CHARCOAL POTENTIAL OF MIOMBO WOODLANDS AT KITULANGALO, TANZANIA

R. E. Malimbwi*, E. Zahabu, G. C. Monela,

Faculty of Forestry and Nature Conservation, Sokoine University of Agriculture, P. O. Box 3013, Morogoro, Tanzania

S. Misana, G. C. Jambiya & B. Mchome

Department of Geography, University of Dar es Salaam, P. O. Box 35049, Dar es Salaam, Tanzania

Received January 2001

MALIMBWI, R. E., ZAHABU, E., MONELA, G. C., MISANA, S., JAMBIYA, G. C. & MCHOME, B. 2005. Charcoal potential of miombo woodlands at Kitulangalo, Tanzania. A study was carried out to determine the charcoal potential of the miombo woodlands of Kitulangalo area, near Morogoro, Tanzania. Systematic sampling design used in an inventory in 1996 was repeated in 1999 in order to determine the general current stand parameters and forest change. A total of 46 sample plots were laid out in the forest reserve. In adjacent public lands stratified random sampling was applied where a total of 30 plots were laid out. The layout was meant to study how species richness and wood stocking vary in public lands and forest reserve. Preferred tree species for charcoal making had standing wood volume of 24.5 $m^3 ha^{-1}$ and 56.5 $m^3 ha^{-1}$ in public lands and reserved forest respectively with corresponding basal area of 3.7 $m^2 ha^{-1}$ and 7.2 $m^2 ha^{-1}$. Stem numbers were 909 stems ha^{-1} in public lands and 354 stems ha^{-1} in the reserved forest. These values indicated more regeneration in public lands following disturbance than in the forest reserve. The weight of charcoal that can be extracted from the woodland at the roadside was 56 kg, equivalent to only one bag of charcoal per hectare. Similarly 54 bags may be extracted at 5 km distance while 125 bags may be extracted from beyond 10 km from the highway. With the established stand growth rate of 2.3 $m^3 ha^{-1} year^{-1}$ for the regrowth of miombo woodland at Kitulangalo, it will take about 8 to 15 years for the degraded woodlands to recover for charcoal production. Therefore, for sustainable charcoal production in this area, felling cycles of 8 to 15 years are recommended, provided the minimum tree size of > 10 cm dbh (diameter at breast height) for charcoal making is observed.

Key words: Renewable energy – growth – management

MALIMBWI, R. E., ZAHABU, E., MONELA, G. C. MISANA, S., JAMBIYA, G. C. & MCHOME, B. 2005. Potensi arang daripada hutan jarang miombo di Kitulangalo, Tanzania. Satu kajian dijalankan untuk menentukan potensi arang hutan jarang miombo di Kitulangalo berhampiran Morogoro, Tanzania. Reka bentuk pensampelan sistematik yang diguna dalam satu inventori pada tahun 1996 diulangi pada tahun 1999 supaya paramater dirian dan juga perubahan hutan semasa dapat ditentukan. Sejumlah 46 plot sampel disediakan di hutan simpan. Di tanah awam yang bersebelahan, pensampelan rawak berstrata diguna dan sebanyak 30 plot disediakan. Susun atur ini bertujuan untuk mengkaji bagaimana kekayaan spesies dan stok kayu berbeza antara tanah awam serta hutan simpan. Spesies pokok yang menjadi pilihan untuk dibuat arang mempunyai isi padu kayu masing-masing sebanyak 24.5 m^3 ha^{-1}

E-mail: remalimbwi@yahoo.com

dan 56.5 m^3 ha^{-1} di tanah awam yang mempunyai luas pangkal 3.7 m^2 ha^{-1} dan hutan simpan dengan luas pangkal 7.2 m^2 ha^{-1}. Bilangan batang di tanah awam adalah 909 batang ha^{-1} dan 354 batang ha^{-1} di hutan simpan. Bilangan ini menunjukkan pertumbuhan semula yang lebih pesat di tanah awam berikutan gangguan berbanding hutan simpan. Berat arang yang dapat dihasilkan daripada hutan jarang di tepi jalan raya adalah 56 kg, bersamaan dengan satu karung arang setiap hektar. Sebanyak 54 karung arang dapat dihasilkan pada jarak 5 km sementara 125 karung arang dihasilkan pada jarak melepasi 10 km dari lebuh raya. Dengan kadar pertumbuhan dirian sebanyak 2.3 m^3 ha^{-1} setiap tahun untuk pertumbuhan semula hutan jarang miombo di Kitulangalo, lapan tahun hingga 15 tahun diperlukan untuk hutan jarang yang ternyah gred pulih untuk penghasilan arang. Oleh itu, untuk penghasilan arang secara mapan di kawasan ini, pusingan tebangan antara lapan tahun hingga 15 tahun disyorkan, dengan syarat saiz pokok minimum > 10 cm dbh (diameter aras dada) untuk penghasilan arang dipatuhi.

Introduction

Tanzania has about 33.6 million ha of forests and woodlands. Of this, 90% are covered by miombo woodlands, while the rest are mangroves, plantations and catchment forests. Most miombo woodlands fall under public lands. Forests on public lands are without legal protection and, in accessible areas, their utilization is without control.

Miombo is a type of tropical woodland dominated by *Brachystegia* and/or *Julbernardia* or *Isoberlinia* from the legume subfamily Caesalpinioideae. It is the most ecologically widespread woodland in Africa after the tropical rain forests.

Miombo woodlands are the chief source of firewood and charcoal in Tanzania. Woodland trees produce a heavier and more concentrated fuel than most fast-growing softwood species (Gauslaa 1988) and tropical rain forest species. Fuelwood extraction, wildfires, shifting cultivation and selective harvesting of trees for different purposes have major effects on the dynamics of miombo woodlands.

In Tanzania, the extent of forest resource, their growing stock and mean annual increment (MAI) are not precisely known. The understanding of the potential of forests to supply firewood and charcoal has implications on the country's ability to design and implement appropriate energy policies. Rational decisions on management of natural forest depend on information available on their growing stock. Acquisition of forest growth information is prerequisite to any forest management system and sustainable land use (Mgeni & Malimbwi 1990). The objective of this study was to determine the potential of miombo woodlands for supplying charcoal and to propose possible interventions that can be carried out in order to sustain the supply of charcoal.

Materials and methods

Study area

Kitulangalo area is located about 50 km east of Morogoro municipality towards Dar es Salaam on the sides of the Tanzania–Zambia highway. The predominate feature in this area is the Kitulangalo hill which is about 800 m asl situated at 6° 4' S and 37° 57' E. The climate of the area is tropical, semiarid and subhumid. The mean annual temperature is 24. 3 °C, while the annual minimum and maximum temperatures are 18 and 30 °C. Soils are well-drained red sand clay loams with brown friable top soil covered by more or less decomposed litter (Mugasha 1996). The pH of the soil is between 5 and 5.5. The topography of the study area has rolling relief on convex slopes (10 to 12%), undulating to rolling relief on dissected linear slopes (6 to 19%) and fairly uniform slope in valley bottoms.

Data collection

Forest growth rate

Inventory procedures employed by Nduwamungu (1996) studying the same forest i.e. Kitulangalo Sokoine University of Agriculture (SUA) Training Forest Reserve were used in order to determine current stand parameters and derive volume mean annual increment. The stand was divided into 10 transects laid perpendicular to the highway at 320 m apart covering the whole forest reserve (approximately 500 ha). A total of 46 sample plots were laid also at an interval of 320 m apart.

Charcoal extraction dynamics

A total of 30 plots were laid out in public lands of the two villages bordering the Kitulangalo SUA Training Forest Reserve. Stratified random sampling was applied when laying out these plots. The parameter used for stratification was distance from the highway to the public lands. The first two strata were laid each at opposite sides of the highway while the others were at 5, 10 and 15 km intervals away from the highway alternatively on the sides of an access road.

In each stratum a transect was laid out approximately perpendicular to the highway or access road. In each transect three clusters of two plots each were laid at intervals of 500 m. The distance between plots in a cluster was 500 m.

Plot shape and size

In order to measure approximately the same number of trees for each size class, circular concentric plots with radius depending on the diameter at breast height (dbh) of the trees were established and measurements were taken for

(1) within 5 m radius; all trees with dbh ≥ 4 cm
(2) within 10 m radius; all trees with dbh ≥ 10 cm
(3) within 15 m radius; all trees with dbh ≥ 20 cm

Species names and dbh of trees measured were recorded in each plot. Local people helped identify tree species for later translation into botanical names using check lists of the area. The number of stems was determined from the dbh tally. Total height of the closest tree (sample tree) to the plot centre was also measured and recorded.

Data analysis

From the collected data the following parameters were computed: density, i.e. the number of stems per ha (N), basal area per ha (G) and volume per ha (V). The total tree volume of individual trees was calculated using a general miombo tree species equation developed by Malimbwi *et al.* (1994) for the area. The equation was:

$$V_i = 0.0001 d_i^{2.032} h_i^{0.66}$$

where,

V_i = volume of the *i*th tree (m^3)

d_i = dbh (1.3 m) for the *i*th tree (m) and

h_i = total height of the *i*th tree (m)

Since this equation required the height of each individual tree, a height–diameter equation was fitted using the sample trees to derive heights for the other trees which were not measured for height.

These parameters were calculated separately for the Kitulangalo SUA Training Forest Reserve and for each stratum in the public lands. The analysis allowed comparison of tree species abundance in the two forests and within strata in the public lands. Also tree species abundance for the preferred tree species for charcoal making was compared between the two forests.

Results and discussion

Tree species composition in reserved forest and public lands

An average of 1405 and 618 stems per ha comprising 44 and 48 different tree species were observed in public lands and reserved forest respectively at Kitulangalo. All the tree and shrub species encountered are shown in Table 1. This list may serve as a checklist for trees and shrubs in Kitulangalo area. The large number of stems in public lands may be attributed to the fact that the woodland in public lands is regenerating following disturbances through harvesting (Chidumayo & Frost 1996).

At the SUA Training Forest Reserve in Kitulangalo, Nduwamungu (1996) reported an average stocking of 691 stems per ha which is comparable with the 618 stem per ha obtained for the forest reserve. Stocking of miombo woodlands in Katanga, Zaire ranged from 520 to 645 stems ha^{-1} (Malaisse 1978).

The distribution of stem number per ha in both public lands and forest reserve follows the usual expected reverse J-shape trend (Figure 1). This is an indication of active forest recruitment and regeneration (Philip 1983).

Twelve species were found only in the forest reserve while eight species were found only in the public lands (Table 2). Since the public lands and the forest reserve are adjacent and hence more or less ecologically similar, differences in species may be due to the disappearance of some species coupled with invasion by pioneer species in the public lands following disturbances.

Table 1 List of tree species found at Kitulangalo area

Local name	Botanical name
Mtogo	*Diplorhynchus condylocarpon*
Myombo	*Brachystegia boehmii*
Kisasamwege	*Acacia goetzei* subsp. *microphylla*
Mnhondolo	*Julbernardia globiflora*
Mhingi	*Ximenia caffra*
Mlama-mtitu/Mlama-mweusi	*Combretum molle*
Mnhindipori/Mhungilo	*Lannea schimperi*
Mfumbili	*Lonchocarpus* sp.
Kifunganyumbu	*Acacia nilotica*
Kikulagembe	*Dichrostachys cinerea*
Mng'ongo	*Sclerocarya birrea* subsp. *caffra*
Mmoze	*Sterculia africana*
Msosoana	*Dombeya rotundifolia*
Msinzira	*Bridelia cathartica*
Mkambala	*Acacia nigrescens*
Mharaka	*Spirostachys africana*
Mgama	*Mimusops kummel*
Mpingo	*Dalbergia melanoxylon*
Mkulwi	*Diospyros kirkii*
Mdaula	*Zanha africana*
Mninga	*Pterocarpus angolensis*
Mnyenye	*Xeroderris stuhrmannii*
Mlama-ng'ombe	*Combretum adonogonium*
Mtanga	*Terminalia mollis*
Mkwaju	*Tamarindus indica*
Msisimizi	*Albizia harveyi*
Msolo	*Pseudolachnostylis maprouneifolia*
Mtutuma	*Catunaregam spinosa*
Mtomokwe	*Annona senegalensis*
Mguluka	*Boscia salicifolia*
Mgovu	*Pteleopsis myrtifolia*
Kilemelantembo	*Gardenia ternifolia* subsp. *jovis-tonantis*
Kisakulanhwale	*Margaritaria discoidea*
Mtwintwi	*Commiphora pteleifolia*
Mnzenzegele	*Dalbergia nitidula*
Mtwintwi	*Commiphora africana*
Mkusu	*Harissonnia abyssinica*
Muwindi	*Acacia polyacantha* subsp. *campylacantha*
Mhembeti	*Sterculia quinqueloba*
Msegese	*Bauhinia petersiana*
Mbwewe	*Lecaniodiscus flaxinifolius*
Mlamamdunku/Mlama-mwekundu	*Combretum zeyheri*
Kilumbulumbu	*Ormocarpum kirkii*
Mkole	*Grewia* sp.
Mkongowe	*Acacia gerrardii*
Mfuru	*Vitex ferruginea*
Mkumbi	*Ochna holstii*

(continued)

(Table 1 - continued)

Local name	Botanical name
Mgwejameno	*Antidesma venosum*
Mseni	*Brachystegia microphylla*
Mnenekenda	*Elaedendron schlechterianum*
Kisasa	*Acacia goetzei* subsp. *goetzei*
Mkomanguku	*Stereospermum kanthianum*
Mufleta	*Albizia anthelmintica*
Msezi	*Manilkara sulcata*
Myuyu	*Makhamia* sp.
Mlama-dori	*Combretum collinum*

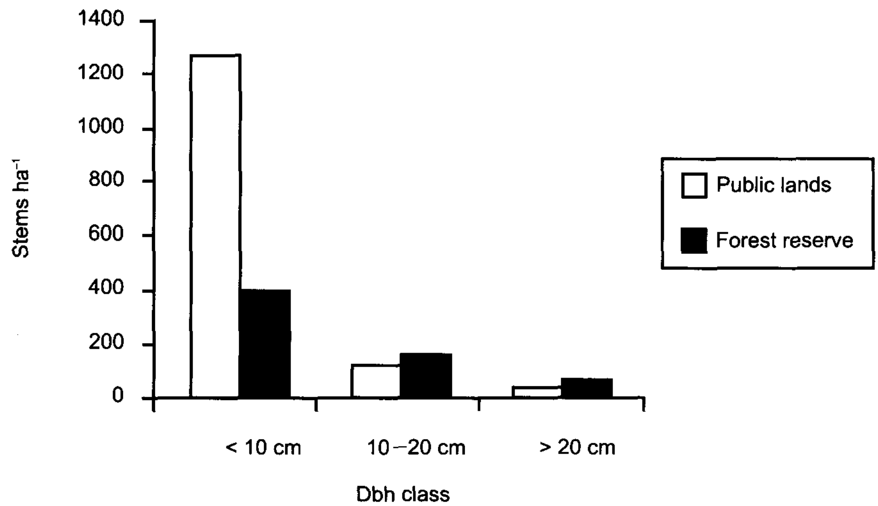

Figure 1 Distribution of stem number in public lands and forest reserve at Kitulangalo

Stand basal area and volume per hectare

The average volumes and basal areas per ha were 46.2 $m^3 ha^{-1}$ and 7 $m^2 ha^{-1}$ in public lands and 78.8 $m^3 ha^{-1}$ and 10 $m^2 ha^{-1}$ in forest reserve respectively (Figure 2). The mean volume in the reserved forest is about twice that of public lands while the basal areas are comparable. This further signifies the over exploitation of public lands. Nduwamungu (1996) observed average volume and basal area of 71.12 $m^3 ha^{-1}$ and 10.34 $m^2 ha^{-1}$ respectively which are comparable with those of the forest reserve.

The distribution of volume and basal area in both public lands and forest reserve showed a J-shape trend as expected in a natural forest with good regeneration and recruitment (Figure 2).

Tables 3 and 4 show the distributions of stem number (N), basal area (G) and

Table 2 Tree species found only in forest reserve and public lands of Kitulangalo area

Local name	Botanical name	Present in forest reserve	Present in public land
Kisasamwege	*Acacia goetzei* subsp. *micropylla*		√
Mhingi	*Ximenia caffra*		√
Mnhindipori	*Lannea schimperi*	√	
Mmoze	*Sterculia africana*	√	
Mkwaju	*Tamarindus indica*	√	
Mguluka	*Boscia salicifolia*	√	
Mgovu	*Pteleopsis myrtifolia*	√	
Kisakulanhwale	*Margaritaria discoidea*		√
Mtwintwi	*Commiphora pteleifolia*	√	
Mkusu	*Harissonnia abyssinica*	√	
Msegese	*Bauhinia petersiana*	√	
Mbwewe	*Lecaniodiscus flaxinifolius*		√
Kilumbulumbu	*Ormocarpum kirkii*	√	
Mkole	*Grewia* sp.	√	
Mkumbi	*Ochna holstii*		√
Mnenekenda	*Elaedendron schlechterianum*	√	
Mkomanguku	*Stereospermum kanthianum*		√
Msezi	*Manilkara sulcata*	√	
Mhungilo	*Lannea schimperi*		√
Myuyu	*Makhamia* sp.		√

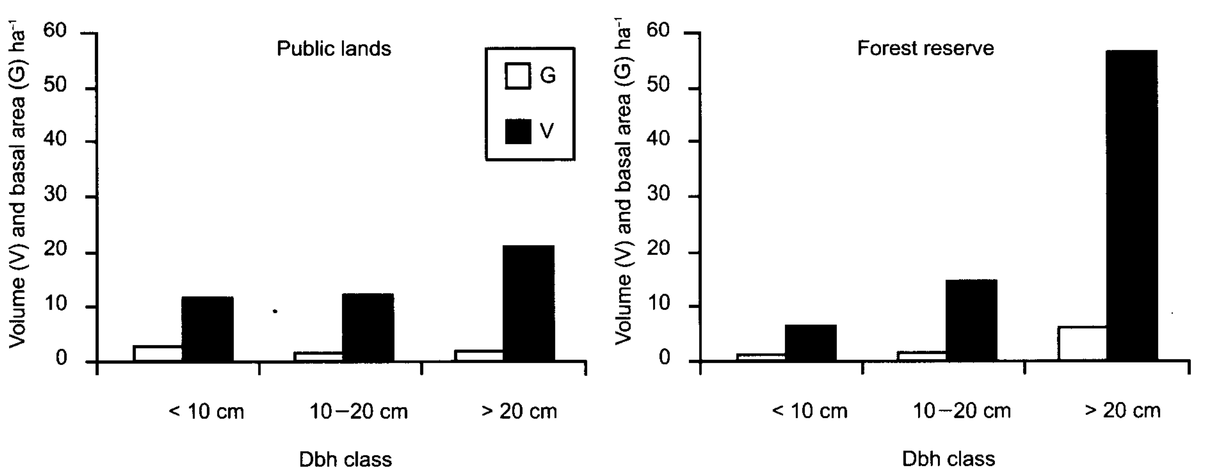

Figure 2 Distribution of volume and basal area in both public lands and forest reserve at Kitulangalo

volume (V) per ha for the suitable tree species for charcoal making in both public lands and forest reserve. Considerably greater values of volume and basal area in the forest reserve were obtained compared with the public lands. Charcoal-making activities are said to be the most likely cause of degradation of the miombo woodlands in eastern Tanzania due to the ever increasing demand for charcoal in urban areas (Monela *et al.* 2000).

Table 3 Distribution of stem number (N), basal area (G) and volume (V) in order of decreasing V (total) for suitable trees for charcoal in Kitulangalo public lands

Species	Dbh Class											
	< 10 cm			10–20 cm			> 20 cm			Total		
	N	G	V	N	G	V	N	G	V	N	G	V
Acacia gerrardii	3	0.008	0.033				6	0.432	4.115	9	0.440	4.147
Diplorhynchus condylocarpon	52	0.124	0.551	12	0.212	1.433	3	0.196	1.873	67	0.531	3.858
Combretum molle	233	0.356	1.372	5	0.092	0.619	1	0.111	1.120	239	0.559	3.111
Acacia nigrescens	35	0.071	0.301	3	0.048	0.310	3	0.202	1.920	41	0.322	2.531
Julbernardia globiflora	286	0.543	2.248	1	0.013	0.073				288	0.556	2.321
Brachystegia boehmii	19	0.043	0.181	13	0.215	1.527	1	0.029	0.244	32	0.287	1.952
Acacia goetzei subsp. *goetzei*	32	0.072	0.308	7	0.140	0.959	1	0.041	0.318	41	0.253	1.585
Xeroderris stuhrmannii	5	0.015	0.069				1	0.104	1.013	6	0.119	1.082
Combretum zeyheri	103	0.201	0.824							103	0.201	0.824
Pseudolachnostylis maprouneifolia	8	0.044	0.225				1	0.056	0.559	9	0.100	0.784
Mimusops kummel							1	0.075	0.674	1	0.075	0.674
Acacia nilotica				4	0.069	0.469				4	0.069	0.469
Terminalia mollis	54	0.092	0.364	1	0.015	0.090				56	0.107	0.454
Lonchocarpus sp.				1	0.020	0.132	1	0.031	0.268	2	0.052	0.400
Albizia harveyi	3	0.008	0.033	1	0.027	0.183				4	0.034	0.216
Lannea sp.	8	0.025	0.113							8	0.025	0.113
Total	841	1.602	6.622	50	0.852	5.80	18	1.277	12.104	909	3.731	24.521

Table 4 Distribution of stem number (N), basal area (G) and volume (V) in order of decreasing V (total) for suitable trees for charcoal in Kitulangalo SUA Training Forest Reserve

Species	Dbh Class											
	< 10 cm			10–20 cm			> 20 cm			Total		
	N	G	V	N	G	V	N	G	V	N	G	V
Brachystegia boehmii	19	0.077	0.359	14	0.224	1.411	13	1.304	12.543	47	1.605	14.314
Julbernardia globiflora	33	0.106	0.481	19	0.307	1.919	12	0.943	8.620	64	1.356	11.020
Acacia nigrescens	8	0.019	0.076	3	0.051	0.329	6	0.899	9.362	17	0.969	9.767
Xeroderris stuhrmannii				3	0.045	0.277	5	0.509	4.872	8	0.554	5.148
Acacia goetzei subsp. *goetzei*	11	0.029	0.125	23	0.358	2.235	3	0.137	1.042	37	0.524	3.402
Combretum molle	53	0.191	0.879	15	0.206	1.256	2	0.060	0.477	69	0.457	2.613
Acacia gerrardii	3	0.008	0.033	3	0.058	0.374	2	0.177	1.638	8	0.243	2.046
Albizia harveyi				1	0.020	0.136	2	0.151	1.470	2	0.170	1.607
Diplorhynchus condylocarpon	28	0.093	0.417	9	0.136	0.836	1	0.306	0.010	37	0.535	1.262
Acacia nilotica	3	0.011	0.048	6	0.107	0.679	2	0.068	0.530	11	0.186	1.258
Pseudolachnostylis maprouneifolia	3	0.018	0.089	1	0.014	0.090	2	0.093	0.736	5	0.124	0.915
Lonchocarpus sp.	30	0.091	0.401	1	0.022	0.135	2	0.038	0.315	32	0.151	0.851
Pteleopsis myrtifolia							1	0.083	0.717	1	0.083	0.717
Terminalia mollis	3	0.005	0.021	3	0.052	0.333	1	0.041	0.316	6	0.098	0.671
Combretum zeyheri	3	0.018	0.089	3	0.048	0.307	1	0.020	0.168	7	0.086	0.565
Mimusops kummel				1	0.008	0.045	1	0.018	0.142	1	0.025	0.186
Boscia salicifolia				1	0.020	0.122	1	0.000	0.000	1	0.020	0.122
Total	197	0.665	3.020	105	1.673	10.48	56	4.848	42.959	354	7.186	56.462

While the commonly known suitable tree species for charcoal making in miombo woodlands, i.e. *Julbernardia globiflora* and *Brachystegia boehmii* appeared to be abundant in the forest reserve (Table 4), in public lands they were less available (Table 3). This could be explained by the overuse of these species in public lands where charcoal-making activities are concentrated.

Changes in woodlands with increased distances from the highway in public lands

The distribution of stem number, basal area and wood volume at the roadside, and at 5, 10 and 15 km from the highway is shown in Table 5. Both volume and basal area increased with distance from the highway while stem numbers showed a reverse trend. This trend suggests that the woodland at roadside had been depleted, mostly for charcoal extraction, because of easy accessibility compared with woodlands away from the highway. The higher stem number observed at the roadside indicated regeneration of the woodlands following cutting for various purposes including charcoal making. Miombo species regenerate largely through coppice regrowth and root suckers rather than seeds (Chidumayo & Frost 1996). The forest conditions at about 10 and 15 km away from the highway are comparable with those of the forest reserve.

Among the species found in Kitulangalo, muwindi (*Acacia polyacantha* subsp. *campylacantha*) seems to be the most dominant at the roadside of Kitulangalo area for trees > 10 cm dbh. The species is a pioneer and not suitable for charcoal as its charcoal easily breaks into small pieces during transportation. Also its thorny stems make it unattractive to handle. Mng'ongo (*Sclerocaria birrea*), mtogo (*Diplorhynchus condylocarpon*) and mharaka (*Spirostachys africana*) are the dominant tree species at 5, 10 and 15 km away from the highway.

Woodland growth rate

Stem numbers

The average number of stems per ha was 691 in 1996 (Nduwamungu 1996) and 618 in 1999. These numbers are in agreement with those observed by Malaisse (1978) and Rees (1974) for miombo woodlands. The stem numbers have decreased

Table 5 Distribution of stocking (N), basal area (G) and wood volume (V) by distance from the highway in public lands

Distance from the highway	N	G	V
Roadside	2480	5.00	22.00
5 km	2029	7.47	48.15
10 km	819	6.98	50.56
15 km	365	7.69	61.45

in the lower diameter classes due to recruitment into higher diameter classes. This generally suggests stand growth. Harvesting and wild fire in the woodland open up the forest and give way for regeneration. Since 1995 the Kitulangalo SUA Training Forest has been managed by the Faculty of Forestry and Nature Conservation of the Sokoine University of Agriculture for training and research purposes. With these management goals no harvesting for whatever purpose is allowed in the forest and less frequent wildfires were reported. Among the consequences there are few newly recruited regenerants for trees less than 10 cm dbh. Nevertheless, the distribution of stem number per ha by plots and dbh classes between 1996 and 1999 (Figure 3) follows a reserve J-shape trend as expected in natural forests.

Basal area and volume

Basal area and wood volume were observed to increase with diameter class. The basal areas were 10.3 and 10.18 m^2 ha^{-1} while wood volumes were 71.12 and 78.16 m^3 ha^{-1} in 1996 (Nduwamungu 1996) and 1999 respectively (Figure 4). This also shows that the forest stand is growing with greater volume and basal area of large-size trees. While there was no opening up of the forest which could encourage regeneration, large trees were growing with little disturbance from wildfires. The distribution of both basal area and wood volume for the two period shows a J-shape trend as expected due to the influence of large trees on basal area and volume (Figure 4).

As with stem numbers, both volume and basal area per ha are low in the lower diameter classes but increased in the higher diameter class. This suggests recruitment of smaller diameter class trees in preceding high classes and thus stand growth, with little regeneration due to absence of disturbances.

The MAI for the period of three years (1996–1999) was 2.35 m^3 ha^{-1} $year^{-1}$. This value agrees with those of Nilsson (1986) and Temu (1980) who estimated an annual growth rate of 1–2 m^3 ha^{-1} $year^{-1}$ for disturbed woodlands in Tanzania. Ek (1994) reported a biomass increment equivalent to 1.88–4.35 m^3 ha^{-1} $year^{-1}$ for an old-growth miombo at Kitulangalo. In Zambia, mean annual fuelwood increment of a dry miombo was 1.96 m^3 ha^{-1} $year^{-1}$ (Chidumayo 1988). However, the rate is contrary to that provided by Malimbwi *et al.* (1998) which was 0.54 m^3 ha^{-1} $year^{-1}$ for regrowth miombo woodland. The small coverage of the study by Malimbwi *et al.* (1998) may have been the source of the discrepancy. Nevertheless, the results caution one against applying existing growth rate data to new locations due to the high variation that may exist between different miombo ecosystems.

Potential of the woodland to produce charcoal

The distribution of volume, basal area and number of stems per hectare for the preferred tree species and sizes for charcoal making in the public lands is shown in Table 6. At the roadside stand parameters showed low values which increase up to 10 km away. However, at 15 km from the roadside, stand parameters slightly decreased (Table 6). This suggests that cutting at 15 km distance from the roadside may be for other uses apart from charcoal. This area is close to a small village and

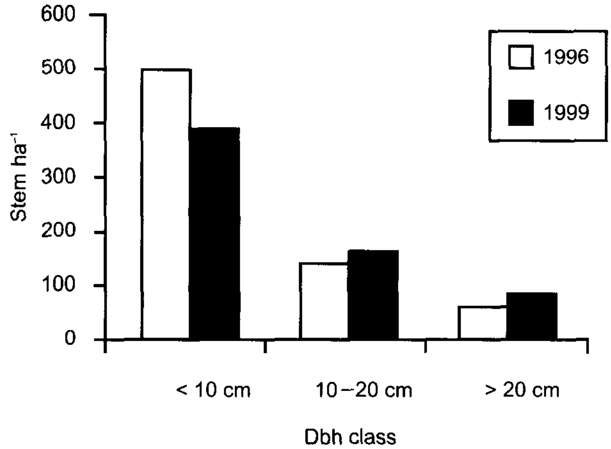

Figure 3 Comparison of the stocking distribution by dbh classes between 1996 (Nduwamungu 1996) and 1999 at Kitulangalo

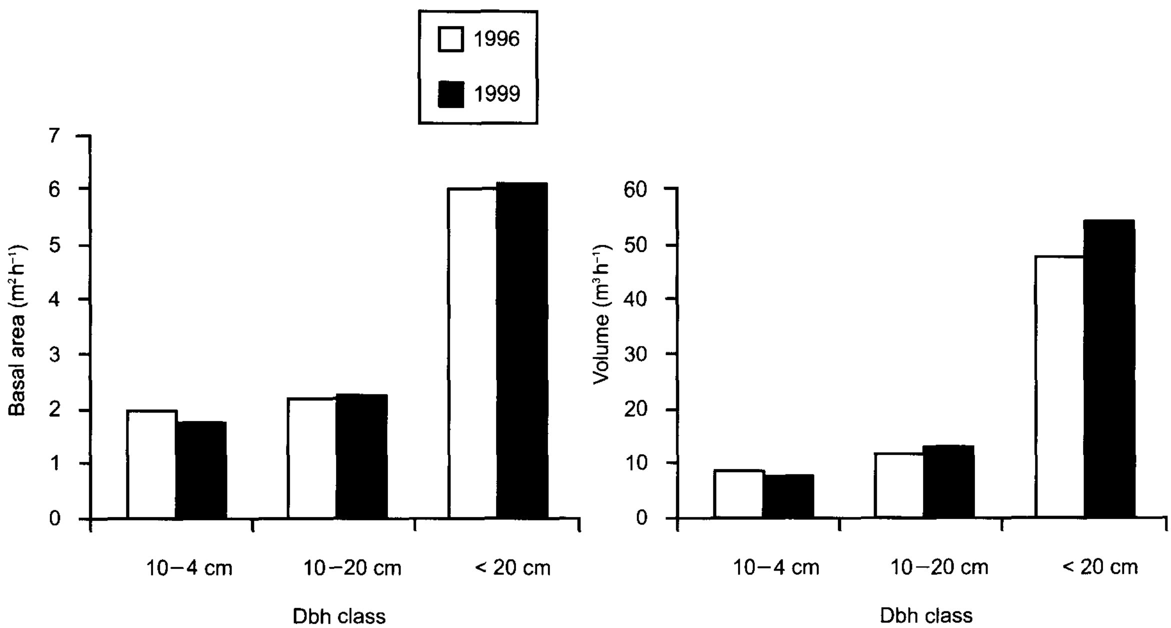

Figure 4 Comparison of the distribution by basal area and volume by dbh classes between 1996 (Nduwamungu 1996) and 1999 at Kitulangalo

more trees may be cut for poles and firewood rather than for charcoal making.

Considering a conversion factor of 0.85 (Malimbwi *et al.* 1994) for fresh wood volume to wood biomass and kiln efficiency of 23% (Zahabu 2001) the weight of charcoal that can be extracted from the woodland at the roadside was 0.29 $m^3 ha^{-1}$ (fresh wood) × 0.85 × 0.23 = 56 kg of charcoal, equivalent to only one bag of charcoal per ha. Similarly 54 bags may be extracted at 5 km distance while 125 bags may be extracted from beyond 10 km from the highway (Table 6).

Table 6 Distribution of tree species of suitable size for charcoal making in the public lands

	Dbh Class									
	10–20 cm			> 20 cm			Total			Bags ha^{-1}
Distance	N	G	V	N	G	V	N	G	V	
Roadside	5	0.05	0.29				5	0.05	0.29	1
5 km	106	1.68	11.06	12	0.50	4.20	119	2.18	15.27	54
10 km	90	1.64	11.23	35	2.48	23.96	125	4.13	35.19	125
15 km	59	0.97	6.5	45	3.00	28.01	103	4.00	34.55	125

It is clear that the reserved forest and the public lands from 5 km away from the highway have higher potential of producing charcoal than public lands at the roadside. Given that the woodland growth potential is 2.35 $m^3 ha^{-1} year^{-1}$ and assuming the better forest condition for charcoal making is that of the forest reserve, which has 53.43 $m^3 ha^{-1}$, the management of the public forest lands can plan charcoal extraction and sustain woodland status at a desired state. The number of years (n) it will take for the 'Z' forest to attain 'Y' forest situation is given by:

$$n = \frac{(Y m^3 ha^{-1} - Z m^3 ha^{-1})}{2.35\ m^3 ha^{-1} year^{-1}}$$

where

n = number of years for the forest to grow before harvesting

Y = desired forest situation with $Y m^3 ha^{-1}$

Z = forest with $Z m^3 ha^{-1}$ needed to attain a desired situation

2.35 = volume mean annual increment

Based on the above assumptions, the time needed for the degraded woodland to attain harvestable status is shown in Table 7. It will take about 23 and 16 years for the woodland at the roadside and at 5 km away from the highway respectively to attain the forest conditions of the forest reserve with 53.43 $m^3 ha^{-1}$ of preferred tree species for charcoal making. This suggests that for the woodland at the roadside to recover for sustainable charcoal production, a felling cycle ranging between 16 and 23 years should be considered. However, charcoal production could also be sustained at the levels observed at beyond 10 km away from the highway, with a shorter felling cycle of eight to 15 years for degraded forest at 5 km away from the highway and at the roadside.

For this mechanism to be practical the public forest lands where charcoal is now being produced could be divided into annual coupes of desirable sizes to be harvested in eight-years felling cycles. During harvesting it should be ensured that only trees > 10 cm dbh are felled. Meanwhile research should be carried out on the felling system of annual coupes to monitor regeneration and succession.

These proposed rotation ages may be useful especially during this period of forest policy reform in Tanzania where communities may be involved in

Table 7 Time lapse for degraded woodland to recover for charcoal production

Distance/ location	Present exploitable volume (m^3 ha^{-1})	Years to attain forest reserve situation	Volume to be attained (m^3 ha^{-1})	Years to attain situation at 10 and 15 km in public lands	Volume to be attained (m^3 ha^{-1})
Forest reserve	53.44				
Roadside	0.29	23	53.44	15	35
5 km	15.27	16	53.44	8	35
10 km	35.19	8	53.44		
15 km	34.55	8	53.44		

forest management. The involvement of village communities in forest management among other things requires them to benefit from the forest they manage. At Kitulangalo where charcoal is the main product extracted from the woodlands, allocation of annual coupes to village communities could be done by responsible forest officers who will also ensure that the minimum tree sizes for harvesting are observed.

Conclusions and recommendations

The former commonly used tree species for charcoal such as *Brachystegia*, *Julbernardia* and *Combretum* have low volume stocking in the public lands where charcoal making takes place. People have now opted for other tree species that are of large sizes which, when mixed with small-size trees of the above species, produce acceptable charcoal. All the suitable tree species for charcoal making were observed to regenerate through coppices, seed or root suckers.

Charcoal production was found to concentrate in the public lands and none in the Kitulangalo SUA Training Forest Reserve. While there are no harvesting control measures in the public lands, no harvesting whatsoever is allowed in the Kitulangalo SUA Training Forest Reserve. Given the fact that the surrounding public lands have similar soil and climatic conditions as this forest, it is important to raise the awareness of the stakeholders and communities on the potential of the woodland to quickly regenerate under controlled access. Public lands from 10 km from the highway were observed to have far better wood volume stocks of exploitable trees for charcoal due to the inaccessibility of these places especially during the rainy season. Good infrastructure development and harvesting control by the provision of harvesting coupes based on stand growth rate could provide sustainable charcoal harvesting in this area.

For sustainable management of these woodlands especially in the public lands, management should consider the felling cycles suggested in this study in order to give time for depleted woodlands at roadsides to regenerate. However, this should go hand in hand with strict laying down of some bylaws that will regulate the charcoal business at the area.

Acknowledgements

This study had financial contribution from the Charcoal Potential in Southern Africa (CHAPOSA) of the European Commission and the co-ordination by Stockholm Environmental Institute (SEI) according to the contract N. IC 18-Ct98-0278. The authors are grateful for this support and are solely responsible for all opinions expressed in this document, which do not necessarily reflect those of the European Union and SEI.

References

CHIDUMAYO, E. N. 1988. Early post-felling response of Marquesia woodland to burning in Zambia Copper belt. *Tropical Ecology* 4: 361–372.

CHIDUMAYO, E. N. & FROST, P. 1996. Population biology of miombo trees. Pp 11–57 in Campbell, B. E. (Ed.) *The Miombo Woodland in Transition: Woodland and Welfare in Africa.* CIFOR, Bogor, Indonesia.

EK, T. M. 1994. Biomass Structure in Miombo Woodland and Semi-Evergreen Forest. MSc. dissertation, Department of Forestry, Agricultural University of Norway, Town.

GAUSLAA, Y. 1988. Management and Regeneration of Tropical Woodlands with Special Reference to Tanzanian Condition. A Literature Review. Report to NORAGRIC 57.

MALAISSE, F. 1978. The miombo ecosystem. Pp 589–612 in *Tropical Forest Ecosystem.* UNESCO, Paris.

MALIMBWI, R. E., KIELLAND-LUND, J. & NDUWAMUNGU, J. 1998. Species diversity and standing crop development in four miombo vegetation communities. Pp. 201–212 in Chamshama, S. O. A. (Ed.) *Proceedings of the First Annual Forestry Research Workshop,* 25–26 March 1997. Arusha, Tanzania. Faculty of Forestry, Sokoine University of Agriculture, Morogoro, Tanzania Record No. 67.

MALIMBWI, R. E., SOLBERG, B. & LUOGA, E. 1994. Estimate of biomass and volume in miombo woodland at Kitulangalo Forest Reserve, Tanzania. *Journal of Tropical Forest Science* 7(2): 230–242.

MGENI, A. S. M. & MALIMBWI, R. E. 1990. Natural Forest Resources of Tanzania and Their Management Needs. Sokoine University of Agriculture, Morogoro. *Faculty of Foresty Record* 43: 67–76.

MONELA , G. C., KOWERO, G., KAONEKA, A. R. S. & KAJEMBE, G. C. 2000. Household livelihood strategies in the miombo woodlands of Tanzania: emerging trends. *Tanzania Journal of Forestry and Nature Conservation* 73: 17–33.

MUGASHA, A. G. 1996. Silviculture in tropical natural forests with special reference to Tanzania. Sokoine University of Agriculture, Morogoro. (Unpublished)

NDUWAMUNGU, J. 1996. Tree and Shrub Diversity in Miombo Woodland: A Case study at Sokoine University of Agriculture Kitulangalo Forest Reserve, Morogoro, Tanzania. M.Sc. thesis, Sokoine University of Agriculture, Morogoro.

NILSSON, P. 1986. Wood—the other energy crisis. Pp. 267 in Boesen, J., Alarenik, J., Odgaard, R. (Eds.) *Tanzania—Crisis and Struggle for Survival.* Scandinavian Institute of African Studies, Uppsala.

PHILIP, M. S. 1983. *Measuring Trees and Forests.* Division of Forestry, University of Dar es Salaam.

REES, W. A. 1974. Preliminary studies into bush utilisation by cattle in Zambia. *Journal of Applied Ecology* 11: 207–214.

TEMU, A. B. 1980. Miombo Woodland Inventory Design, a Response to Fuelwood Scarcity in Tabora, Tanzania. Ph.D. thesis, University of Dar es Salaam.

ZAHABAU, E. 2001. Impact of charcoal Extraction on the Miombo Woodlands: The Case of Kitulangalo Area, Tanzania. M.Sc. thesis, Sokoine University of Agriculture, Morogoro.