ESTIMATION OF BIOMASS AND VOLUME IN MIOMBO WOODLAND AT KITULANGALO FOREST RESERVE, TANZANIA

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MALIMBWI, R.E., SOLBERG, B. & LUOGA, E. 1994. Estimation of biomass and volume in miombo woodland at Kitulangalo Forest Reserve, Tanzania. Seventeen sample trees of different miombo species distributed in 10 sample plots were excavated and measured for volume and green weight. Samples from the roots and stems were taken and treated in the laboratory for biomass determination of the sample trees. Using these data biomass equations for roots and stems as functions of diameter at breast height (DBH) and total height were developed. Stem volume equations were also developed. These equations were used to estimate biomass and volume per hectare for different tree parts. Twenty per cent of the biomass in miombo woodlands was found to be in the roots and 80% was in the aerial parts. Fifty-one per cent was volume of stems ≥ 15 cm diameter and forty-nine per cent was volume of stem < 15 cm diameter.

Key words: Biomass - volume - miombo - equations - roots - stems

MALIMBWI, SOLBERG, B. & LUOGA, E. 1994. Anggaran biojisim dan isipadu hutan jarang miombo di Hutan Simpan Kitulangalo, Tanzania. Tujuh belas sampel spesies pokok miombo yang tersebar di sepuluh plot sampel telah digali untuk ukuran isipadu dan berat hijau. Sampel dari akar dan batang dikaji di makmal untuk menentukan biojisim sampel pokok tersebut. Persamaan-persamaan biojisim untuk akar dan batang sebagai fungsi diameter aras dada (DBH) dan tinggi keseluruhan dihasilkan dengan meng-gunakan data yang diperolehi. Persamaan isipadu batang juga dihasilkan. Persamaan-persamaan yang dihasilkan digunakan untuk menganggar biojisim dan isipadu sehektar untuk pelbagai bahagian pokok. Dua puluh peratus dari biojisim di hutan jarang miombo didapati di bahagian akar manakala 80% pula di bahagian aerial. Isipadu batang yang mempunyai diameter > 15 sm berjumlah 51% manakala isipadu batang yang mempunyai diameter < 15 sm berjumlah 49%.

Introduction

The term 'tropical woodlands' refers to the dry, open types of woodland often consisting of two tiers: a top tier of tree canopy and ground layer of grasses and young regeneration. The canopy closure rarely exceeds 75% and the lower limit is normally 20% (Temu 1985). Adaptation to environmental conditions has resulted in the formation of different types of tropical woodlands such as the miombo woodland, coastal semi-evergreen forests, combretum woodland, and ground water forests (Kielland - Lund 1982). The miombo woodland is the dominant forest type in Eastern and Central Africa with more than 175 tree species (Schultz & Co. Ltd. 1973), most of which belong to the family Caesalpiniaceae and Papilionaceae.

Tropical woodlands have a role in supplying fuelwood, small timber, fodder and other products to the local people and in conserving the environment. However, many areas in which tropical woodlands naturally occur are suffering from wood shortages and ecological degradation as a result of deforestation. Rural populations rely on wood as the major source of energy. In areas within close proximity to major cities and major roads charcoal production and fuelwood collection are commercial enterprises. In Tanzania this is especially true with Morogoro, Tanga and Coastal Regions (Ministry of Natural Resources and Tourism 1989).

At global level increases in economic activities and fosil use have resulted in huge changes in the quality of pollutants released. One of the released is carbon dioxide, a green house gas implicated in global warming and climate change (Speth 1989)

Forests play a critical role in terrestrial carbon cycle. Active forest management to maintain high amounts of standing biomass, to reduce tropical deforestation and to aggressively reforest marginal agricultural or degraded lands, offer possibilities of reducing atmospheric pollution (Speth 1989).

The roots of miombo woodlands are generally known to be well developed to allow rapid coppicing after felling or defoliation due to drought and fire, browse or injury. To survive these harsh conditions miombo trees must have relatively more developed root systems than their aerial parts especially during the younger age. The development of roots acts as stress tolerance adaptation and a reserve for recovery. As such miombo tree roots could be expected to store relatively more carbon then other vegetation types. Biomass studies especially those involving root excavation are normally expensive, and for miombo woodlands in Tanzania no such study has been carried out before. This paper reports on the technique used to estimate biomass and volume per hectare for miombo woodland species at Kitulangalo Forest Reserve in Morogoro Region, Tanzania. The vegetation of this area has been described by Welch (1960) and Kielland-Lund (1982, 1990).

Material and methods

Data collection and analysis

The data were collected from one transect 1 km long, perpendicular to the Morogoro - Dar es Salaam road, with the starting point selected at random. Ten plots were laid out on the transect at approximate intervals of 100 m. The plots were circular and the sizes varied to contain 15 - 20 trees of diameter at breast height (DBH) equal to or greater than 5 cm. Consequently the plot sizes ranged from 0.03 - 0.23 ha, with larger plots in sparcely stocked areas and smaller plots in densely stocked areas.

All trees with DBH equal to or greater than 5 cm were numbered, marked and measured for DBH and height. Furthermore each tree was identified in local name and later its botanical name confirmed with the assistance of a taxonomist.

A total of 17 sample trees (at least one from each plot) irrespective of species were selected at random for biomass and volume assessment. Fifteen species altogether were represented. The trees were felled, and the stems (including branches) were trimmed and cross cut into billets ranging from 1 to 2.5m in length. The roots were excavated and finally each tree was arranged into the following categories:

- roots to surface level,
- stems > 15 cm top diameter including stump,
- branches < 15 cm.

The billets were measured individually for mid diameter and actual length before being tied into bundles for weighing. The roots were also tied into bundles and weighed.

Two disks of about 2 cm thickness were cross cut from the roots and stems for laboratory analysis. In the laboratory, from each disk a block measuring 2 cm width was cut from bark to pith and soaked in water for at least a week, after which it was measured for green weight and volume by water displacement. The blocks were then dried in oven at 103 ± 2 °C for four days to constant weight and the oven dry weight recorded.

From these data the following were computed:

$$\text{Basid density} = \frac{\text{Block oven dry weight}}{\text{Block green volume}}$$

$$\text{Biomass ratio} = \frac{\text{Block oven dry weight}}{\text{Block green weight}}$$

Biomass functions: (Stromgaard 1986, Marklund 1988):

1. $\ln X = a + b \ln DBH$
2. $\ln X = a + b \ln DBH + c \ln H + d \ln DBH^2 + e \ln H^2$

where X = biomass (green weight X biomass ratio in kg) for different tree parts (roots, stems $\geq$ 15 cm, branches (15 cm, all stems, roots + all stems),

DBH & H = diameter (cm) at breast height and total tree height (m) respectively ,

a,b,..... = parameters to be estimated separately for the two equations.

ln = natural logarithms.

Volume equations

1. ln x a + b ln DBH
2. ln x a + b ln DBH + ln H

where x = volumes (m^3) of aerial parts of the tree (stems $\geq$ 15 cm, branches < 15 cm, all stems), all other definitions are as in (iii).

Logarithmic transformations were used in an attempt to reduce heteroscedasticity (inconstant variance) often associated with most volume or biomass data (Philip 1983). Alternatively, the weighted least squares estimates of the regression parameters could have been calculated.

Results and discussion

Table 1 shows the list of the sample trees and their basic densities.

Table 1. Sample trees for biomass assessment at Kitulangalo Forest Reserve

Tree No.	DBH (cm)	H (cm)	Basic density (g cm $^{-3}$) Roots	Stems	Species
1	13.5	7.5	0.62	0.68	*Acacia* sp.
2	14.0	7.0	0.67	0.69	*Acacia nigrescens*
3	10.0	5.5	0.29	0.44	*Annona senegalence*
4	19.0	11.1	0.68	0.75	*Acacia* sp.
5	17.8	5.0	0.69	0.70	*Acacia nilotica*
6	26.0	16.5	0.62	0.74	*Brachystegia boehmii*
7	21.0	8.0	0.84	0.78	*Combretum* sp.
8	41.0	8.0	0.60	0.63	*Diplorhynchus condylocarpon*
9	30.0	22.2	0.59	0.66	*Brachystegia* sp.
10	12.0	9.5	0.55	0.51	*Pterocarpus angolensis*
11	26.5	12.0	0.43	0.58	*Albizia versicola*
12	11.5	3.5	0.56	0.53	*Pterocarpus rotundifolius*
13	14.8	5.0	0.92	0.78	*Dichrostachys cinerea*
14	16.0	8.0	0.62	0.71	*Acacia nilotica*
15	9.3	4.4	0.55	0.61	*Brachystegia spiciformis*
16	43.0	21.0	0.63	0.75	*Brachystegia boehmii*
17	8.0	5.0	0.79	0.78	*Combretum* sp.
Mean			0.63	0.66	

Basic density

The general trend of basic density (Table 1) is that the roots have lower mean basic density than the stems although not significantly different. A similar pattern was noted by Haygreen and Bowyer (1987) for birch and maple. A few species, *Combretum* spp. *Pterocarpus,* and *Dichrostachys cinerea,* have consistently heavier roots than the stems. Chonge (1987) also noted that with poplar the roots had higher basic density than the stems.

Biomass equations

Table 2 shows the biomass equations for the different trees parts. In the first equation the allometric equation relating biomass to DBH alone gives a good fit with r^2 ranging 0.84 - 0.92.

Table 2. Biomass functions for various parts of miombo trees at Kitulangalo

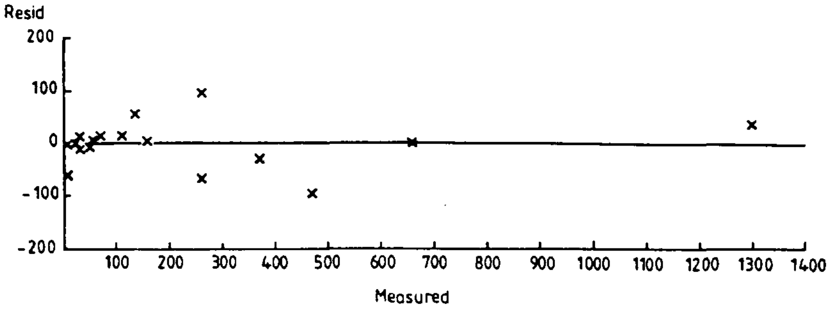
Dependent variable	Model	Regression estimators						
		a	b	c	d	e	r^2	SE
Roots	1	- 3.416 (0.69)	2.305 (0.24)	-	-	-	0.86	0.48
	2	- 3.251 (0.61)	-	-	0.871 (0.13)	0.344 (0.12)	0.90	0.40
Stems ≥ 15 cm	1	- 4.193 (1.25)	2.762 (0.39)	-	-	-	0.84	0.46
	2	- 4.008 (0.86)	-	-	1.016 (0.17)	0.451 (0.13)	0.93	0.31
Stems 1<15 cm	1	- 1.320 (0.55)	1.893 (0.20)	-	-	-	0.86	0.38
	2	- 1.175 (0.47)	-	-	0.698 (0.12)	0.304 (0.11)	0.90	0.32
All stems	1	- 2.959 (0.57)	2.603 (0.36)	-	-	-	0.92	0.39
	2	- 2.789 (0.45)	-	-	1.012 (0.12)	0.355 (0.11)	0.95	0.31
All stems + roots	1	- 2.462 (0.51)	2.516 (0.18)	-	-	-	0.92	0.39
	2	- 2.284 (0.36)	-	0.735 (0.18)	0.958 (.10)	-	0.96	0.25

Model 1 $\ln X = a + b \ln DBH$

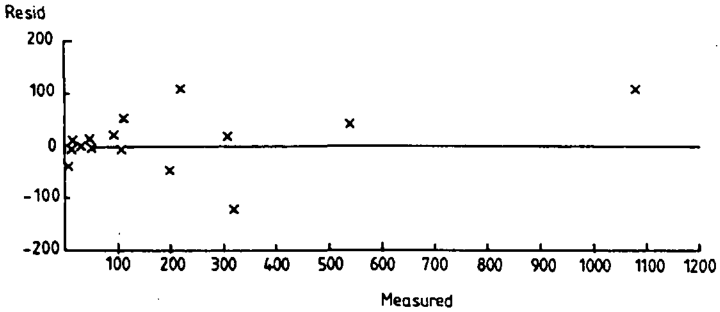
Model 2 $\ln X = a + b \ln DBH + c \ln H + d \ln DBH^2 + e \ln H^2$

where X = biomass (kg), and other definitions as before,
number in brackets indicate the standard errors of the coefficients.

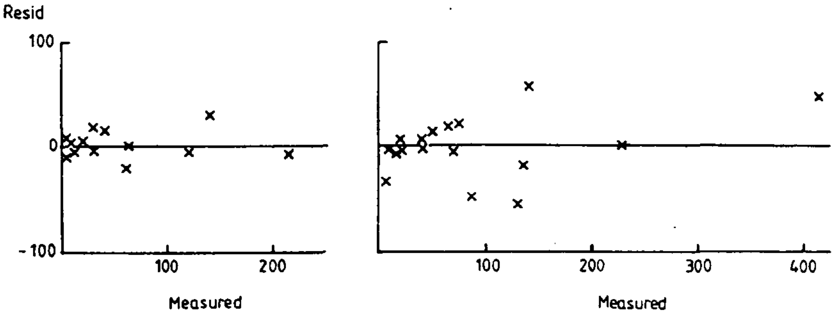
In the second equation the fit improves further by including height (H) in the polynomial equation with r^2 ranging 0.09 - 0.96. Since a stepwise regression package was used ln DBH and ln H were eliminated in the equation in favour of their squared versions because of their close correlation. The resulting biomass



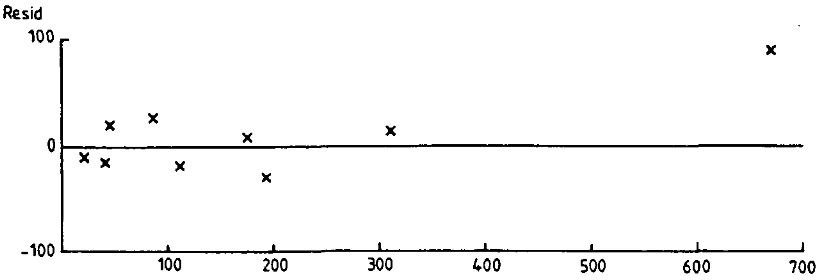
(a) Total tree biomass



(b) All stems biomass



(c) Roots biomass (d) Branches<15 cm biomass



(e) Stem ≥ 15 cm biomass

Figure 1. Biomass (kg) residuals distribution for various parts of miombo tree species

equations (kg/tree) simplify to the following forms:

Roots = $0.0387\ DBH^{1.74}H^{0.69}$ (1)
Stems ≥ 15 = $0.018\ DBH^{2.03}H^{0.90}$ (2)
Branches < 15 cm = $0.31\ DBH^{1.396}H^{0.61}$ (3)
All stems (+branches) = $0.06\ DBH^{2.012}H^{0.71}$ (4)
Roots + all stems = $0.1\ DBH^{1.916}H^{0.74}$ (5)

For the estimation of total biomass no attempt was made to force additivity of the component equations in order to avoid accumulated error inherent in the component equations. The total biomass equations (4 & 5) were therefore fitted separately.

Figure 1 shows the distribution of the residuals resulting from the equations. It is clear that the equations are not biased although the residuals are not homogenous because the plot is on the original scale. In Figure 1e the trend is less obvious because smaller trees of less than 15 cm are excluded.

Volume equations

Table 3 shows the volume equation for the different tree parts. As with the biomass equations the allometric functions with DBH and height as independent variables have better fits with r^2 ranging 0.88 - 0.96. Similar allometric equations were developed by Malimbwi and Temu (1984) for miombo trees in Tabora, Western Tanzania.

The equations are:

Stems ≥ 15 cm volume = $0.00002\ DBH^{2.212}H^{0.79}$ (6)
Branches < 15 cm volume = $0.00056\ DBH^{1.358}H^{0.55}$ (7)
All stems volume = $0.0001\ DBH^{2.032}H^{0.66}$ (8)

Just like the biomass equations, the volume equations exhibit non-homogenous variance and they are unbiased (Figure 2).

Stand biomass and volume

Using the developed equations and stand data for the 10 plots, the biomass and volume per hectare were computed. Table 4 shows the distribution of stem numbers, volume, biomass basal area, root biomass percentage, and biomass/volume ratio by species.

The biomass/volume ratio varies only very little with species and has an average value of 0.85. This value may be used as conversion factor to estimate volume from biomass.

The total biomass (Table 4) is 33 t ha^{-1}. This is generally lower than biomass in monoculture plantations, e.g. 45 t ha^{-1} for an 3-y-old *Eucalyptus* trial (Ahimana & Maghembe 1987) and 216 t ha^{-1} for a 6-y-old *Prosopis juliflora* planting (Maghembe *et al.* 1983). *Combretum* spp. appear to be the most abundant species in terms of numbers and biomass constituting 22% of total biomass. *Brachystegia boehmii* has the second highest biomass but with relatively fewer stems, indicating the presence of large trees.

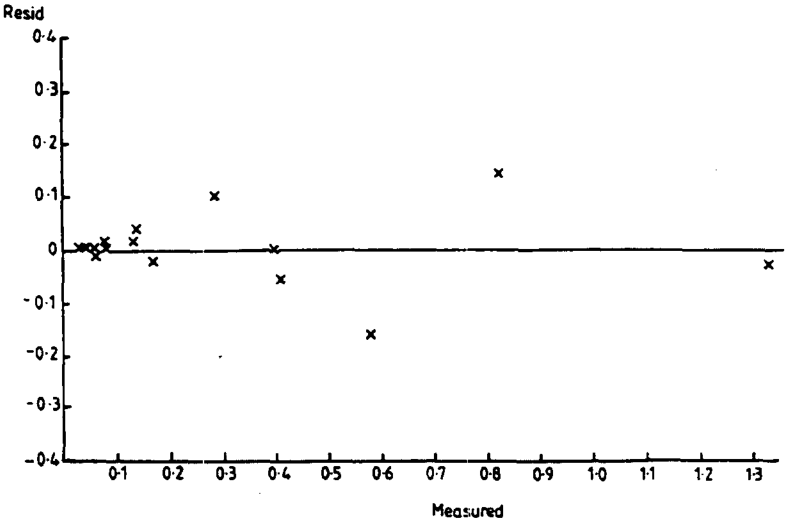
Table 3. Volume functions for miombo trees at Kitulangalo

Dependent variable	Model	Regression estimators a	b	c	r^2	SE
Stems ≥ 15 cm	1	-10.965	2.85		0.89	0.39
		(1.08)	(0.34)			
	2	-10.802	2.212	0.795	0.96	0.26
		(0.72)	(0.29)	(0.22)		
Stems < 15 cm	1	-7.606	1.806		0.84	0.39
		(0.56)	(.20)			
	2	-7.474	1.358	0.550	0.88	0.35
		(0.51)	(0.27)	(0.25)		
All stems	1	-9.363	2.57		0.91	0.38
		(0.56)	(0.19)			
	2	-9.205	2.032	0.659	0.95	0.31
		(0.46)	(0.24)	(0.22)		

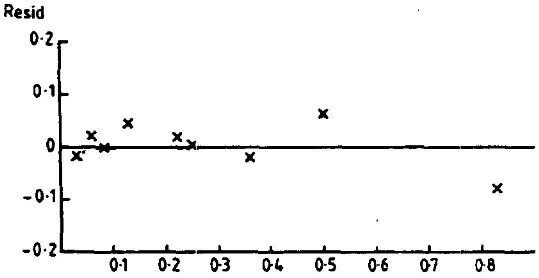
Model 1 $\ln x = a + b \ln DBH$
Model 2 $\ln x = a + b \ln DBH + c \ln H$
where x = volume (m^3),
numbers in brackets indicate the standard errors of the coefficients.

Acacia nilotica is the second most abundant in terms of numbers but the biomass is not so high because the trees are small. As a genus, *Acacia* has 28% of the total biomass. The least represented species include *Albizia, Acacia polycantha,* and *Acacia* spp. This composition suggests that the forest in this area is more of a combretum woodland than a typical miombo. *Julbernadia,* normally a dominant key genus in miombo, has not been recorded.

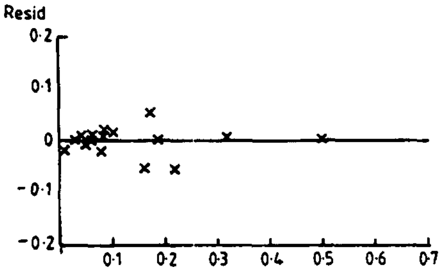
Table 5 shows the biomass and volume for different parts of the tree. It shows that more than 80% of the total biomass is in the stems above ground, of which 38% is stem ≥ 15 cm and 42% is branches < 15 cm. Only about 20% of the biomass is in the roots and the variation between species is very little (Table 4). At Mafiga, Ahimana and Maghembe (1987) found that the root biomass percentage for *Eucalyptus tereticornis* ranged 11-18%.



(a) Total tree volume



(b) Stems ≥15 cm volume



(c) Branches <15 cm volume

Figure 2. Volume (m^3) residuals distribution for miombo tree species

Table 4. Distribution of various stand parameters by species at Kitulangalo Forest Reserve

Species	Local name	Stems ha^{-1}	Volume * (m^3 ha^{-1})	Biomass* (tons ha^{-1})	Basal area (m^2 ha^{-1})	Root %	Biomass/ volume ratio
Acacia nigrescens	Mkambala	30	4.86	3.99	0.70	19	0.82
Acacia usambarensis	Mkongowe	2	0.16	0.13	0.05	22	0.82
Acacia nilotica	Kisasa	112	4.54	3.80	1.28	22	0.84
Acacia polyocantha	Mwindi	1	0.37	0.32	0.04	19	0.87
Acacia sp.	Kifunganyumbu	16	1.12	0.99	0.19	22	0.88
Albizia harveyi	Msisimisi	1	0.01	0.01	0.00	27	0.91
Albizia versicolor	Mnyanda/Mkongo	1	0.55	0.46	0.08	19	0.84
Annona senegalense	Mtomokwe	4	0.24	0.20	0.06	21	0.84
Brachystegia boehmii	Myombo	44	5.69	4.88	0.77	19	0.86
Brachystegia microphylla	Muyuye	4	1.38	1.10	0.18	17	0.80
Brachystegia spiciformis	Nondora	23	2.25	2.00	0.33	21	0.89
Combretum spp.	Mlama	122	8.58	7.40	1.56	21	0.86
Cremaspora confluens	Msaku-lang'wale	14	0.18	0.16	0.06	25	0.89
Dalbergia melanoxylon	Mpingo	5	0.08	0.85	0.24	20	0.79
Dichrostachys cinerea	Kikulagembe	8	0.20	0.17	0.06	23	0.85
Diospyros mespiliformis	Mkulwi	4	0.03	0.86	0.16	20	0.84
Diospyros sp.	Mkumbi	3	0.09	0.08	0.02	24	0.89
Diplorhynchus condylocarpon	Mtogo	26	2.21	1.85	0.42	21	0.84
Dombeya rotundifolia	Msosowana	6	0.33	0.29	0.08	22	0.86
Pseudolachnostylis sp.	Msoro	7	0.08	0.07	0.02	26	0.91
Pterocarpus angolensis	Mninga	15	2.06	1.79	0.29	21	0.87
Stereospermum kunthianum	Myegea	0	0.50	0.40	0.06	18	0.80
	Kilemelatembo	10	0.23	0.21	0.05	23	0.91
Brachystegia sp.	Mnyanza/mseni	1	0.96	0.84	0.09	18	0.87
Total/average		460	38.70	32.90	6.80	20	0.85

* A log bias correction factor was not applied in the estimation of biomass and volume. The values indicated here may therefore be slightly understimated.

The 20% biomass obtained in this study does not reflect a particularly significant role of miombo roots in storing atmospheric carbon compared to other forest types.

The root/stem ratio could have been affected by coppicing and/or pruning, but these were not observed although dead branches may have fallen to the ground or been lopped for fuelwood. This would have only little effect on the root/stem ratio since the stand was not in such a state of competition to cause mortality of many lower branches.

A compilation of some volume figures from miombo and other vegetation types in connection with miombo woodlands is given in Table 6. The volume of 39 m^3 ha^{-1} of woody plants at Kitulangalo obtained in this study is generally on the lower side. This may be mainly due to exploitation of trees for poles, charcoal and timber, activities which were evident at the time of data collection despite the site being a protected forest reserve.

Kitulangalo Forest reserve is surrounded by villages. Like all villages in Tanzania the people depend almost entirely on the forest for these supplies. The proximity of the Forest to Morogoro municipality makes the charcoal business particularly attractive.

In Table 5, 51% of the volume are stems ≥ 15 cm and the remaining 49% is in the branches. This observation was also noted by Temu (1979) who estimated the volume of branches including useless species to be 70% of the total.

Table 5. Biomass and volume per hectare for different parts of miombo trees (≥ 15 cm DBH) at Kitulangalo Forest Reserve

Stand variable	Mean stand value	% of total @	Error % * at p = 5 %
Biomass t ha^{-1}			
Roots	4.3	19.4	32
Stems ≥ 15 cm	8.7	39.2	40
Stems < 15 cm	9.2	41.4	29
Total	22.2 (33.0)	100.0	36
Volume ($m^2 ha^{-1}$)			
Stems ≥ 15 cm	13.7	51.5	41.5
Stems < 15 cm	12.9	48.5	28.7
Total	26.6 (38.7)	100.0	36.9

( ) All trees down to 5 cm DBH.

* = Error per cent calculated as: $\frac{t_{9\,df,\,5\%} \times Sx \times 100}{X}$

where Sx = standard error of the mean,

@ The totals of biomass and volume are obtained by application of their equations and not by predictions of their components.

Table 6. Above ground volume from Tanzanian and Zambian natural forests

Country and vegetation type	Volume $m^3 ha^{-1}$
Tanzania	
Ground water forest	168
Combretum woodland	35
Semi evergreen forest	155
Miombo	79
Kitulangalo (this study)	39
Woodland in Tabora	99
Bushland in Tabora	17
Woodland in Iringa	56
Bushland in tringa	25
Zambia	
Undisturbed & mature miombo	47
The same 27 years later	60
Miombo fire wood	200

Source: Gauslaa 1988.

Conclusion

Biomass studies especially those involving roots excavation are expensive. Due to time and funds constraints only a crude and localized sample was used which is by no means representative of all miombo woodlands in Tanzania. The methodology, however, may be adopted for a more organized large scale study. The results may be used as a basis for comparison with those from other studies.

There are two points worth noting: (1) high r^2 values were obtained in the volume and biomass equations despite many species being involved. This may eliminate the need to construct different equations for each species, a special advantage considering the high species diversity in miombo wood lands, (2) miombo species did not show exceptionally high root/stem ratio compared to other vegetation types.

Acknowledgements

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