Stackwood volume estimations for miombo woodlands in Malawi

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SUMMARY

One metre billets of known volume were piled in 1 m^3 stacks to estimate a stacked to solid volume conversion ratio. An average conversion factor of 0.44 for stacked to solid volume was calculated. Mean stackwood yield (m^3) per m^2 of basal area removed was 16.1 m^3m^{-2}. Stand basal area (m^2ha^{-1}) and height (m) varied between sample plots. There was no significant correlation between total plot basal area (m^2) and yield (m^3) per m^2 basal area removed, but there was a significant correlation between tree height (m) and yield. Regression models of stackwood yield against basal area removed and mean height were developed for the estimation of stackwood volume for miombo woodland in Malawi.

Keywords: Miombo; Malawi; Stackwood Volume; Regression.

INTRODUCTION

Malawi's indigenous woodlands have for a long time provided a valuable range of resources to both urban and rural populations. Woodfuel is one of the most important products provided by these woodlands (Kayambazinthu, 1988). According to the World Bank (Hardcastle, 1988) woodfuel use in Malawi was 8.6 million m^3 in 1984 and is set to rise to 10.6 million m^3 by the year 1994 (source IBRD 1986).

In Malawi, the Forestry Department has historically sold fuelwood in mendles. Although originally an imperial measure, the metric mendle is defined in this case as a stack of 1m x 1m x 1m. Estimations of stack/solid volume ratios for plantation timbers are available but a review of the forestry literature indicates that there are few published records of stackwood volume and conversion ratios for natural woodland in southern Africa. In the light of recent evidence from the Blantyre City Fuelwood Project (BCFP) (Cornelius pers. comm.) it is suggested that stacked volume/solid volume ratios used for indigenous timbers in Malawi overestimate the solid volume of wood stacked in mendles.

Realistic estimates for stackwood volume prediction in miombo woodlands would be useful in the planning, management and sale of expected and realized yield, particularly where the forest licensing system is based on volume.

STUDY SITES

The dominant indigenous woodland type in Malawi is the semi-deciduous miombo woodland, characterized by the genera *Brachystegia* and *Julbernardia* (Shaxon, 1977). Miombo woodlands are the most extensive vegetation type in the region, covering 2.7 million km^2 (Chidumayo, 1993). These woodlands, with the exception of those on the Kalahari sands of west central-southern Africa, are poor in timber quality. They are, however, rich in other wood and non-wood forest products widely used by rural communities (Shaba, 1993).

The study sites comprise two areas of miombo. Phuyu, in the BCFP Indigenous Forest Area - Chikwawa district, falls under the drier Zambezian miombo of White (1983). The second site is situated in the Chongoni Forest Reserve near the Malawi College of Forestry (MCF) - Dedza district. It is characterized by species from the wetter miombo (White 1983).

The site at Phuyu lies about 300m above sea level, only a few kilometres north of Kapichira falls on the Shire River. It has an average annual rainfall between 600 and 700mm. The canopy is dominated by *Brachystegia boehmii, Burkea africana, Pterocarpus rotundifolius, Lonchocarpus bussei* and *L. capassa*. The common subcanopy species include *Bauhenia petersiana, Diospyros kirkii, Diplorhynchus condylocarpon* and *Flacourtia indica*. Timber species from the genera *Pterocarpus, Terminalia* and *Combretum* are present in small numbers.

The soils are escarpment lithosols, and mostly shallow and stony. They are acidic with a small proportion of silt and clay. The basement rock is precambrian metamorphic. The site is in relatively undisturbed customary (communally owned) woodland. The area has a history of low population density but is presently experiencing an inward migration of small farmers (Coote, Lowore, Luhanga, Abbot 1993b).

The site at Chongoni (Malawi College of Forestry) lies about 1700m asl, with an average rainfall of 800 - 900mm. The canopy is dominated by *Brachystegia floribunda* and *Faurea saligna*. The sub-canopy is dominated by *Uapaca kirkiana*.

The soils at Chongoni are ferruginous, the sandy clay loam top soil is moderately acid. The parent rocks are basement complex. Although the site is within the Chongoni Forest Reserve, the surrounding area is heavily populated and has a sparse tree cover. Cattle are grazed in the Reserve by local people.

METHODOLOGY

The present study was based on information gathered during the establishment of silvicultural systems trials in 1992. The silvicultural treatments imposed were coppice, coppice with standards, and selective thinning. The fourth plot per block was left uncut as the control. At both sites the treatment layout was a simple random complete block design with the four treatments replicated in three blocks. All trees felled in the eighteen plots of 0.125 ha (25m x 50m) were measured. The proportion of trees felled varied in accordance with the treatment applied. The data used represent different intensities of basal area removal from study plots. This is therefore likely to be a source of data variation. No trees below 5cm diameter at breast height (dbh) were felled. In total, some 692 trees were measured and stacked. For all trees in the sample plots, species, height (m) and dbh (cm) were recorded.

All the felled trees were marked at 1 metre intervals along their length. Using rounded-down centimetre diameter tapes, mid-diameters (at 0.5m centres) were recorded for all 1m sections down to 5cm log mid-diameter. Billet volumes were estimated using Huber's formula[1]. For sticks of less than 5cm mid-diameter, butt-diameter was measured and recorded. Volume for these sticks was estimated using the equation for cone volume.

When considering stackwood volumes for fuelwood production, all utilizable wood should be included in the equation. Studies have shown that procurement for domestic fuelwood utilizes diameters as low as 2cm butt diameter (Coote *et al.* 1993a, b). The cut-off point for measurement was therefore a butt diameter of 2cm. End branches less than 1m were discarded and their contribution to volume assumed to be negligible. The data obtained were used to calculate total tree volumes.

Thereafter the trees were cross-cut into 1m billets and all wood stacked by plot using a stacking frame of 1m by 1m by 1m. The sum of the stacked volumes per plot was then determined and compared with the total measured volume of the plot.

RESULTS AND DISCUSSIONS

Stack to solid volume ratios

According to Smith (1979) a measure of stacked volume is useful where an estimate is required, where weigh scales are inaccessible, and where a more costly measurement is not justified. This is the prevailing situation in Malawi and many of the countries where miombo woodland occurs.

However, it is the solid wood volume which is of most practical use (Smith*ibid*) and an accurate conversion estimate is therefore important. Conversion ratios vary with species and population, and are greatly dependent on log straightness. Grodzki (1977) estimated a stack to solid ratio of 0.42 for stacked 2 metre lengths of Scots pine, whilst Derfoldi (1966) computed a conversion ratio of 0.638 for Hungarian poplar billets. Makkonen (1960) calculated an average conversion ratio of 0.605 for 2-metre birch fuelwood billets with a minimum top diameter of 8cm. These studies refer to temperate tree species and as such cannot be equated to miombo species. However, they indicate the extent of the variability between species and the necessity for a relevant estimate for miombo woodlands.

The findings summarized in Table 1 indicate a mean ratio of 0.44 for solid to stack wood volume in the sample plots investigated (n=18, sample mean 0.441, standard error 0.0128, 90% C.I. ± 0.022).

TABLE 1: *Stacked and measured volume with corresponding mean height and basal area removed in per hectare equivalent for i) Phuyu and ii) Chongoni sites*

Plot (0.125ha)	Measured/ stacked Vol. removed (m^3ha^{-1})	Solid:stack volume ratio	Basal area removed (m^3ha^{-1})	Mean height of felled trees (m)
Phuyu Site:				
1	40.6 / 92.0	0.44	6.0	7.00
2	49.6 / 116.0	0.42	7.8	6.86
3	76.3 / 140.7	0.54	8.7	9.18
4	28.8 / 61.6	0.46	4.6	6.08
5	14.2 / 33.2	0.42	3.3	5.57
6	28.8 / 64.8	0.44	4.3	6.62
7	8.2 / 18.4	0.44	1.6	7.40
8	7.3 / 25.0	0.29	1.7	6.90
9	6.5 / 16.0	0.41	1.5	6.52
Means:	28.9 / 63.0	0.43	4.38	6.90
Chongoni Site:				
1	100.9 / 190.0	0.53	9.8	8.80
2	98.7 / 213.6	0.46	13.0	9.90
3	78.8 / 160.0	0.44	10.4	7.00
4	54.1 / 120.0	0.45	7.0	8.27
5	71.1 / 160.0	0.44	8.4	8.06
6	63.2 / 158.0	0.40	8.4	7.20
7	42.9 / 102.4	0.43	4.1	8.30
8	68.0 / 134.4	0.51	7.1	9.32
9	25.8 / 60.8	0.42	3.3	7.40
Means:	66.8 / 144.3	0.45	7.95	8.25

Working in Malawi, Edwards (1981) used a mean conversion ratio of 0.49 based on four solid/stack samples in sites at Chikala hills (Machinga District). In trials at Bunda College (Lilongwe District) Edwards recorded a ratio of 0.53 (Edwards, 1982), but provides no data for the figure. Using accurate displacement tank methods, studies by BCFP produced an average conversion ratio of 0.48 for 1 metre eucalypt billet stack volumes (BCFP 1992). This ratio varied between 0.6 for billets of 9.5cm butt diameter to 0.38 for billets of 4cm butt diameter (*ibid*).

Making the general assumption that eucalypt billets are straighter than miombo billets, a solid to stackwood volume ratio for indigenous timbers would be expected to be lower than the 48% calculated by BCFP for eucalypts.

In Malawi, the Forestry Department usually stacks wood using piece work, with the result that stacks are likely to be less meticulously constructed in comparison to those constructed under research and reported on here. The ratio of 0.44 calculated in this study should be considered a maximum conversion figure and it might be prudent to recommend the lower 90% confidence interval of 0.42 as the operational stack:solid volume conversion ratio.

[1] Huber's Formula; $v = Lg_m$
where L = Log length, m
g_m = Cross sectional area at midlength of log, m^2

Stackwood yield

TABLE 2: *Stack-wood yield (m^3) per m^2 basal area removed and corresponding total plot basal areas for BCFP and Chongoni sites*

Plot (0.125ha)	Stack Yield per m^2 Basal area removed (m^3m^{-2})		Total plot Basal area (m^2ha^{-1})	
Phuyu				
1	15.33		6.00	
2	14.91		7.78	
3	16.24		8.66	
4	13.39		5.95	
5	10.21		7.00	
6	15.07		6.72	
7	11.50		8.54	
8	14.36		6.40	
9	10.73		7.39	
Mean (Standard Error)	13.53	(0.732)	7.26	(0.338)
Chongoni				
1	19.25		9.80	
2	16.38		13.00	
3	15.38		10.40	
4	17.21		9.88	
5	19.02		11.83	
6	18.74		10.60	
7	24.87		7.66	
8	18.92		12.28	
9	18.20		8.39	
Mean (Standard Error)	18.69	(0.904)	10.67	(0.581)

Using the data collected from BCFP and Chongoni; mean stack-wood yield (m^3) per m^2 of basal area removed was 16.1m^3m^{-2} (Table 2). Chidumayo (1987) calculated a mean stackwood yield of 14.8m^3 per m^2 basal area removed for charcoal production in Zambia. He took 3.7cm (11cm butt-girth) as the minimum diameter used for measurement, compared to 2.0cm for the present study. This may contribute to the higher mean stack yield observed in this case.

Chidumayo (*ibid*) concluded that miombo woodlands in Zambia yield similar amounts of stackwood per m^2 basal area. In the present study, a significant difference in mean yield per unit area removed was observed between Chongoni (18.7m^3m^{-2}) and Phuyu (13.5m^3m^{-2}) ($t = 4.44$ $P = 0.0005$).

A comparison of mean height of removed trees (Table 1) shows that trees at Chongoni were significantly taller than those from Phuyu ($t=2.88$, $P=0.011$) with a significant correlation between height and yield ($r=0.601$ $p<0.01$). Total basal area was variable throughout the sample plots. This reflects the heterogenous nature of the indigenous woodlands sampled. There was, however, no significant correlation between total basal area per plot (m^2) and stackwood yield (m^3) per m^2 basal area actually removed from the plot (correlation = -0.434 $p > 0.05$).

The Phuyu site is hotter and drier than Chongoni, so the variation in yield between the two sites might have been expected. The miombo associations are also different, with biomass per unit area being higher in Chongoni. Although undocumented, it is likely that the the drier woodlands at Phuyu have been cut over for fine timber species at some time, so that the large trees, which would provide a larger proportion of biomass per unit area, are not present.

Stackwood yield prediction models

A number of prediction models for stackwood yield (per hectare) were calculated using regression analyses. A simple regression of stack volume on basal area removed (Table 1) gives the equation:

$$\text{Stack Vol.} = -5.61 + 17.7 \text{ Basal Area Removed} \quad (1)$$

$$r^2 = 93.8\%$$

$$s = 15.66 \quad n = 181$$

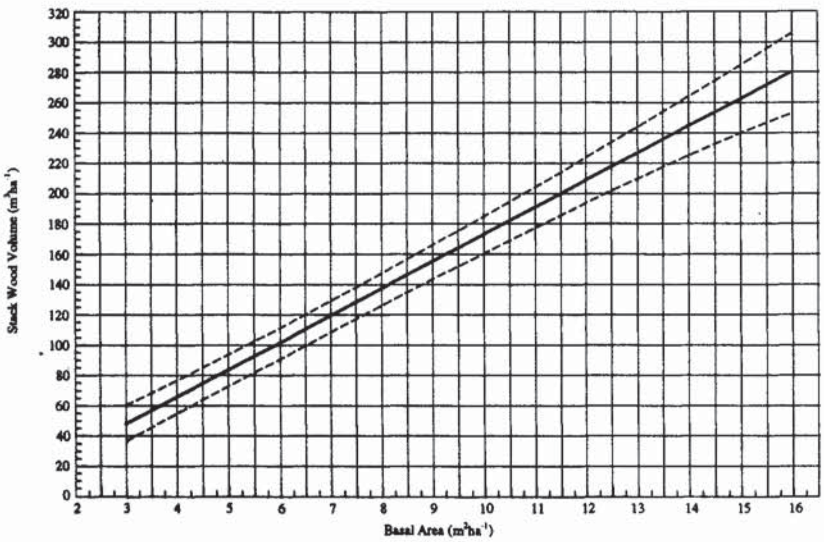

FIGURE 1. *Basal Area Removed (m^2ha^{-1}) to Stack Wood Yield (m^3ha^{-1}) Chart, with 95% Confidence Intervals (The bold line represents the regression line predicted by equation 1. The dashed lines represent the 95% confidence intervals.)*

Equation 1 suggests a good correlation between the sample data on stack volume and total basal area removed. The plot of residuals implies that the model was most accurate at the lower range of prediction. This is also evident from Figure 1, which can be used as a simple tool for reading off appropriate stack volume estimation for a known basal area. Regression analyses using transformed variables did not give a better plot of residuals or higher regression coefficient.

In his study in Zambia, Chidumayo (1987) also calculated a linear relationship between basal area and stackwood yield (for charcoal). The model was established with a correlation coefficient of 88.7% (n = 90, Y = - 6.82 + 16.8X, r^2 = 78.7%).

Using equation (1), Table 3 was drawn up for the prediction of stackwood yield and the corresponding solid volume estimate using basal area removed (m^2) as the predictor variable. In Table 3, stackwood yield is predicted from the basal area given in column 1. Column 3 represents the solid volume estimated using the lower confidence limit of the calculated conversion ratio of 42% of stacked volume (from column 2).

A multiple regression model based on the variables basal area removed and mean height of trees removed gives the equation:

Stack Vol. = - 63.9 + 15.7 Basal Area Removed + 9.35 Mean Height (2)

r^2 = 95.8%

s = 13.21 n = 18

TABLE 3. *Prediction of stacked and solid wood volume (m3) from basal area at breast height (m^2ha^{-1}). Figures rounded to one decimal place.*

Basal area to be cut m2	Predicted yield (m^3ha^{-1})	
	Stacked	Solid
3.0	47.6	19.9
3.5	56.4	23.7
4.0	65.3	27.4
4.5	74.2	31.2
5.0	83.0	34.9
5.5	91.9	38.6
6.0	100.7	42.3
6.5	109.6	46.0
7.0	118.5	49.8
7.5	127.5	53.5
8.0	136.2	57.2
8.5	145.1	50.9
9.0	153.9	64.9
9.5	162.8	68.3
10.0	171.6	72.1
10.5	180.5	75.8
11.0	189.4	79.5
11.5	198.2	83.2
12.0	207.1	87.0
12.5	216.0	90.7
13.0	224.8	94.4
13.5	233.7	98.1
14.0	242.5	101.9
14.5	251.4	105.6
15.0	260.3	109.3
15.5	269.1	113.0
16.0	278.0	116.8

The second model, represented by equation (2), gives a slightly higher correlation, but the spread of residuals differs little compared to that for the simple regression model. Accurate height assessment in miombo woodland can be a difficult task (Philip 1994) and the increase in predictive accuracy provided by the inclusion of the mean height variable might be outweighed by the extra resources required to take the measurement.

Although the number of samples in the present study (n = 18) was low, the authors believe these predictions to be reliable. Despite the large sample size, the majority of samples (72 of 90) in the Zambian study were located in only one third of the prediction range. Chidumayo (1987) took kiln stack dimensions to assess stackwood volume. The direct method of measuring each billet and each stacked metre or part thereof, should be equally as accurate as the measurements used by Chidumayo (*ibid*).

CONCLUSION

Although the study was limited in geographical extent, to the authors' knowledge the results provide the most reliable information available on stackwood estimations for miombo woodland in Malawi.

The study results suggest that, until a more accurate survey is undertaken, the conversion ratio of stack to solid wood volume used for miombo woodlands in Malawi should be taken as 0.42.

Stackwood yield in Malawian miombo is variable and relates to climate, species composition and woodland use history. Mean stackwood yield per m^2 basal area was estimated as 16.1m^3m^{-2}.

The study has demonstrated the effectiveness of using regression models in predicting stackwood yield from standing wood stocks.

Since wood fuels provide a major energy source to the Malawian population, the study results should be of value to forest managers planning to manage their woodlands for energy production and requiring simple guidelines for the estimation of solid and stacked volume.

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