). Models for estimation of tree volume in the miombo woodlands of Tanzania. Southern Forests 76: 209-219.

Mugasha, W.A., Eid, T., Bollandsås, O.M., Malimbwi, R.E., Chamshama, S.A.O., Zahabu, E. and Katani, J.Z. (2013). Allometric models for prediction of above- and belowground biomass of trees in the miombo woodlands of Tanzania. Forest Ecology and Management 310: 87-101.

Mwinjaka, S., Chiduza, C., Temu, A., Sukume, C. and Diehl, L. (1999). Coconut palm replacement model for Tanzanian farming systems. Journal of Agricultural Economics & Development 3: 61-70.

Revolutionary Government of Zanzibar (2013). Zanzibar wood biomass survey, biophysical inventory report, Department of Forestry and Non-Renewable Natural Resources, Ministry of Agriculture and Natural Resources. Zanzibar. 104pp.

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

Thampan, P.K. (1981). Handbook on coconut palm. Report No. 8120402146. 311pp.

Zianis, D., Muukkonen, P., Mäkipää, R. and Mencuccini, M. (2005). Biomass and stem volume equations for tree species in Europe. Silva Fennica Monographs 4. 63pp.